Reliability Enhancement Using Optimal Sizing and Placement of Distributed Generation

(Case study- Debrework feeder)

Almaz Ayalew Mekonnen

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

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Electrical Power and Control Engineering

(Power System Engineering)

Office of Graduate Studies

Adama Science and Technology University

Jun, 2024

Adama, Ethiopia

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Major Advisor: Dr. Tafesse Asrat

Co-advisor: Mr. Mesfin Megra

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DECLARATION

I hereby declare that this Master Thesis entitled "Reliability Enhancement Using Optimal Sizing and Placement of Distributed Generation (Case study- Debrework feeder)"is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Almaz Ayalew Mekonnen ________________ ____________________

Name of student Signature Date

RECOMMENDATION OF ADVISORS

We, the advisors of this thesis, hereby certify that I have read the revised version of the thesis entitled "Reliability Enhancement Using Optimal Sizing and Placement of Distributed Generation (Case study- Debrework feeder)" prepared under my guidance by Almaz Ayalew Mekonnen. Submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Power System Engineering. Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

____________________	____________________	____________________
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Co-Advisor	Signature	Date

APPROVAL PAGE

We, the advisors of the thesis entitled “Reliability Enhancement Using Optimal Sizing and Placement of Distributed Generation (Case study- Debrework feeder)” and developed by Almaz Ayalew Mekonnen, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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______________________	____________________	_____________________
Co-Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Almaz Ayalew Mekonnen have read and evaluated the thesis entitle “Reliability Enhancement Using Optimal Sizing and Placement of Distributed Generation (Case study- Debrework feeder)” and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Power System Engineering.

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LIST OF ABBREVIATIONS

Abbreviations	**Description**
AAC	All Aluminum Conductor
AC	Alternative Current
ACCI	Average Customer Curtailment Index
AENS	Average Energy Not Supplied Index
ASAI	Average Service Availability Index
ASUI	Average Service Unavailability Index
BDO	Bichena District Office
BDS	Bichena Distribution Substation
CAIDI	Customer Average Interruption Duration Index
CAIFI	Customer Average Interruption Frequency Index
CO	Carbon Monoxide
CO2	Carbon Dioxide
DC	Direct Current
DG	Distribution Generation
DPEF	Distribution Permanent Earth Fault
DPSC	Distribution Permanent Short Circuit
DTEF	Distribution Transient Earth Fault
DTSC	Distribution Transient Short Circuit
Dur	Duration
E.C	Ethiopia Calendar
EEA	Ethiopia Electric Agency
EEP	Ethiopia Electric Power
EENS	Expected Energy Not Supply
ETAP	Electrical Transient Analyzer Program
EEU	Ethiopia Electric Utility
ENS	Energy Not Supplied
Frq.	Frequency
G.C	Gregorian Calendar
GHG	Greenhouse Gas
GW	Gega Watt
Hr/yr	Hour per Year

Hr/cus/yr	Hour per Customer per Year
IEEE	Institute of Electrical and Electronics Engineers
INT	Interruption
INT/Yr	Interruption per Year
ISC	Short Circuit Current
KM	Kilo Meter
KV	Kilo Volt
KVArh	Kilovolt Ampere Hour
KW	Kilo Watt
KWH	Kilo Watt Hour
Impp	Maximum Power Point Current
Vmpp	Maximum Power Point Voltage
MVA	Mega Volt Ampere
MW	Mega Watt
MWA	Mega Watt Ampere
NASA	National Aeronautics and Space Administration
NREL	National Renewable Energy Laboratory
Voc	Open Circuit Voltage
VDC	Volte of Direct Current
P	Active Power
PF	Power Factor
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
SHS	Solar Home System
TWH	Tera Watt Hour
VSI	Voltage Stability Indices
W/M	Watt per Meter

ABSTRACT

*This thesis investigates the challenges of unreliable power supply due to frequent interruptions on the feeder lines of the Bichena substation. It explores distributed generation (DG) as a potential solution to enhance the substation's reliability. The current state of the Bichena Distribution Substation was characterized by a high SAIFI of 364.0334 f/y, SAIDI of 232.657 h/yr and EENS of 2302.898MWhr/yr, and Deberework feeder reliability indices value SAIFI of 402 f/yr, SAIDI of 271.1hr/yr, and EENS 618.5383MWhr/yr. These values significantly exceed the standards set by the Ethiopian Electric Agency (SAIFI = 20 and SAIDI = 25), highlighting a critical reliability issue. This thesis proposes the strategic integration of DG units to bridge this reliability gap. The study focused on the Debrework feeder within the 15 kV systems, analyzing the effectiveness of a photovoltaic (PV) DG system in improving reliability. Factors such as availability, economics, emissions, and suitability for the area motivated the selection of PV technology. The proposed DG system consists of a 444.465 kWh PV generate, 577.8KW inverter, and 1,0380 Ah battery. This system was injected power into the grid during outages, serving as a backup solution. ETAP software was utilized to simulate various DG scenarios and assess their impact on reliability. The optimal placement and size of DG units were determined with the primary objective of maximizing reliability improvement on the Debrework feeder, particularly for sensitive loads. The analysis aims to achieved a significant reduction in SAIFI, SAIDI and EENS on the Debrework feeder, targeting values of 20.798 f/yr,18.0119h/yr, and 22.28MWhr/yr respectively.so, that the Debrework feeder was achieved the EEA standard. Additionally, the overall substation's reliability indices have improved, with SAIFI decreasing to 179.84 f/yr and SAIDI reducing to 91.*909 h/yr. *Generally, Due to the DG at an optimal feeder. the overall system's reliability was improved where the values of the SAIFI, SAIDI, and EENS common reliability indices improved by 50.6%, 60.6%, and 51%, respectively. And from the selected Debrework feeder was 94.8%, 93.4%, and 96.4% reliability improvement were achieved.*

Keywords: Distribution Generation, Reliability Enhancement, SAIFI, SAIDI, EENS.

CHAPTER ONE

1. INTRODUCTION

1.1 Background of Study

Bichena is one of the cities in Amhara region of Ethiopia located at 10.44783 Latitude and 38.202679 Longitude. It is 169 km away from the capital city Addis Ababa. People's daily lives rely heavily on electricity, such as those related to cooking, lighting, water supply, education, health sector, etc., thus a steady and dependable electric power supply system is necessary for every society to advance technologically and economically, as electrical energy is crucial to the economic, environmental, and social development of any nation. Customers of electric power utilities ought to receive a constant supply of electricity (Mamo & Hizkiel, 2023). This research focuses on assessing the problem of unreliable power supplies and exploring cost-effective mitigation techniques**.** Many studies have been conducted worldwide to increase the reliability of electricity distribution systems (Abrha et al., 2021)**.**

The primary issue that electric power companies in the Bichena substation are dealing with is power outages. Insufficient technological research has been done on the distribution system, nevertheless. Reliability is thus a frequent issue in the electricity system. Consequently, distribution generation must be used to increase the power system's reliability. For Ethiopian electric power as well as the electric utilities that provide energy to end users of electric service, the economic and social ramifications of losing electric service have a big influence (Mamo & Hizkiel, 2023). Bichena substation has a voltage capacity of 66 kV and two transformers (33 kV and 15 kV). The fast rates of demand growth cause the Bichena distribution substation equipment to become overloaded, and because replacing the overloaded power system components is expensive, it is not a simple task. New kinds of incentive schemes, like distribution generation (DG), load shifting, permanent demand reduction, and others, have been created to lower peak demand as the economic need to fully use the capacity of current power equipment develops.to improve customers' pleasure with electric energy, the electrical utility must be appropriately reliable. Utilities have seen this trend and have started considering DG while managing distribution networks and making dependability decisions.

The major goal of the power distribution system's establishment was to give its clients a sufficient quantity of electricity at the lowest feasible cost while maintaining a respectable level of dependability. In the last few years, Ethiopia's electricity distribution infrastructure has experienced exponential growth in both size and technology. In order to meet the customer's demand for reliability, the utility business must make every effort to ensure that costs are kept to a minimum while maximizing strategic planning. the reliability of the system, which is defined as its capacity to deliver a sufficient amount of electric energy (Mamo & Hizkiel, 2023). Indexes are used to assess reliability and are intended to investigate the impact of disruptions in terms of their frequency and length (Sperandio, 2021)**.**

Reliability is associated with consumer or load-point disruptions given that power quality is a subset of it. Another definition of distributed generation (DG) is an electric power-generating unit positioned close to the load center. To get the highest reliability standards, it is important to first understand the placement, before inserting the DG unit into the distribution system, determine its size and kind. A distribution system's harmonics, voltage profile, dependability, and many other characteristics are affected by where a distributed generation unit is placed inside it. The Monte Carlo method and the analytical method are the two primary techniques used to assess the distribution system's reliability. While the reliability indices are created using different mathematical formulations via analytical methodologies, In order to calculate the probability of the reliability indices, the Monte Carlo approach samples network component failures (Ahmad & Asar, 2021).

Three fundamental reliability indices are employed in this thesis: average outage time, average failure duration, and frequency of failure. The system reliability indices that are used to assess network performance are the Average Service Unavailability Index (ASUI), Average Service Interruption Duration Index (SAIDI), Average Service Availability Index (ASAI), Average Energy Not Served Index (AENS), and Energy Not Served Index (ENS) (Idowu et al., 2021). which provide details regarding the indices' variability, must also be obtained in order to raise the reliability indices (Mamo & Hizkiel, 2023).

According to the above Motivated by the identified reliability problem and the proposed solution involving distributed generation (DG), this thesis leverages the use of voltage stability indices (VSI) and reliability indices to determine the optimal size and location for DG units within the Bichena distribution substation. By simulating the insertion of DG units with varying sizes and placements, the study analyses the impact on the reliability of the substation's feeder lines, comparing pre- and post-DG scenarios using appropriate software.

1.2 Statement of the Problem

Motivated by the need to assess and enhance reliability and ensure sustainable electricity delivery to consumers, the thesis focuses on addressing the reliability issues affecting one of the seven outgoing distribution feeders from the Bichena substation. This feeder currently suffers from high power interruptions, ultimately impacting domestic, commercial, industrial, and agricultural users in various cities and villages. Ethiopia is working to change from a least developed country to a medium-income country economically. A robust and reliable power supply sector is crucial. Strengthening this sector aligns with the government's emphasis on expanding and reinforcing the electric power supply as a key economic driver. The thesis addresses the problem of reliability. So that this problem can be solved using solar to fulfil load demand requirements and satisfy customers, In addition to this, it also investigates the role of renewable DG in distribution substation reliability for an energy source that is emission-free and sustainable.

1.3 Objective of the Thesis

1.3.1 General Objective

To enhance the reliability of the Debrework feeder through the optimal sizing and placement of Distributed Generation (DG) systems.

1.3.2 Specific Objectives

The specific objective of the thesis includes:

- To assess the existing reliability indices and performance of the Debrework feeder.
- To determine the optimal sizing of distributed generation systems for improving reliability in the Debrework feeder.
- To identify suitable locations for thee placement of distributed generation units within the Debrework feeder.
- To evaluate the impact of the optimal sizing and placement of distributed generation on the reliability indices of the Debrework feeder.

1.4 Significance of the Thesis

This thesis focuses on the Bichena distribution substation, which suffers from frequent power interruptions on its feeder lines. It proposes a solution by strategically placing DG units. This approach has the potential to:

- Addressing reliability concerns involves injecting power closer to demand centers, thus enhancing reliability.
- Ensure sustainable electricity delivery to consumers by potential utilization of renewable energy sources for DG.

1.5 Scope of the Thesis

This thesis involves enhancing the reliability of the Bichena substation by integrating DG resources**.** First, the definition and importance of distribution generation are explained. Second, determine the impact of distribution generation, which will be selected based on economic cost benefits and reliability. After that, the reliability of the system is analyses before and after the inserting of DG with the help of ETAP 19.0.1. Software.

1.6 Limitation of the Thesis

This thesis focuses on a radial distribution system model for the Bichena substation. While the placement of DG within this model is valuable, it is important to acknowledge a limitation. The study does not consider the applicability of these findings to other distribution system configurations, such as meshed or ring networks. This thesis focuses on software, not hardware.

1.7 Thesis Organizations

Chapter one contains an introduction to the case study area, a statement of the problem, a general objective, a specific objective, the significance of the thesis, and the scope of the thesis to be explained. Chapter two contains an overview of the study and the literature reviews of different papers related to the thesis. Chapter three to explain materials, methodology, and the different data collected based on the case study from Bichena Substation and Bichena District Office, such as interruption duration, frequency, and different types of faults in the case study. After a numerical analysis of the gathered data, reliability indices are computed and presented. The cost of ENS for the Bichena Substation owing to an outage is computed using the EEU tariff. Techniques for enhancing distribution system reliability for optimization goals and reliability enhancement plans the suggested system calculates the VSI to determine the ideal DG site. The size was determined by the sensitive load capacity. Chapter four choosing DG technology, creating a BDS model and design using ETAP software, meteorological data from a case study, and the DG (PV) optimization cost were calculated. The chosen feeder receives DG as backup and is simulated using ETAP software for reliability improvement. Comparisons are made between the thesis work's outcomes and the simulation's discussions. And also, a cost analysis was calculated. Chapter five Finally, conclusions and recommendations are discussed in this chapter. The appendix included the two-year data power interruption of duration and frequency and each month's average load. solar radiation data from NASA and PVGIS data in different years.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Overview

The Ethiopian power system consists of interconnected generation, transmission, and distribution systems. Transmission systems transfer bulk power over long distances at high voltages, while distribution systems deliver power to consumers at lower voltages, typically in the range of 11 kV to 33kV (Meier, 2006)**.** DG offers a multitude of resources, encompassing both renewable and non-renewable options. This thesis will discuss specific DG choices based on carefully defined selection criteria. Distribution system reliability is vital, as it directly impacts component uptime and customer service. Under normal operating conditions, all components and customers receive power. However, this state can be disrupted by both scheduled and unscheduled events. Scheduled events include power shading and equipment maintenance, while unscheduled events can be caused by human error, environmental factors, tree-related issues, and outages. Evaluating system reliability involves specific indices that assess its resilience and performance**.**

2.2 Definition of Distribution Generation

Electricity was produced by generators and sent to distribution systems via transmission lines in conventional power networks. The issues with these systems were: severe transmission costs; environmental issues; and frequency and voltage volatility. However, the rising population and load demand have led to an increase in power consumption in recent times. That's why so many nations favor using DG to meet a portion of their energy needs (Gholami, 2017). The term "distributed generation" refers to the idea of producing tiny amounts of electricity close to the customer's location in order to meet their growing energy needs. (Fulfilment et al., 2020) DGs are becoming more prevalent and crucial to the power system. Numerous studies have been conducted on the advantages of using DG in the power system (Gholami, 2017).

These advantages are numerous and include the following lists: Air pollution and environmental problems can be resolved in a number of ways by using common DG sources, like solar and wind.

Cost benefit: Although the cost of DG units is higher than that of a plant, they produce less power overall since we do not require transmission lines to deliver the power to customers. Power produced by a DG unit is less expensive overall. As shown in Figure 2.2.

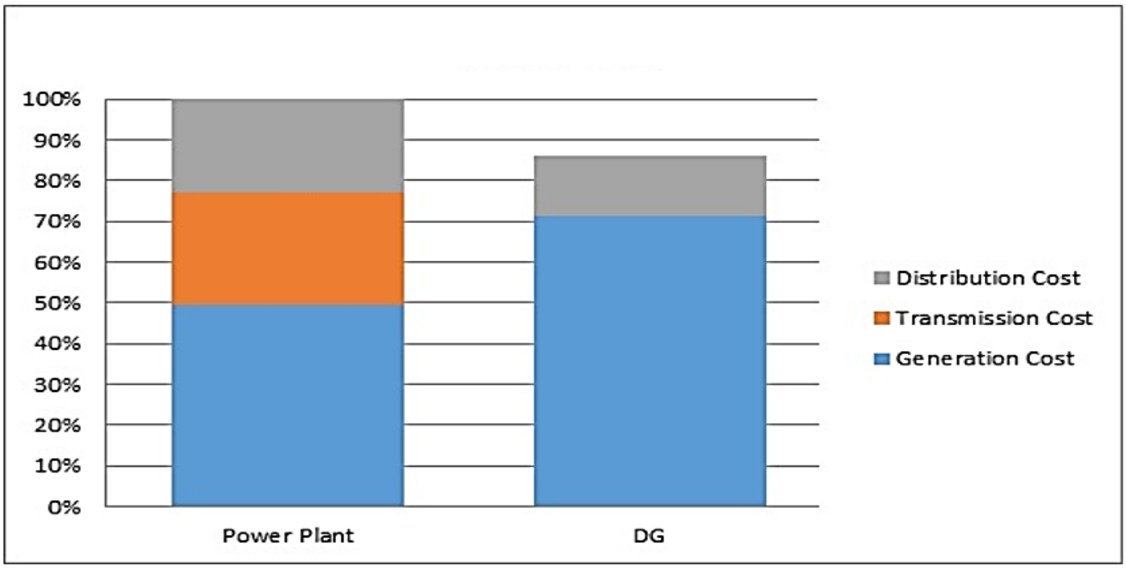

Figure 2.1: Economic Comparison between DGs and Power plants (Gholami, 2017)

As transmission lines are removed, the power system's losses are decreased, which enhances voltage stability. As a result, a network's ability to operate with steady voltage can be enhanced by utilizing DG units. We can determine the active and reactive power values, together with other data, at each bus prior to the positioning of DG. After the DG is placed, we will utilize the power flow method to get the data once more in order to observe the impact on the DG power distribution network (Shuang & Qinxiang, n.d.). a number of categories that specify the size of the generation units are provided in order to further clarify the DG idea. According to the reference, the size of DG is defined (Fernandez Sarabia, 2011).

- Micro DG between 1 Watt and 5 kW
- The small DG between 5 kW and 5 MW
- The medium DG is between 5 MW and 50 MW.
- The large DG between 50 MW and 300 MW

2.3 Distribution Generation Technology (DGT)

With uses in the commercial, industrial, and residential domains, DG technologies may satisfy the demands of a broad spectrum of customers (System et al., n.d.). DG technologies are often divided into two categories: renewable and non-renewable. Hydropower, biomass, geothermal, solar, and wind energy are examples of renewable technology. Examples of non-renewable DG technologies include fuel cells, microturbines, diesel generators, internal combustion engines (ICE), and combustion turbines (Zareipour & Bhattacharya, 2016).

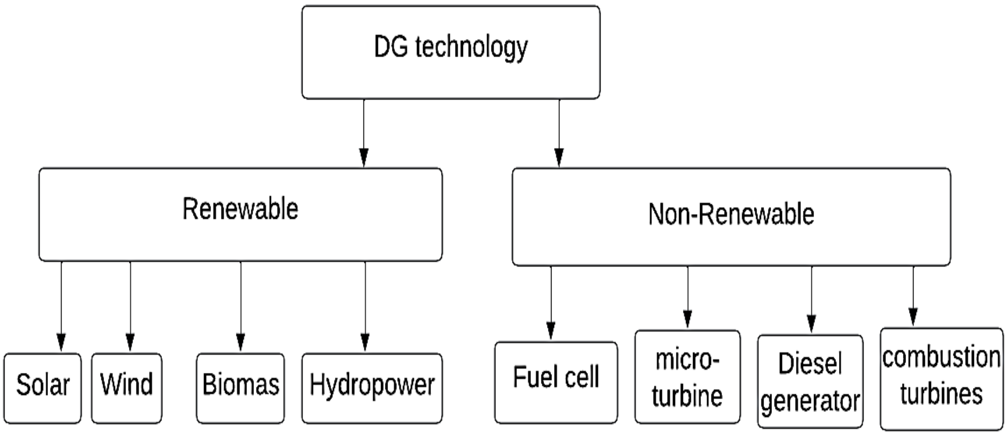

Figure 2.2: Types of distribution generation technology

Photovoltaic Systems: A photovoltaic system generates electricity from solar light. In this technology, solar cells made of semi-conductive materials convert photons' inherent energy into electrical energy when they are exposed to daylight. To produce the most power, the cells are arranged in a moving or stationary array that continuously tracks the sun. These systems are simple to use, have no emissions, and just require solar light as fuel. They are also environmentally friendly (Fernandez Sarabia, 2011). A solar panel cell is depicted in Figure 2-3.

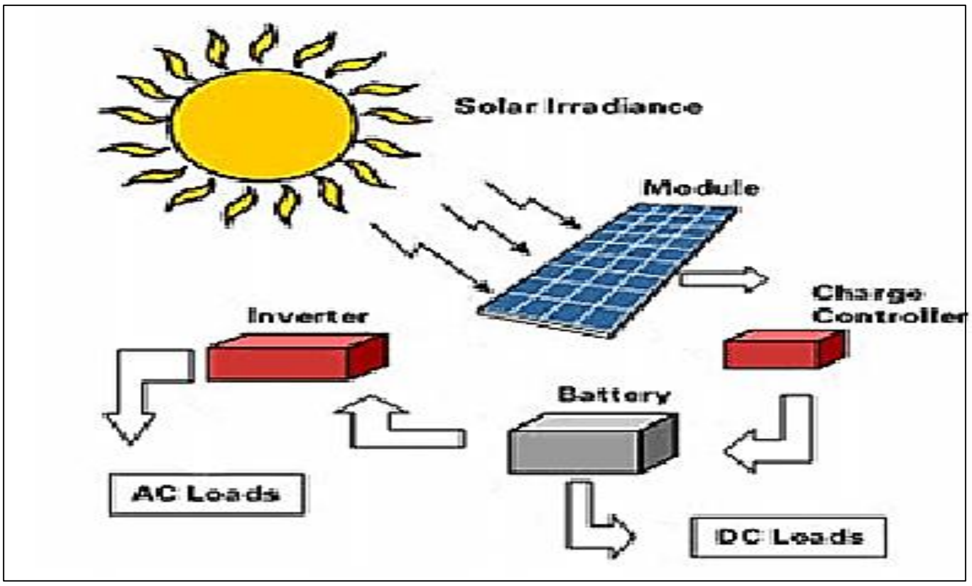

Figure 2.3: Schematic diagram of a solar energy system (Fernnandez Sarabia, 2011)

PV systems provide DC voltage, which is subsequently converted to AC with the use of an inverter. Two basic designs are commonly employed, one with and one without battery storage.

Major Features of the Solar System

Solar energy comes from the radiation emitted by the sun and is a free resource that can be used to generate heat or electricity. Some of the advantages of the solar system are listed as follows:

- Among all energy resources, solar energy boasts the smallest environmental footprint.
- Generating your own electricity through solar panels translates to reduced reliance on the utility grid, leading to immediate savings on your energy bill.
- Solar panels generate electricity during peak demand hours, contributing to peak shaving and potentially lower energy costs.
- Unlike most traditional energy sources, solar energy can be harnessed anywhere with sunlight, making it ideal for off-grid or remote locations.
- With the widespread adoption of solar power, numerous small, distributed power generation points have been created. This enhances grid resilience and reduces vulnerability to disruptions from natural disasters or human intervention.
- Solar energy minimizes transmission losses compared to the long-distance transportation of electricity from centralized power plants.

Application of Solar System

Photovoltaic (PV) systems have many applications due to their benefits of increased efficiency, reduced cost, and fewer emissions. Some of the applications are listed as follows:

- Dry-cell batteries and kerosene can be affordably replaced with solar home systems (SHS), which are widely available in the commercial sector. thereby reducing greenhouse gas (GHG) emissions and making an important contribution to climate protection.
- Pump drip irrigation systems powered by solar energy offer a sustainable solution for growing orchards in arid regions.

- Solar energy also extends to water heating through solar heaters, which use rooftop panels to take in heat from the sun and distribute it to water tanks.
- Solar lighting has become commonplace and widespread, ranging from public lights and road signs to home landscaping and security lights.
- Solar energy can also be used for ventilation and transportation.

Wind Turbine: Wind turbines act as converters, transforming the variable and un storable energy of wind into electricity. The basic principle involves two conversion steps: first, the rotor captures the wind's kinetic energy and converts it into mechanical torque applied to a shaft. Second, the generator system transforms this torque into electricity. In most wind turbines, the generator produces an AC output voltage directly related to the wind speed. Due to the inherent variability of wind, this voltage needs conversion to DC for further processing and then back to AC for grid compatibility. This conversion is typically handled by inverters. However, there are also fixed-speed wind turbines that connect directly to the grid without these conversion steps (Fernandez Sarabia, 2011).

Fuel cell: Like a battery constantly replenished with hydrogen-rich fuel, fuel cells function by combining this "fuel" with air, which provides the necessary oxygen for a chemical reaction. This reaction, facilitated by an ion-conducting electrolyte, generates direct current (DC) voltage within the fuel cell. Inverters then convert this DC voltage into alternating current (AC) for delivery to the grid (Fernandez Sarabia, 2011). In Figure 2.5, the operation and characteristics of a fuel cell are presented. Although fuel cells have a high running cost, a major disadvantage, they offer unique benefits: 1) high reliability due to the absence of moving parts, resulting in quieter operation; and 2) the ability to use a wide range of fossil fuels with greater efficiency than other generation devices. However, careful assessment of their environmental impact is crucial, including assessing pollution emissions and the effect of electrolyte degradation on both efficiency and lifespan.

Micro-turbine: A microturbine operates by converting thermal energy into mechanical energy through the flow of gas. Fuel, typically in the form of gas, mixes with air within a combustion chamber, fueled by a compressor. This resulting hot gas mixture drives the turbine's rotation, which in turn powers both the generator and the compressor. Most commonly, the compressor, turbine, and electric generator share the same shaft for efficient operation (Fernandez Sarabia, 2011). Though microturbines generate electricity, their output voltage isn't compatible with the grid directly. It requires conversion to DC first, then back to AC, matching the grid's standard voltage and frequency. This conversion step adds complexity. While microturbines boast clean operation with low emissions and good efficiency, they face some drawbacks. The main challenges include high maintenance costs and limited field experience. Most haven't operated long enough to establish a reliable performance database. Additionally, effective control and dispatch methods for managing large-scale microturbine networks and selling excess energy are still under development (Fernandez Sarabia, 2011).

Advantages of DG

Some benefits of DG are listed below:

- Reduced transmission and distribution losses:
- Improved grid stability and security: DG systems can help to improve grid stability by acting as backup power sources and reducing reliance on a single point of failure.
- Reduced environmental impact: Many DG technologies, such as solar and wind power, generate electricity with minimal greenhouse gas emissions.
- Increased energy independence: By generating their own power, homes, businesses, and communities can become less reliant on the traditional grid and potentially reduce their electricity bills.
- Promotes innovation and diversification: DG creates opportunities for the creation and use of novel, environmentally friendly energy technology.
- Potential for local job creation.

Disadvantages of DG

DG offers a range of benefits, but it also has some drawbacks to consider.

- Power converters, which have the ability to introduce harmonics into the system, are required in order to link DG to the necessary grid.
- Overvoltage, fluctuations, and unbalance of the system voltage might occur from the connection of DG if appropriate coordination with the utility supply is not established.

2.4 Reliability of Power Systems

Evaluation of power system reliability essentially focuses on analyzing both healthy and failure states of the system. The ability of the power system to work as a whole is referred to as power system reliability. the entire capability of the power system to carry out its task is referred to as power system reliability. Talks about power system reliability typically focus on two distinct issues: security and adequacy (Vrana & Johansson, 2015).

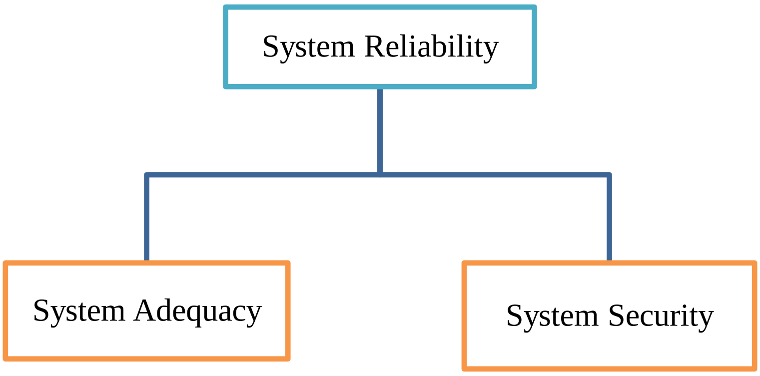

Figure 2.4: System reliability subdivisions

There are two basic aspects of a power system.

Adequacy: is the state in which there are enough resources to meet demand. Static conditions affect a power system's adequacy.

Security: is the system's capacity to tolerate abrupt, unforeseen disruptions, like short circuits, in order to maintain the supply of electricity.

2.5 Worth and the Cost of Reliability

Figure 2.4 presents the fundamental idea of reliability cost/reliability worth evaluation. The graphic illustrates how, in general, increased reliability translates into higher investment costs. In contrast, as reliability rises, the expenses incurred by customers due to malfunctions drop. Therefore, the overall expenses are the sum of these two separate expenses. Accordingly, an ideal objective for reliability is reached when the additional expense of enhancing service reliability matches the corresponding decrease in societal interruption costs. This equilibrium occurs when the total customer interruption costs represent the societal value or utility derived from service reliability (Gupta & Goel, 2003).

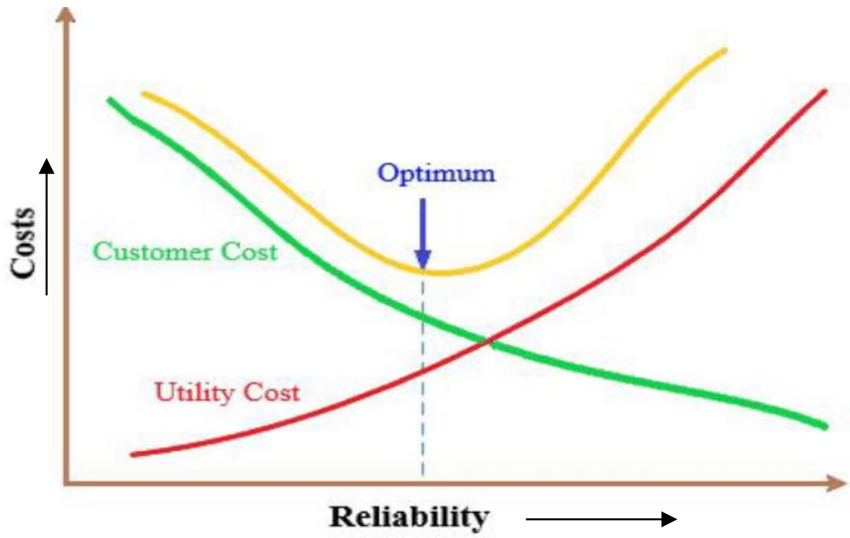

Figure 2.5:Cost according to reliability (Kebede, 2023)

Figure 2.5 illustrates how, when service reliability rises, utility costs, that is, investment, maintenance, and operating costs, increase but socioeconomic customer interruption costs fall. The total of the two curves represents the cost. When the entire cost is at its lowest, reliability is at its highest.

2.6 Reliability Analysis Method

Reliability analysis methods are a collection of techniques used to assess the ability of a system or component to function without failure over a specified period under specific operating conditions. There are two primary methods used to assess distribution networks' reliability. These are analytical methods and simulation (Monte Carlo) methods. The foundation of the analytical approach is the solving of mathematical models. Typically, an analytical method based on failure mode assessment and the application of series and parallel network equations is used to evaluate reliability indices. The predicted failure rate (λ), average outage time (r), and expected yearly outage time (u) are the three commonly used reliability indices that are sufficient for the basic radial system to define the level of service continuity (Anteneh & Khan, 2019).

2.7 Analytical Methods

A system consistency and dependability can be evaluated systematically using reliability analysis. It involves identifying potential failures, analyzing their causes, and implementing measures to prevent or mitigate them.

Model of the Markov Chain: A model of Markov is widely utilised in assessments of quantitative reliability and is a good way to provide a general understanding of the reliability evaluation approach. It is possible to calculate the radial distribution network's reliability using Markov model computations.

It has two central concepts. (Kebede, 2023)

- Frailer frequency (λ)
- Repair time or duration (r)

For instance, it is believed that component-wise reliability can only occur in the following situations:

- Initial part of a functioning or operational condition (input)
- A second component that is not in service or needs repair (output)

The two modal states are shown in Figure 2-6 (0 and 1), where 0 represents a downstate and 1 represents an operating state.

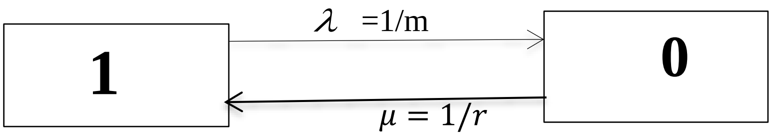

Figure 2. 6: Diagram of transition state components

Where: λ is Fault frequency, m is main time to failure, μ is Repair frequency, and r is a main time to repair

$$\lambda = \frac{total\ number\ of\ outage\ on\ a\ component\ a\ given\ period}{total\ time\ in\ a\ component\ in\ opration} \tag{2.1}$$

A component's expected functional and outage time (also known as its state cycle) is shown in figure 2-7. the Markov process can be used to model the system, and the following equations were created to determine the probabilities of living in each state in terms of state transition rates (Gupta & Goel, 2003).

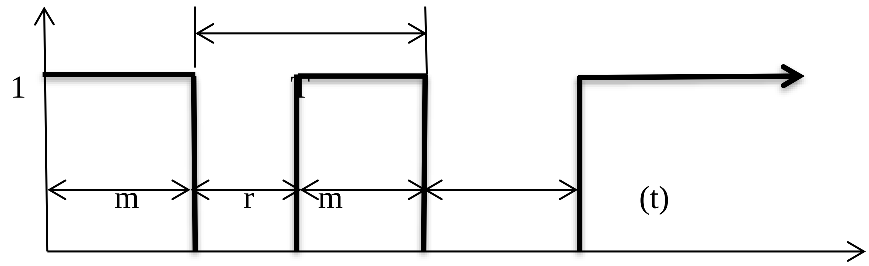

Figure 2.7: Average state cycle

The formula for calculating the average function time, where: m is mean time to failure

(m = MTTF) = 1/λ, r = MTTR, is the mean time to repair, r=1/ μ

m+r = MTBR, mean time between failures, T =1/f, f = cycle frequency = 1/T; which is equivalent to cycle T = 1/f,

The graphic displays the probability that a component will be in one of the two states.

$$p_o = \frac{r}{m+r} = \frac{\lambda}{\lambda+\mu} = \frac{r}{T} = \frac{f}{\mu} = \sum \frac{(down\,time)}{(down\,time)+(up\,time)} \tag{2.2}$$

$$p_o = \frac{m}{m+r} = \frac{\mu}{\lambda+\mu} = \frac{m}{T} = \frac{f}{\lambda} = \sum \frac{(down\,time)}{(down\,time)+(up\,time)} \tag{2.3}$$

Where: $f = \mu . p_o$, $f = \lambda + p_1$, $f = p_o . \lambda = p_1 . \mu$

p_o= probability of a component to be in state o (down)

p_1 = probability of a component to be in state 1 (up)

f = The frequency of a cycle, whether it is in or out)

System in Series: Essentially, the Bichena Distribution System is created, built, and run as a radial system. Breakers, lines, switches, transformers, and, at the end, "customers" are the essential series components that make up a radial system. Whereas "a chain is no stronger than its part" applies to systems in series structures, where both components must fail for the system to fail, parallel structures require both to fail before the system breaks. In this instance, as illustrated in figure 8., every component is linked in series, and the following equations are required to assess the basic indices (Gupta & Goel, 2003).

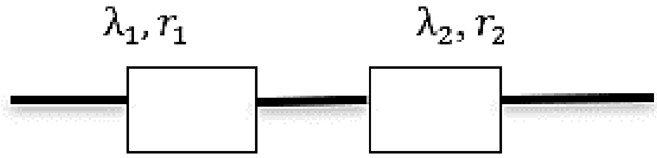

Figure 2.8: System in Series

system failure rate on average;

$$\lambda_s = \lambda_1 + \lambda_2 = \sum_{i=1}^{2} \lambda_i \tag{2.4}$$

System outage duration on average;

$$r_s = \frac{\lambda_1 r_1 + \lambda_2 r_2 + \lambda_1 \lambda_2 r_1 r_2}{\lambda_1 + \lambda_2} = \frac{\sum \lambda_i r_i}{\sum \lambda_i} = \frac{\mu_s}{\lambda_s} \tag{2.5}$$

if $\lambda_1 \ \lambda_2 \ r_1 \ r_2 \ll \lambda_1 \ r_1 or \lambda_2 \ \ r_2$

Annual outage duration on average:

$$\mu_s = f_s \times r_s = \lambda_s \times s_s \tag{2.6}$$

The failure rate at node i is represented by λ(i)., The outage time at node i is denoted by r(i).

System in Parallel: In this instance, the load point's failure modes involve overlapping outages, meaning that to interrupt a load point, multiple components have to be out of service simultaneously, as shown in Figure 2-8. Assuming that the malfunctions are separate, and that restoration calls for either replacement or repair, the formulas used to calculate the overlapping outage indices are as shown below (Gupta & Goel, 2003).

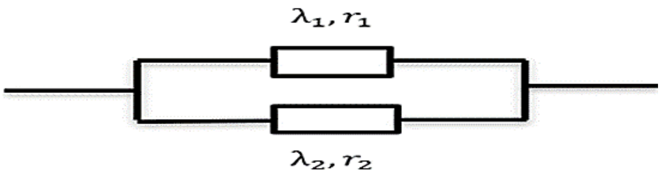

Figure 2.9: System in parallel

Average failure rate of the system;

$$\lambda_s = \frac{\lambda_1 \lambda_2 (r_1 + r_2)}{1 + \lambda_1 r_1 + \lambda_2 r_2} = \lambda_1 \lambda_2 \lambda_2 (r_1 + r_2) \tag{2.7}$$

Where, $\lambda_1 \ r_1$and $\lambda_2 \ r_2$ usually $\ll 1$

Average outage time of the system:

$$r_p = \frac{r_1 r_2}{r_1 + r_2} \tag{2.8}$$

Average annual outage time of the system;

$$\mu_P = \lambda_P \, r_p \tag{2.9}$$

More extended indices must be employed for general distribution systems, which include mixed radial and meshed systems. These are suitable for simple radial systems (Gupta & Goel, 2003).

2.8 Review on Related Works

In this part, methods for enhancing the research publication's distribution system reliability are covered. In the electrical system, power outages are a major issue that has an impact on the nation's economic development. Additionally, the delivery network did not get more focus than the network for generation and transmission, which influences the needs of the client. Enhancement of the distribution system is necessary to meet customer needs and improve service quality and dependability efficiency. Given its ability to reduce costs and enhance operational reliability as well as system security, power systems optimization is a crucial subfield in power systems engineering. Massive and intricate power systems are becoming the standard. The development of optimization strategies that address the various inherent restrictions in power system optimization is therefore necessary.

(Sandeep Kumar et al., 2019) in order to ascertain the ideal placement and the most fixed-size DGs that are permitted to be incorporated into the distribution structure, this study suggested a new modelling method called VSI. The writers of this study are mostly focused on maximizing the reduction of the voltage stability index and reducing power losses. The primary contribution of this study is an increase in the operational power factor and steady-state voltage stability of each individual diesel generator integrated into the system. The maximum number of DGs that are suitable for use in the IEEE 12 Bus test system that is being considered is 1, 2, 3, 4, 5, and 100 KV, 200 KVA, 300 KVA, 400 KVA, and 500 KVA, respectively. five numbers of these standard sizes can be applied to get the least amount of real power line loss for DG. But in this paper, the reliability enhancement was not considered.

(Ankaliki, 2020) in this paper used an algorithmic technique to determine the best location and size of DGs in a distribution network to enhance voltage stability and minimize losses under different loading conditions. This research's strength is that an algorithm is provided to ascertain the perfect placement and size of the distributed generating system to lower overall power losses, enhance the voltage profile in the main distribution system, and perform a voltage stability evaluation at various load levels. Nevertheless, the effectiveness of the approach has not been proven when positioning many DGs in the network at once. This paper was not calculated cost analysis of DG.

(Ankaliki, 2018) In addition to a novel methodology that employs a power world simulator to determine where and how DG should be placed, an algorithm has been given to raise voltages and lower losses at the various buses, improving voltage stability within the structure bundle. To enhance the voltage profile and lower total power losses in a primary distribution network, the authors provide a technique to ascertain the appropriate size corresponding to the ideal position for DG at various buses. The primary contribution of this research is the sensitivity-based analysis. A new methodology has been developed to use a power world simulator package to determine the ideal DG position and size in order to lower losses and raise voltages at various buses. But the method cannot be used to place more than one DG.

Kazeminejad & Banejad (2020) investigated maximum load-ability using the Generalized Voltage Stability Index (GSI) and applied a recently proposed GSI technique to optimize DG location and size. Additionally, they employed an analytical approach to evaluate the impact of DGs on distribution system characteristics. The primary contribution of this paper lies in introducing GSI as a recent indicator to maximize DG size and placement, aiming for enhanced load capacity and reduced losses in real-world networks. While the study's strength is evident in recognizing three distinct DG modes in voltage control, namely reactive power voltage control mode (PV mode with VAR), constant power mode (PQ mode), and constraint mode (PV mode), its weakness lies in focusing solely on power loss reduction without considering further enhancements.

(Kazeminejad et al., 2019) It is necessary to employ a forward-backward power flow incorporating a voltage stability index (VSI) in order to establish the appropriate size and placement of DGs within the network. The recommended approach is the research's strongest point because of its computational complexities, such as quick run times and minimal iterations required to reach convergence, which make it ideal for real-world use.

But rather than taking reliability indices into account, the focus of this research is on voltage stability and minimizing power loss index improvement.

(Ahmed et al., 2021) This paper provides an overview of distribution generation (DG) in the context of the challenges faced by power systems and researchers due to increasing electrical demand and network congestion. DG is primarily integrated into distribution networks, particularly in rural and remote areas, to overcome voltage drops and high line losses. The optimal planning of DG units is crucial to ensuring maximum benefits, including improved voltage stability and power quality. The optimization methodologies used in the paper cuckoo search algorithm are multi-objective evolutionary algorithms. Objective functions in DG planning, such as reducing power loss and enhancing the voltage profile, However, the investment cost required to install the DG and the payback period are not calculated.

Summary of related works

The literature mentioned above indicates that the majority of publications concentrate on one or two particular issue But, didn't considered: Investment cost to installed the DG, Payback period, and Reliability enhancement. But this thesis proposes upgrading the distribution system was crucial to meet customer needs. this includes enhancing service quality, dependability, and efficiency. DG offers a compelling solution, as it was reduced costs, improve operational reliability, and strengthen system security. this thesis proposes to use the VSI optimization method for distribution system optimum placement and size of distributed generation. and also uses the analytical method to enhance reliability. In addition, to assess the actual, surviving Debrework feeder line's capacity to deliver reliable electricity distribution.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Materials

DG technologies can improve the reliability and efficiency of distribution systems. This thesis will utilize ETAP software to model and analyses DG for a specific distribution system. The analysis will compare key reliability indices (SAIFI, SAIDI, etc.) and energy losses for different DG configurations. Math Type will be used to present complex mathematical models and equations related to power flow and reliability calculations. A cost-benefit analysis considering installation costs, energy savings, and potential system upgrades will be conducted in MS Word to identify the most optimal DG integration strategy. In addition, Mendeley Desktop is a software application you can install on your computer to manage your research references and citations.

3.2 Methodology

In the methodology of the thesis, the following methods and techniques will be employed

First, identifying the issue and then reviewing relevant research. Then, identifying the existing problems in the Bichena distribution feeders and collecting technical data for the Bichena distribution substation and Bichena district office, such as interruption duration, frequency, and types of faults. Following data collection, the analytical method will be applied to determine the optimal location of DG concerning the specified distribution network based on calculated VSI values. Afterward, using the ETAP software model, the existing system will be simulated to contrast both the initial and optimal installation of DG in the distribution network. Subsequently, the results from the model will be utilized to compare how much reliability is improved by adding DG to the selected feeder and the overall substation. Finally, a cost analysis will be conducted to estimate the revenue saved by the Bichena Distribution Substation after the reliability enhancement. Generally, the method followed to accomplish this research can be shown as the Figure 3-1 below.

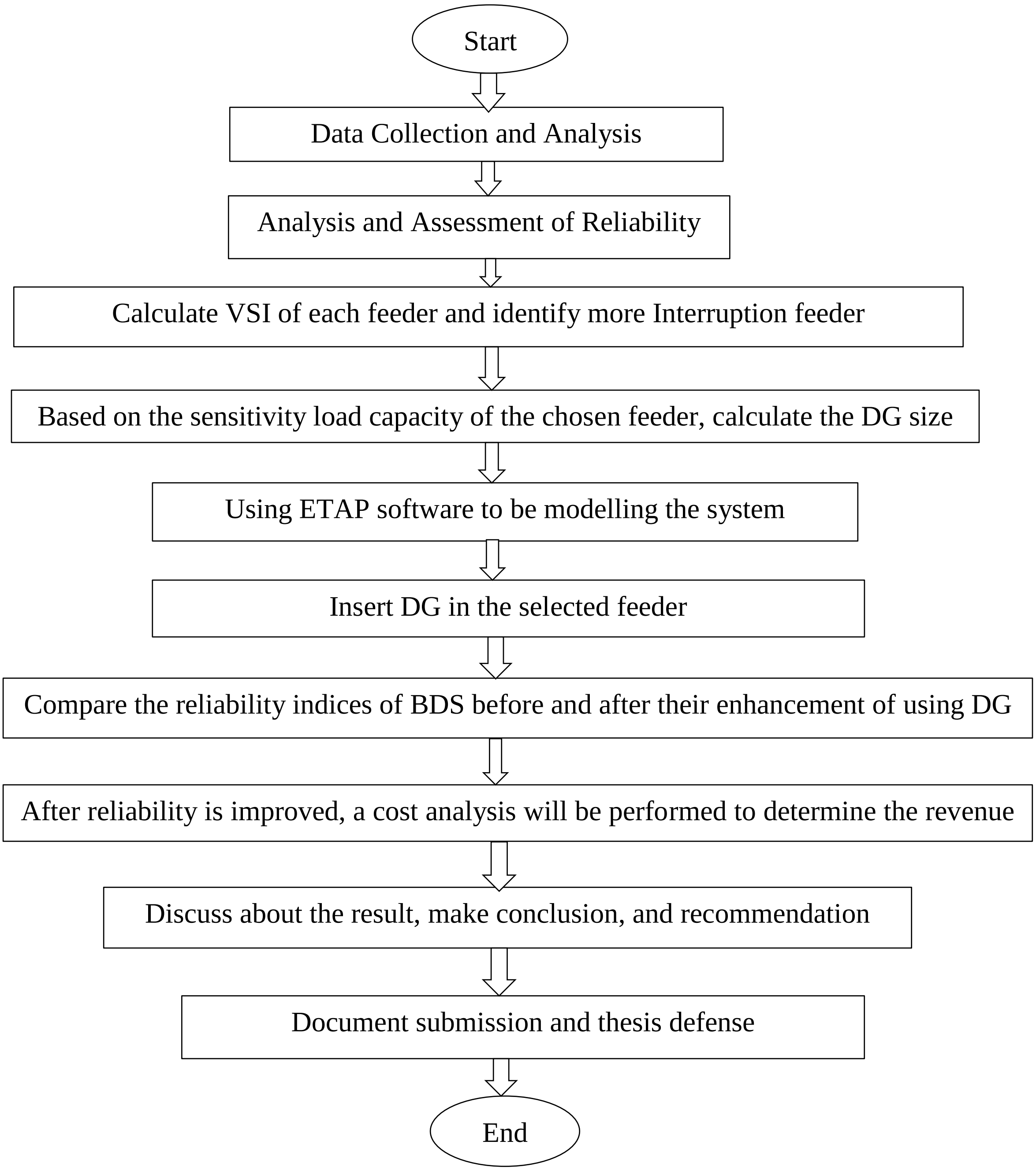

Figure 3. 1: Proposed method of study flowchart

3.3 Case Study Description

Bichena substation is one of the step-down substations established near the town of Bichena. The feeder for these substations comes from Debremarkos substation through the transmission line. So, this 66 kV input is stepped down to 33 kV and 15 kV via a 6.3 MVA and 12.5 MVA power transformer. Now, the substation gives power to different woreda towns and some factories. The substation mainly has seven outgoing feeders. From these 3 feeders, i.e., Bichena, Dejen, and Kuyi, it is 66/33/15kV. And the other 2 feeders are

Debrework and Meadrok, which are 66/15 kV. And the two feeders, i.e., tike and telema, are 66/33 kV.

Table 3.1: Substation with the corresponding feeders

Substation	Feeders	Lines		Feeders	Lines
Bichena	Bichena	66/33/15kv		Debrework	66/15kv
	Dejen	66/33/15kv		Tike	66/33kv
	Meadrok	66/15kv		Telema	66/33kv
	Kuyi	66/33/15kv			

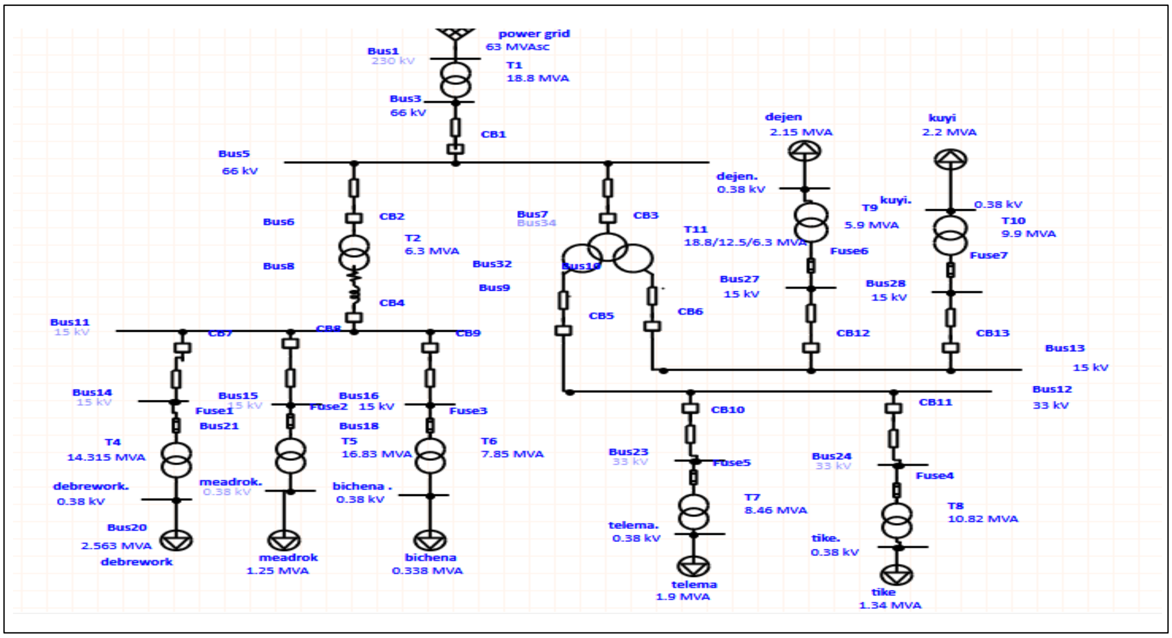

Figure 3.2: Single line diagram of Seven outgoing feeders of BDS

As it is shown above, the incoming voltage is 66 kV from Debremarkos main substation through a 66 kV line, and the outgoing is 66/33/15 kV and 66/15 kV feeders to different woreda towns and rural areas. As soon as this 66 kV reaches the substations, it is connected to the bus bar and current transformer. This current transformer steps down the incoming current and uses a measurement system as well as protection for the main transformer. After the current transformer, it is given to the main two step-down transformers, which are 66/15 kV and 66/33/15 kV. After these transformers, the line is given to the breaker for the controlling system.

3.4 Data Collection

The information has been collected from the Bichena substation, Bichena district, and an Ethiopian electric utility. The collected data are based on the types of faults, number of transformers, feeder length and rating of transformers, interruption frequency and duration of two consecutive years, peak load, and minimum load. The substation's two-year data collected on the main voltage 33 kV and the 15 kV outgoing feeders' interruption frequency and duration can be seen in Appendix B.

3.5 Basic Information About Bichena Substation

They have provided the Bichena substation with a 66kV transmission line from Debremarkos, which was reached at the substation back then. The distributed networks in the town have main voltages of 33 kV and 15 kV. Additionally, this voltage decreases to 220 volts single-phase and 380 volts three-phase. The substation has seven outgoing feeders. the substation data listed in Table 3.2.

Table 3.2: Bichena distribution substation data

Substation's name	Transformer quantity	Level of voltage (KV)	Capacity of transformers (MVA)	Total capacity (MVA)
Bichena	2	66/33/15kv	12.5	18.8
		66/15kv	6.3	

Transformer rating for every feeder: the quantity of transformers paired with the rating for every feeder is indicated as below.

Table 3.3: Rating of Transformer and total Numbers of capacity

No	Feeders	Rating of transformers (KVA)	No of trafo.	Total capacity of Transformer (MVA)	Conductor size
1	Bichena	7850KVA	32	7.85	AAC_50mm2
2	Debrework	15212KVA	94	15.212	AAC_50mm2
3	Meadrok	16020KVA	47	16.02	AAC_50mm2
4	Dejen	5900KVA	41	5.9	AAC_50mm2
5	Kuyi	9900KVA	64	9.9	AAC_50mm2
6	Telema	8460KVA	56	8.46	AAC_50mm2
7	Tike	10820KVA	48	10.82	AAC_50mm2

Below Tables 3.4 and 3.5 are the recorded data from each feeder customer's annual average energy and power consumption, calculated from 2021–2022 G.C. (2014 E.C.) and 2022–2023 G.C. (2015 E.C.), respectively. Each month recorded data from Appendix A.

Table 3.4:The average yearly energy and power usage of (2021/22 (2014 E.C)

Feeder Name	Average power (MVA)	Average active power (MW)	Average reactive power (MVAr)	Average active energy (KWh)	Average reactive energy (KVArh)
Bichena	0.32	0.3	0.12	2.628	1.0512
Debrework	2.37	2.3	0.57	20.148	4.9932
Meadrok	1.16	1.12	0.29	9.8112	2.5404
Dejen	1.79	1.72	0.53	10.2492	4.6428
Kuyi	2.27	2.20	0.57	19.272	4.9932
Telema	1.99	1.9	0.59	16.644	5.1684
Tike	1.51	1.34	0.7	11.7384	6.132
Total	11.41	10.78	3.37	90.4908	29.5212

From this table It is possible to calculate the substation power factor (PF). PF= Cos (tan-1(Q/P)) Cos (tan-1(29,521,200/90,490,800)) = 0.95.

Table 3.5:The average yearly energy and power usage of 2022/2023 (2015 E.C)

Feeder name	Average power (MVA)	Average active power (MW)	Average reactive power (MVAr)	Average active energy (KWh)	Average reactive energy (KVArh)
Bichena	0.36	0.34	0.13	2.9784	1.1388
Debrework	2.4	2.33	0.60	20.4108	5.256
Meadrok	1.18	1.14	0.32	9.9864	2.8032
Dejen	1.86	1.77	0.58	15.052	5.0808
Kuyi	2.42	2.34	0.61	20.4984	5.3436
Telema	2.04	1.93	0.65	16.9068	5.694
Tike	1.61	1.38	0.82	12.0888	7.1832
Total	11.87	11.23	3.71	98.3748	32.4996

From the above table, it is possible to calculate the substation power factor (PF). PF = Cos (tan-1(Q/P)) Cos (tan-1(32,499,600/98,374,800)) = 0.93. The next table shows the average energy, power consumption, average, and peak load of both 2014 and 2015 E.C.

Table 3.6**:** Average usage of power and energy

Feeder name	Average (MVA)	Average active power (MW)	Average reactive power (MVAr)	Average active energy (KWh)	Average reactive energy (KVArh)
Bichena	0.34	0.32	0.13	2.8032	1.1388
Debrework	2.39	2.32	0.59	20.3232	5.1684
Meadroke	1.17	1.13	0.31	9.8988	2.7156
Dejen	1.83	1.745	0.56	12.8772	4.9056
Kuyi	2.35	2.27	0.59	19.8852	5.1684
Telema	2.02	1.915	0.62	16.7754	5.4312
Tike	1.56	1.36	0.76	11.9136	6.6576
Total	11.66	11.055	3.56	94.4328	4.4551

Table 3**.**7**:** Bothe the Average and peak load of 2014 and 2015 E.C

Feeder name	Average demand (MW)	Peak load (MW)
Bichena	0.32	2.81
Debrework	2.27	3.31
Meadrok	1.13	3.05
Dejen	1.75	2.76
Kuyi	2.75	2.67
Telema	1.92	2.56
Tike	1.36	2.55
Total	11.02	19.71

Monthly average load of each outgoing feeder lines (MW) are indicates in this pie chart using recorded data from Appendix.

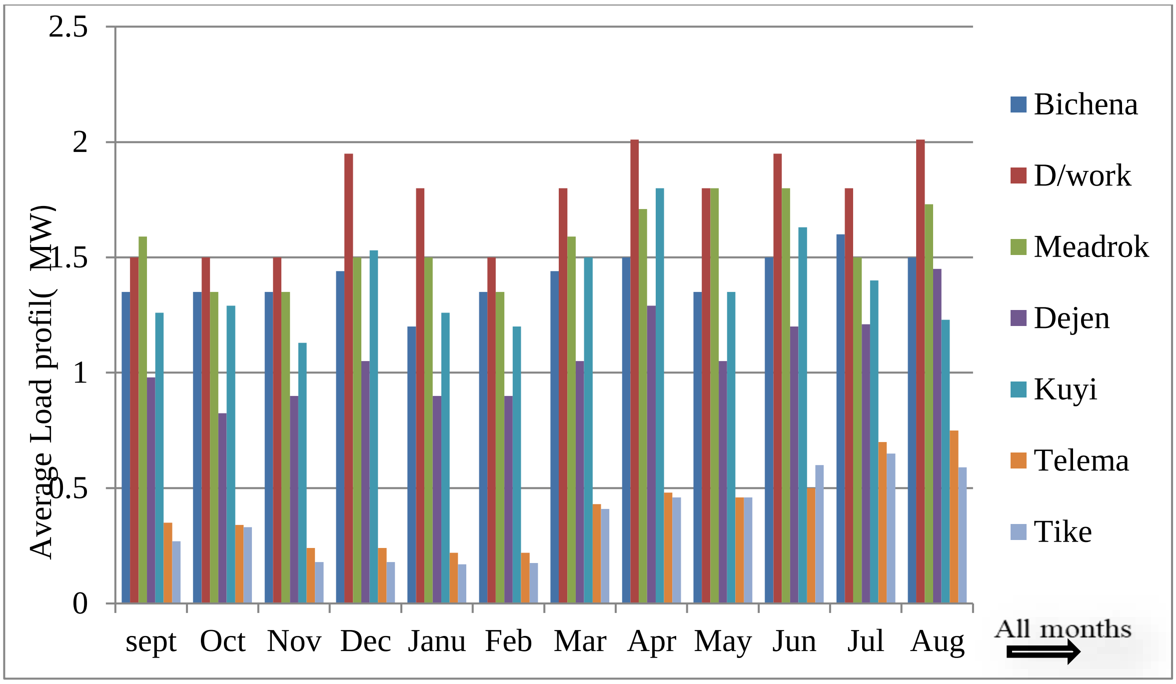

Figure 3.3**:** Monthly average load of each feeder

As shown in the above figure, the lowest and highest feeders' loads are 0.17 MW and 2.01 MW, respectively. The highest load is noted in April and August, and the minimum load is observed in October, November, and February. The next figure shows the overall mean load of each outgoing feeder in the Bichena distribution substation.

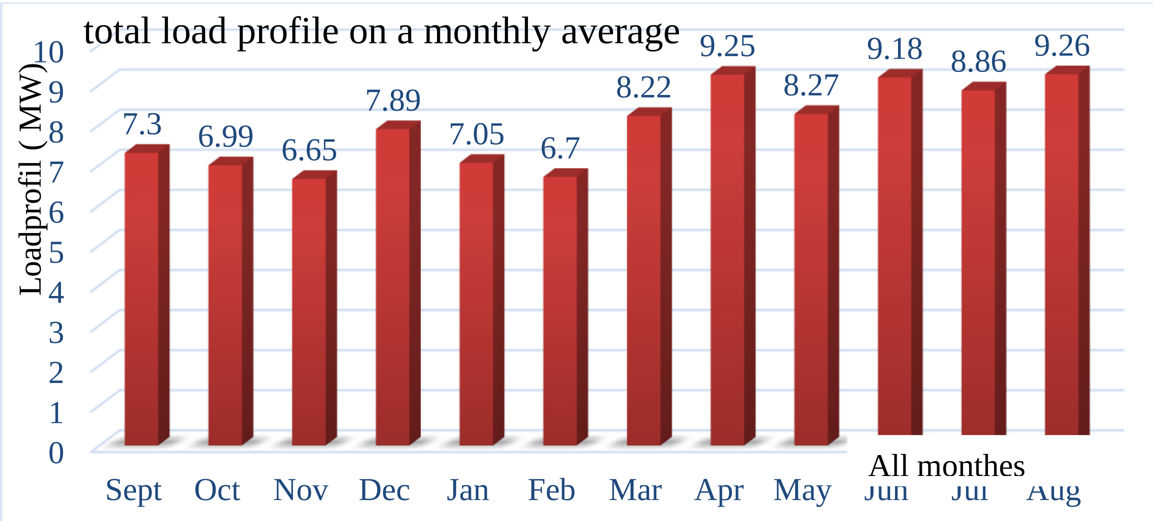

Figure 3.4: Overall average load profile

Monthly load is the amount of load measured on that particular day; the whole amount of load is known as the overall load from all of the feeders combined. Thus, April and August are its maximum total average loads. This value is 9.26 MW.

3.6 Bichena Distribution Substation Power Interruption Data (2014 and 2015) E.C.

Finding the reason for a failure is the first step towards eliminating flaws. This classification makes it possible to identify the kinds of problems that have caused the system to experience more interruptions, which will improve the distribution system's reliability. Among the several forms of power, System faults, which commonly occur at Bichena distribution substations, include earth faults that are both permanent and transient, short circuits that are both permanent and transient, and interruptions brought on by operation or maintenance. Momentary interruptions involve a variety of fault types, including distribution transient earth faults (DTEF), distribution transient short circuits (DTSC), and system blackouts. Sustained interruption includes distribution of the permanent earth fault (DPEF), load shaving, and distribution of the permanent short circuit (DPSC). Both planned and unforeseen disruptions have occurred throughout operations. The following table shows the frequency and duration of operations and forced interruptions.

Table 3.8: Annual interruption frequency of several faults and durations of 2014 E.C

Feeder name	Forced interruption				operational interruption		Total=forced + operation	
	Momentary inter.		Sustained inter.					
	Freq.	Dur.	Freq.	Dur.	Freq.	Dur.	Freq.	Dur.
Bichena	74	3.39	57	64.03	92	62.08	223	129.5
Deberwork	185	7.28	249	574.29	122	156.32	556	738:29
Meadrok	110	3.51	97	194.2	91	80.19	198	277:09
Dejen	146	16.12	154	425.04	108	116.07	408	557:23
Kuyi	236	8.37	239	460.39	78	52.46	553	521:22
Telema	335	10.12	221	560.12	113	125.50	669	696.14
Tike	280	10.2	170	460.2	48	39.08	498	509:48

Table 3.9: Annual interruption frequency of several faults and durations of 2015 E.C

Feeder name	forced interruption				operational interruption		total= fore+oper	
	Momentary inter.		Sustained inter.					
	Freq.	Dur.	Freq.	Dur.	Freq	Dur.	Freq	Dur.
Bichena	77	3.03	71	121.25	75	48.12	223	172.4
Debrework	190	8.42	277	593.34	174	149.07	641	751.23
Meadrok	127	4.24	126	261.36	96	57.54	349	323.14
Dejen	144	5.19	177	489.12	71	61.23	392	555.54
Kuyi	199	10.9	223	450.34	85	82.28	507	543.52
Telema	266	5.35	233	575.27	99	108.53	598	689.15
Tike	298	11.9	180	393.34	54	47.55	532	453.19

Table 3.10: provides information on the number of interruptions (hours/year) induced by forced interruptions those caused by operational or maintenance needs. And also, it is show that how often interruption (interruption/year) are caused by the maintenance or operation.

Table 3.10: Both forced and operational outage Duration of 2014 and 2015 E.C

Feeder name	Forced int. Dur	Operational int. Dur	Total int. Dur (2014)	Forced Int. Dur	Operation int. Dur	Total int. Dur (2015)	Average int. Dur
Bichena	67.12	62.8	130.32	124.28	48.12	172.4	151.36
Debrework	580.77	155.92	737.09	601.36	149.07	750.43	744.16
Meadrok	197.71	80.19	277.9	264.8	57.54	322.34	300.12
Dejen	440.36	115.67	556.03	494.31	61.23	555.54	556.18
Kuyi	468.36	52.46	521.22	461.24	82.28	543.52	532.37
Telema	569.44	125.55	695.39	580.6	108.53	689.13	692.26
Tike	470.4	38.68	509.08	405.24	47.55	453.19	481.13

Table 3.11: Both forced and operational outage frequency in 2014&2015 E.C

Feeder name	Forced int freq.	Operation int freq.	Total int freq. (2014)	Forced int freq.	Operation Int freq.	Total int Freq. (2015)	Average Int freq.
Bichena	131	92	223	148	75	223	223
D/work	434	122	556	467	174	641	598.5
Meadrok	207	91	298	253	96	349	323.5
Dejen	300	108	408	321	71	392	400
Kuyi	475	78	553	422	85	507	530
Telema	556	113	669	499	99	598	633.5
Tike	450	48	498	478	54	532	515

In 2014 and 2015, E.C. Telema, Debrework, and Kuyi were the primary feeders due to their long length and frequency of interruption. As shown below in the in the charts for 2014 E.C., the percentage of each fault's type duration and frequency is shown in the figure below. System blackout, line overload, load shedding, distribution permanent earth fault (DPEF), distribution permanent short circuit (DPSC), distribution transient earth fault (DTEF), and distribution transient short circuit (DPSC) are part of the forced interruption. Additionally, there have been both planned and unplanned operational disruptions.

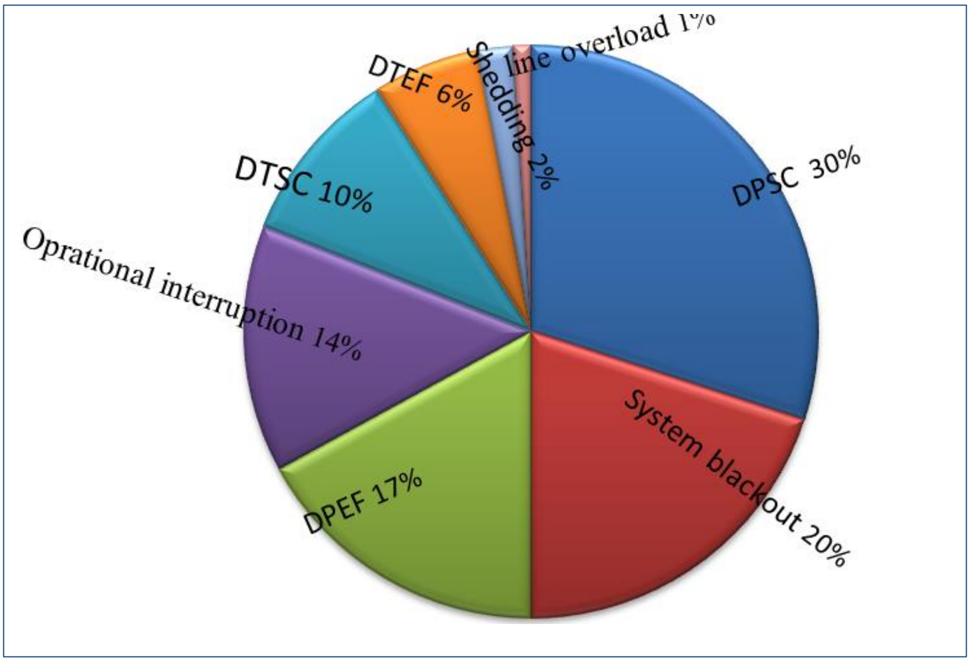

Figure 3.5: Percentage of duration each fault type

As shown in the pie chart figure 3.6, 30% of the distribution is permanent short circuit, 20% of the system is blacked out, 17% is permanent earth fault, 14% is operational interruption, 10% is transient short circuit, 6% is transient earth fault, and the other reaming covers shedding and line overload.

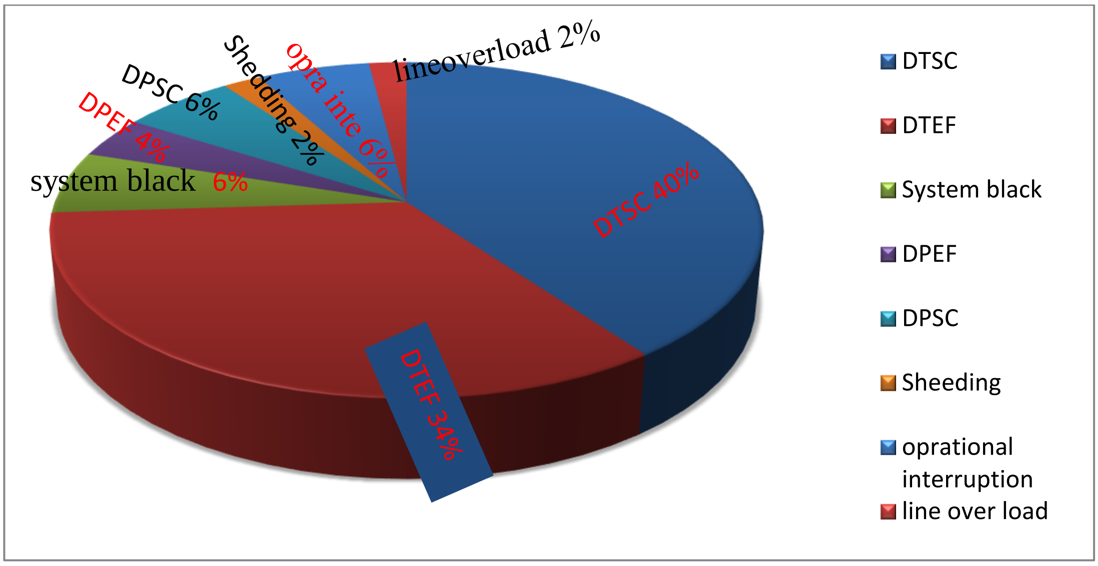

Figure 3.6: Percentage of frequency each fault type

Show from the above pie chart, 40% of the distribution transient short circuit, 34% due to DTEF, 6% are due to system blackout, DPSC, Operational interruption covers, and the other is 8%.

3.7 Major Interruption Causes

In the Bichena Distribution Substation, many distinct faults exist. But major faults occur frequently in earth faults, blackouts, short circuits, and overloading. And also for maintenance and operational purposes. The main errors that arise can be either transient or permanent in nature. Interruptions lasting more than five minutes are referred to as permanent or sustained, whereas those lasting less than five minutes are called momentary. Most power outages are temporary, like those caused by trees, animals, or bad weather. These outages can often be fixed automatically by the power system itself, and your power will come back on quickly. However, longer outages caused by equipment failure, cable damage, or persistent tree contact require repairs by repair crews before power can be restored. Permanent interruptions can be divided into two categories: planned and unplanned interruptions. A planned interruption, also known as a planned outage, is a temporary suspension of service that is scheduled in advance. This is done by utility companies or service providers for various reasons, such as maintenance, upgrades, and safety. An unplanned interruption, also known as an unscheduled outage, is a sudden and unexpected loss of service. This can happen in various infrastructure systems like power grids, water treatment facilities, communication networks, or transportation services. Unlike planned interruptions, these outages occur without prior warning and can cause significant disruption. Equipment failure, weather events, natural disasters, and accidents. The following are the primary fault types that disrupt the present distribution system:

- **Distribution Earth (ground) fault**

An electrical fault happens when a live wire touches something conductive that's connected to the ground (or could be). Electricity naturally seeks the easiest path back to the ground. A ground fault occurs when electricity escapes its intended path (like through a wire) and finds a different way back to the ground, such as through someone's body. This detour, often caused by damaged insulation, creates a safety hazard and can potentially damage equipment in the facility (Gutema, 2023).

- **Distribution Short Circuit**

The term "short circuit" is commonly used to describe the cause of power failures. This occurs when electrical current deviates from its designated path within a circuit. The unintended path creates an abnormally high current, which can result in damaged equipment, fires, and even explosions. In reality, short circuits are a leading cause of electrical fires on a global scale. Short circuits can also happen when the protective layer around wires (insulation) crumbles or when something conductive from outside the circuit, like water, accidentally gets in. Even everyday things can cause short circuits. Batteries can explode if pushed too hard with electricity, and jammed motors can create an overload, forcing electricity to take a dangerous shortcut. Water can cause big problems for electronics. Because it conducts electricity easily, water acts like a shortcut, disrupting the intended flow of current and leading to power outages. To avoid costly repairs, keep electrical components like switchboards, wires, and circuits far from water(Gutema, 2023).

- **Distribution Line Overload**

The rising demand for electricity is straining existing power grids, leading to overloading, a common cause of voltage fluctuations. Additionally, insufficient power generation capacity and outdated distribution systems can contribute to voltage issues. Improperly designed or malfunctioning power regulation equipment can introduce instability into the electrical supply, resulting in voltage fluctuations. Voltage fluctuations can be caused by poor or corroded connections at the end of the electric service. Problems with the power lines themselves can also lead to voltage fluctuations. Insufficient infrastructure is the root cause of many voltage fluctuation issues (Gutema, 2023).

- **System Overload**

A system overload occurs when the demand for electricity (load) is greater than the power generation capacity. This can lead to a widespread power outage, though not necessarily affecting all areas.

- **Blackout**

A blackout is a complete power outage affecting an entire area. These can be triggered by massive equipment breakdowns, extreme weather events, or even planned power cuts by utility companies to manage electricity demand during peak usage times.

3.8 System Reliability Indices

The system's overall reliability as well as the reliability of individual members are measured using reliability indices. Two types of reliability indices are used in evaluating system performance in distribution system and measuring reliability (Ayamolowo, n.d.) both load-oriented indices and customer-oriented indices and to see one by one based on classification(Anteneh & Khan, 2019).

A. Customer-oriented Reliability indices:

The System Average Interruption Frequency Index (SAIFI) estimates the number of prolonged outages that a typical customer will see over the course of a year.

$$SAIFI = \frac{total\ number\ of\ customer\ \mathrm{int}erruption}{total\ number\ of\ customer\ served} \tag{3.1}$$

The System Average Duration of Interruption Index (SAIDI): It is an indicator of the total number of hours a typical client would encounter disruptions in a year.

$$SAIDI = \frac{total\ duration\ of\ all\ \mathrm{int}erruption\ in\ customer}{total\ number\ of\ customer\ served} \tag{3.2}$$

The Customer Average Duration of Interruption Index (CAIDI): It gauges the average duration of an outage and is used to gauge the utility's reaction time to emergencies involving the system.

$$CAIDI = \frac{\sum customer\ \text{int}\, erruption\ duration}{total\ number\ of\ customer\ \text{int}\, erruption} \tag{3.3}$$

Index of Average Service Availability (ASAI): It is the percentage of the reporting period that the customer is in charge of. higher reliability levels are indicated by a higher ASAI value.

$$ASAI = \frac{customer\ hours\ service\ avaliable}{customer\ hours\ service\ demand} \tag{3.4}$$

The Customer Average Interruption Frequency Index (CAIFI), which is used to calculate the proportion of affected customers within the entire customer base, displays patterns in the number of interrupted customers.

$$CAIFI = \frac{total\ number\ of\ customer\ \text{int}\, erruption}{number\ of\ customer\ affectted} \tag{3.5}$$

Average Service Unavailability Index (ASUI):

$$ASUI = 1 - ASAI \tag{3.6}$$

B. Energy- oriented Reliability indices:

The equation Present the mathematical formulas for average outages, annual outages, failure rates, and the cost of interruptions at a specific load point. (Ahmad & Asar, 2021)

The Average failure rate, or λi (failures per year), at load point i.

$$\lambda_i = \sum j_{\in N\ e} \lambda_e,\ j \tag{3.7}$$

Duration of Annual Outage at Load Point I, Ui (hours annually):

$$\mu_i = \sum j_{\in Ne} \lambda_e,\ j.r_{ij} \tag{3.8}$$

Duration of the Average Outage at Load Point I, ri (hours):

$$The\ average\ length\ of\ the\ outage\ at\ load\ point\ \text{i},\ ri = \frac{annual\ outageduration\ at\ load\ po\,\text{int}\, i, \mu_i}{average\ failure\ rate\ at\ load\ po\,\text{int}\, i, \lambda_i} \quad (3.9$$

The variables λi, μ_i, and r_{ij} represent the average failure rate, annual outage time, and failure duration at load point i, respectively, caused by a failed element j.

$\sum$ it is function of summation, N_e is the total number of components that a fault in will cause to stop load point i, $\lambda_{e,} j$ is average failure rate

Energy of Not Supplied Index (ENSI):

$$EENS = \sum L_i * \mu_i \tag{3.10}$$

Where**:** At load point i, Li represents the average connected load.

At load point i, Ui represents the average annual outage time.

The Average Energy Not Supplied Index (AENS):

$$AENS = \frac{total\ energy\ not\ \sup plied}{total\ number\ of\ customer\ served} \tag{3. 11}$$

3.9 Reliability Indices Calculation

The current substation's dependability indices are determined using equation (3.1) to (3.11) based on the collected data in 2014 and 2015 E.C.

Table 3.12: Indices of reliability in 2014 E.C.

Feeder name	SAIFI	SAIDI	CAIDI	ASAI	ASUI	ENS(MW))	AENS
Bichena	133	153	0.7824	0.9805	0.0195	10.87	1.5528
Debrework	203	167	0.7741	0.9787	0.0213	219.102	31.3001
Meadrok	157	174.4	0.6113	0.9888	0.0112	64.683	9.2404
Dejen	269	94.2	0.4941	0.9899	0.0101	19.19	2.7414
Kuyi	222	138.2	0.4282	0.9909	0.0091	94.31	13.4728
Telema	162	167	0.4582	0.9912	0.0088	251.216	35.888
Tike	168	127	0.4928	0.9907	0.0093	3.292	0.4703
Average	187.8	145.8	0.5773	0.9872	0.0127	94.666	13.5237

Table 3.13: Reliability of indices in 2015 E.C

Feeder name	SAIFI	SAIDI	CAIDI	ASAI	ASUI	ENS(MW)	AENS
Bichena	415	300.6	0.6238	0.9594	0.0406	13.266	1.895
Debrework	601	375	0.7901	0.9457	0.0543	277.062	39.580
Meadrok	489	278.4	0.5693	0.9682	0.0318	107.932	15.4188
Dejen	495	345	0.6981	0.9605	0.0395	24.122	3.446
Kuyi	600	225	0.7094	0.9514	0.0486	124.76	17.823
Telema	590	285.8	0.6529	0.9560	0.044	250.777	35.825
Tike	480	216.8	0.4513	0.9752	0.0248	12.512	1.7874
Average	524.3	289.5	0.6421	0.9594	0.0405	115.776	16.5394

Table 3.12 and 3.13 are shows the comparison between 2014 and 2015 E.C of reliability indices for Bichena Distribution Substation. And the next figure show compares SAIFI and SAIDI in 2014 and 2015E.C.

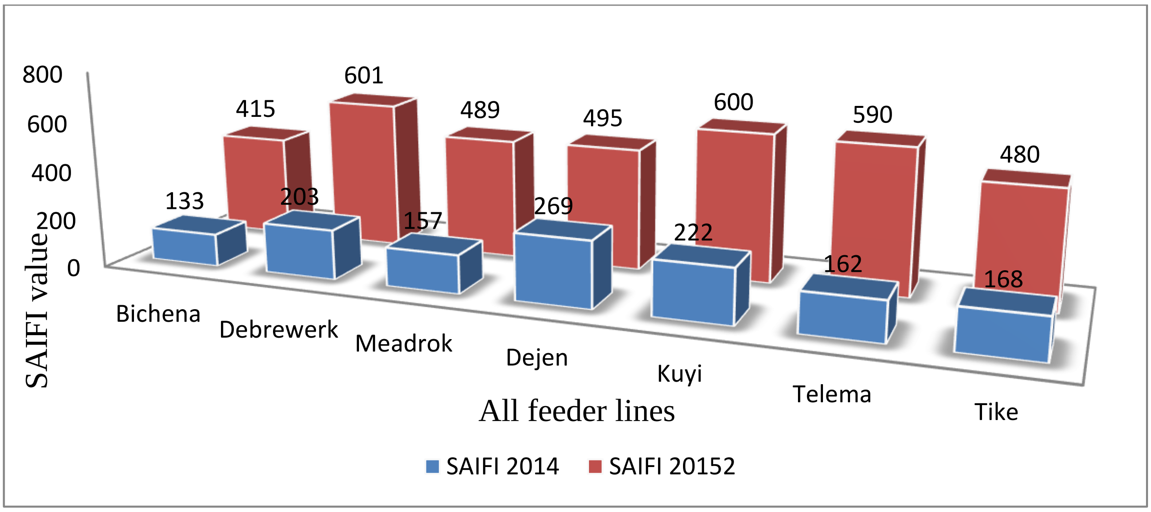

Figure 3.7: SAIFI comparison of 2014 and 2015 E.C

According to above figure the maximum interruption frequency in 2015 was 601 int/yr. and also 269 int/yr. in 2014 E.C. From the graph, it is evident that SAIFI increseas from 2014 to 2015. Due to the fact that the distribution line's issue was resolved by performing some preventive maintenance, such trimming trees and upgrading the line dips. Yet, the Ethiopian Electric Agency (EEA), the regulatory body, has set requirements for the Bichena substation, which still has a lot of dependability issues. In addition, the network experiences a high rate of service outages. Form that below figure show that comparison value of SAIFI in both 2014&2015

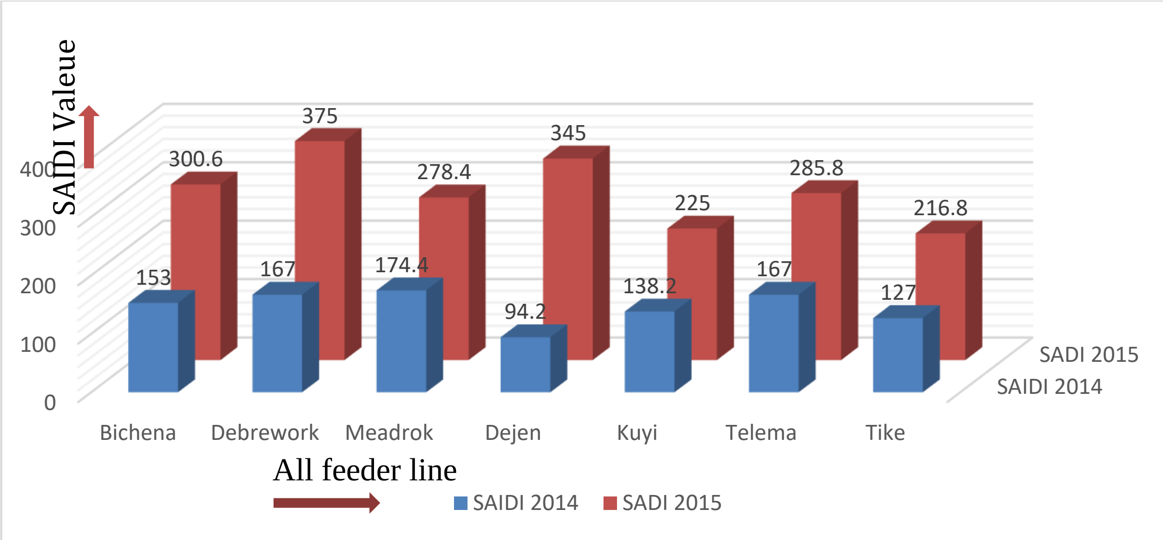

Figure 3.8: SAIDI comparison of 2014 and 2015 E.C

According to above figure maximum interruption duration in 2015 was 375hr/yr. and also 174.4hr/yr. in 2014 E.C. The figure illustrates that the System Average Interrupted Duration Index, or SAIDI, has displayed the identical information as previously discussed for the SAIFI comparison in figure 3.10. The 2015 E.C. computed reliability indices show poor system reliability. The existing substation for Bichena Distribution has a Significant reliability problem.

Table 3.14: Average reliability indices of both 2014 and 2015 E.C

Feeder name	SAIFI	SAIDI	CAIDI	ASAI	ASUI	ENS(MWh)	AENS
Bichena	324	226.5	0.7031	0.9699	0.03	65.05148	21.724
Debrework	402	271.1	0.7862	0.9622	0.0378	618.538	94.763
Meadrok	323	226.4	0.7009	0.9785	0.0215	240.57	45.4405
Dejen	382	219.6	0.5961	0.9752	0.0248	321.07	42.3296
Kuyi	411	231.6	0.5688	0.9711	0.0288	432.06	43.0937
Telema	376	226.4	0.6021	0.9736	0.0264	366.24	45.6478
Tike	324	226.9	0.7003	0.9829	0.0170	258.35	35.8566
Average	364	232.685	0.6455	0.9733	0.0266	2301.898	328.855

3.10 Generally the Analysis of Above Data

- The table 3.14 shows a concerning (SAIFI) value of 364 in/yr for the overall system. This is significantly higher than the recommended standards set by the Ethiopia Electricity Agency (EEA). When compared to countries like Denmark and Germany, where SAIFI values are typically less than 20 interruptions per year, the calculated value for Bichena substation highlights a serious reliability problem in the current distribution substation.
- The system displays 232.6572 hours of SAIDI for each customer annually in Table 3.14 Every consumer experience 232.6572 hours every year, according to this data. This demonstrates how seriously the current Bichena Distribution substation's reliability issue is. (EEA) states that the SAIDI value never go over 25 hours a year for each client (Setegn, 2022). In Denmark, each customer receives 0.4 each hour annually, and in Germany it is 0.383.
- ASAI: The average service availability index looks like this, and it displays the percentage duration of a consumer spent having electricity over the course of the reporting period. Table 3-14 indicates that the system's total power supply is 97.33% available. Still, this value is not excellent. sufficient because, according to EEA standards, the ASAI value should be higher than 99.98%(Setegn, 2022).
- ENS: It shows how much energy each feeder has that is unsold or unserved. According to Table 3.14 the total unsold energy for the entire system was 2301.898 MWh.
- AENS: This index shows how much energy the system typically does not supply to each customer. The AENS value for the entire system is 328.855 MWh per customer.

The Ethiopian Electric Agency (EEA), the regulatory agency, has set requirements for substation reliability, and the Bichena Distribution substation does not exceed these requirements. The Bichena Distribution substation's reliability is insufficient when measured against the global reliability metrics of the country with the most experience.

The most popular reliability indices performance standard benchmark comparison is displayed in Table 3.15 below.(Setegn, 2022) and table 3-16 the energy tariff amendment study according to consumer class.

Table 3.15: Standard reliability indices of several countries

Country	SAIFI (int/yr)	SAIDI (hr/yr)	ASAI (%)
Netherlands	0.3	0.55	99.97
Denmark	0.5	0.40	99.98
Germany	0.5	0.383	99.99
Australia	0.9	1.00	99.97
France	1.0	1.03	99.97
United state	1.5	4.00	99.91
Spain	2.2	1.73	99.96
Ethiopia	20	25.00	99.425
BDS	364.0334	232.6572	97.33
Debrework feeder	402	271.1	96.22

According to EEU tariff Appendix -D cost of energy not supplied due to interruption for Bichena Substation is calculated to using formula.

$$\text{Cost of energy} = \text{power}*1000*\text{time}*\text{tariff for electricity} \tag{3.12}$$

In Bichena Substation is Seven outgoing feeder lines are used to calculate the average cost of not supplied energy due to power interruptions during average of 2015E.C. average electric price of residential 7th tariff block is 2.48 Birr/kwh from (onward December 21, computed and recorded).

3.11 Distribution System Reliability

In each modern economy, electricity is an essential component. A steady supply of electricity at a reasonable cost is necessary for a nation's economy to thrive. Therefore, global electric power companies strive to offer dependable service while doing economically. The distribution system must deploy DG in the best possible location in order to meet customer requirements as the electrical utility changes. Based on global data, distribution system problems account approximately 90% of all cases of dependable customers concerns. Consequently, enhancing the reliability of distribution is necessary to boost customer reliability.

3.12 Voltage Stability

A power system's capacity to sustain adequate voltages at all of its buses both under normal circumstances and following a disturbance is known as voltage stability. the voltage of a power system is steady when it is working normally, but when a defect or other disruption arises in the system, the voltage gradually and uncontrollably drops as a result of the voltage being unstable. Another name for voltage stability is load stability. Voltage collapse may occur in a power system as a result of the voltage instability. if the equilibrium voltage following disturbances close to loads is lower than permitted thresholds. Another definition of voltage collapse is the process through which voltage instability benefits the crucial component of the system by having a very low voltage profile. Partial or complete blackouts can result from voltage collapse. Voltage collapse and instability are frequently used synonymously(Stability, 2017).

Voltage instability can cause the following possible effects:

- Localized load loss.
- Line trips and other events that trigger cascade outages.

Cause of voltage collapse

- high load demand.
- low generation output.
- transmission line outages, or reactive power shortages.
- generator failure.
- voltage source is too far from the load center.

3.13 Voltage Stability Indices (VSI)

Power plants must run at full capacity to keep up with the rising demand for electricity.

This problem heightens the possibility of voltage breakdown, which may result in power system blackouts. The improvement of voltage stability is one benefit of placing DGs properly. The method of voltage stability indices is accurate, efficient, and effective. The best candidate buses for installing DG are identified in this thesis by using a static voltage stability index for radial distribution systems. The index indicated above is calculated based on a line of impedance R + jX that is connected between two buses, as illustrated in Figure 3.10 (Moravej et al., 2018).

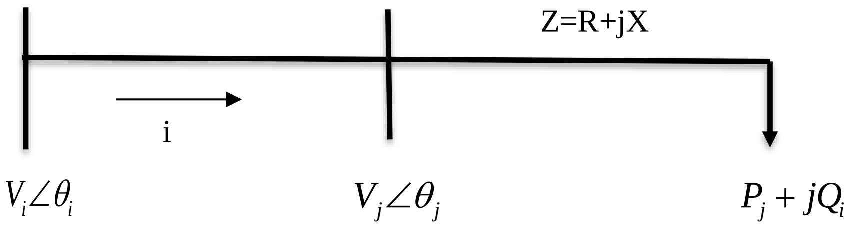

Figure 3.9: Simple distribution system line models

$$VSI_j = \frac{\left(\sqrt[4]{(P_j^2 + Q_j^2)(R^2 + X^2)}\right)}{V_j} \tag{3.13}$$

The above equation describes voltage stability indicators. P_j is active power and Q_j is reactive power at bud j. and V_j is the voltage at bus j. A bus's VSI value must to be less than unity in order for it to be considered stable. The bus is getting closer to the voltage collapse as VSI values get near to units. VSI is in our analysis assessed for every bus to determine which bus is the weakest among the Seven outgoing feeders that is best suitable for installing DG. The following requirements must be met by the problem solution:

Constraint on Inequality

Each bus voltage must be bounded upper and lower value given as:

$$V_{i\,min} \leq V_i \leq V_{i\,max}$$

Where: Vmin minimum permissible bus voltage, Vmax maximum permissible bus voltage

Reliability on constraint

$0 < SAIFI < (SAIFI)a$

$0 < SAIDI < (SAIDI)a$

$0 < ENS < (ENS)a$

$0 < ASUI < (ASUI)a$

Where: (SAIFI) a, (SAIDI) a, (ENS) a and (ASUI) are base indices, SAIFI, SAIDI, ENS, and ASUI are after DG placement indices

3.14 Select Best location for DG Based on VSI

To choose the best location for the DG, the following procedures are followed:

- To calculate VSI for each feeder line
- To a list out the most sensitive feeder line
- Based on a voltage stability point of view, select the weakest feeder line as the candidate for installing DG.

Determine the size of DG considered: The optimal DG position and size are suggested in favorable of the distribution feeder, the proper DG size is determined by Based on optimal cost consideration, determine the optimal DG size based on the selected sensitive load capacity.

3.15 Calculating the Voltage Stability Index (VSI)

VSI is calculated using the above equation (3.13) Consider the line parameter of impedance R+jX connected between two buses. And real, reactive powers are applied to the load. And the other is receiving voltage. Below the Table 3.17, the VSI calculation value is used to identify the lowest feeder of Seven outgoing feeders.

Table 3.16: BDS Seven outgoing feeder line Load data and VSI Calculation values.

Feeder name	Length (Km)	Connected Load (MVA)	P (MW)	Q (MW)	R (ohm)	X (ohm)	VSI
Bichena	8	0.34	0.32	0.13	10.4902	4.5073	0.2253
Debrework	**26**	**2.39**	**2.27**	**0.59**	**20.4784**	**9.9832**	**0.5873**
Meadrok	37.3	1.17	1.13	0.31	7.5845	4.5524	0.2106
Dejen	32	1.83	1.75	0.56	12.3627	5.8241	0.3341
Kuyi	35	2.35	2.27	0.59	16.2431	8.4368	0.4368
Telema	24	2.02	1.92	0.62	14.1576	5.9561	0.3711
Tike	26.8	1.56	1.36	0.76	12.1548	3.3878	0.2955

The VSI from the above figure is used to determine the weakest feeder among the seven outgoing feeders. When VSI approaches one, the system is considered to be nearing a voltage collapse. Based on the above calculated VSI values, the weakest feeder among the seven outgoing feeders is the Debrework feeder. Recommended as the best location to installed DG. Once the ideal site for the DG has been chosen, the DG size is ascertained by choosing a sensitive load from the various Debrework load points. As a result, the

Debrework load is chosen for the DG size as a priority among the several lateral load spots. 67kw and 1,608KWh, respectively, are the Debrework's average daily power and energy loads.

3.16 PV Solar Energy Potential

Due to its abundant solar energy potential, the majority of Africa has yearly average irradiance levels above 2,000 kWh/m2. Theoretically, Africa could generate more than 660 000 TWh of electricity per year from solar PV, significantly more than what is expected to be needed. However, its installed capacity of 5 GW for solar photovoltaic (PV) accounts for less than 1% of the world's total capacity. One of Africa's main energy sources might be solar power, if it is installed properly and with the appropriate regulations. East Africa was shown to have the most theoretical potential among the African continent, with about 200,000 TWh/year. One of the nations in East Africa with a wealth of solar energy resources is Ethiopia. It is calculated that the country's yearly average irradiation is 5.2 kWh/m2 per day. While the country's western and eastern lowlands, as well as the rift valley regions, see higher annual average irradiance (over 6 kWh/m2/day), the country's most populous highlands, the northern, central, and western highlands, have reduced sun resource levels. Only about 14 MW of solar PV have been employed for telecom service, lighting, powering water pumps in rural regions, and water heating in large cities, despite the country having an abundance of solar energy resources.

3.17 Analyzing Data for Solar Energy in Case Study to Different Sources

To comprehend the influence of weather on solar energy generation in Debrework, Ethiopia, we can analyze data from two sources: NASA and PVGIS. These sources offer monthly average solar irradiation data for the location. By comparing these datasets, we can glean insights into the seasonal variations in solar radiation and their potential effects on electricity production from solar panels in Debrework.

Table 3.17: Debrework Solar radiation in (kwh/m2/d) (from PVGIS)

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Montly.Avg
Jan	5.96	5.82	6.22	5.16	6.71	5.69	6.64	5.99	6.38	5.96	6.05
Feb	6.96	6.25	6.73	6.48	5.74	6.33	6.4	6.32	6.36	6.6	6.69
Mar	6.15	6.62	7.04	6.48	6.83	6.81	6.33	6.18	7.4	6.97	6.68
Apr	7.18	6.42	7.05	5.56	6.89	6.22	6.27	6.27	6.61	6.82	6.53
May	6.64	6.48	6.4	6.12	6.14	6.22	6.4	6.06	6.34	6.68	6.35
Jun	5.31	5.97	5.5	5.54	5.89	5.48	5.53	5.45	5.97	5.83	5.65
Jul	4.59	4.99	5.85	4.6	5.29	5.16	5.25	4.12	4.16	4.37	4.84
Aug	4.25	5.18	5.38	4.95	4.93	5.09	4.36	4.52	5.07	4.65	4.84
Sep	6.29	5.84	6.26	5.73	5.81	6.56	5.35	5.75	5.66	5.29	5.85
Oct	6.21	6.25	6.79	6.24	6.2	6.26	6.54	6.5	6.35	6.17	6.35
Nov	5.98	5.89	5.81	6.33	6.31	5.58	5.47	6.27	6.08	6.24	5.99
Dec	6.05	5.6	5.34	6.39	6.46	6.11	5.91	6.31	6.23	5.53	5.99
Ann.Avg	5.96	6.44	6.19	5.79	6.1	5.96	5.87	5.81	6.05	5.92	5.98

The table above presents 10 years of solar irradiation data for Debrework, obtained from PVGIS. The data reveals that Debrework experiences a minimum solar radiation level of 4.84 kWh/m²/day in July and a maximum level of 6.69 kWh/m²/day in February.

Table 3.18: Debrework Solar radiation in (kwh/m2/d) (from NASA)

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Montly.Avg
Jan	6.43	6.28	6.04	6.43	5.8	6.81	6.15	6.64	6.18	6.38	6.28
Feb	7.18	7.04	6.35	6.84	6.76	6.08	6.53	6.59	6.49	6.36	6.62
Mar	7.03	6.73	6.71	7.21	6.77	7.02	6.81	6.59	6.43	7.4	6.87
Apr	6.72	7.11	6.61	7.2	6.22	7	6.36	6.48	6.52	6.61	6.69
May	6.57	6.21	6.27	6.36	6.15	6.21	6.35	6.52	6.38	6.34	6.36
Jun	5.64	5.74	6.04	5.64	5.89	6.27	5.52	5.92	5.86	5.97	5.84
Jul	5.06	4.73	5.2	6.03	4.95	5.33	5.15	5.12	4.44	4.16	4.95
Aug	5.23	4.51	5.06	5.37	4.99	4.83	5.01	4.8	4.7	5.07	4.92
Sep	5.91	5.94	5.66	5.97	5.79	5.63	6.32	5.31	5.76	5.66	5.74
Oct	6.93	6.16	6.39	6.58	6.66	5.99	6.29	6.43	6.34	6.35	6.39
Nov	6.25	6.15	6.13	6.03	6.3	6.31	5.86	5.56	6.47	6.08	6.12
Dec	6.15	6.24	6.07	5.59	6.37	6.47	6.14	5.87	6.21	6.23	6.07
Ann.Avg	6.26	6.06	6.04	6.27	6.05	6.16	6.04	5.98	5.98	6.05	6.07

The table above displays 10 years of solar radiation data for Debrework, obtained from NASA. The data indicates that Debrework experiences the lowest solar radiation level of 4.93 kWh/m2/day in August, while the highest level occurs in March, reaching 6.87 kWh/m2/day.

Solar Radiation Data Comparison for Debrework: Two datasets were analyzed to understand solar irradiation patterns in Debrework, Ethiopia. The first dataset, obtained from PVGIS and covering 10 years, revealed a minimum solar radiation level of 4.84 kWh/m2/day in July and a maximum of 6.69 kWh/m2/day in February. The second dataset, obtained from NASA and spanning 10 years, indicated a slightly lower minimum of 4.93 kWh/m2/day in August, with the highest level reaching 6.87 kWh/m2/day in March. Based on the comparison, the data from NASA (10 years) suggests Debrework experiences greater overall solar irradiation.

3.18 PV Sizing of Photovoltaic Array

In order to provide an alternate solution for the power interruption issues at the Debrework feeder line resulting from its distribution system, this section addresses the PV array's architecture as well as the associated inverter that might constitute the solar photovoltaic subsystem. The PV power system indicates the below diagram in the proposed area.

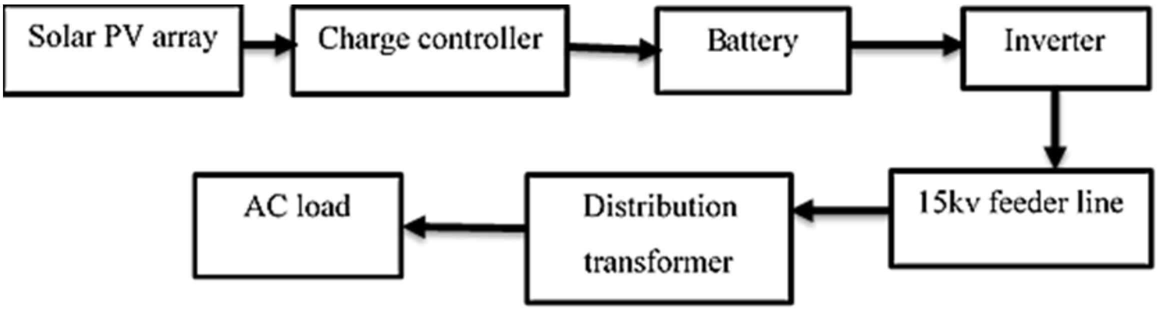

Figure 3.10: Diagram of PV power supply system

The following actions were taken into consideration when the size was implemented: information gathered about the demand for load, the local weather, and synchronization to manage line interruptions. The temperature and irradiance during peak sun hours are determined using ETAP 19.0.1 software, taking into account metrological data. The suggested site's latitude and longitude are utilised to determine the optimal location for the solar photovoltaic system, which will be developed for highest power point monitoring. The case study area's power requirements cannot be satisfied by the power of a single module. A few of the PV array modules are connected in parallel to produce current, while others are connected in series to gate the desired voltage (Thuku et al., 2017).

Sizing of PV arrays, the following equipment are being considered:

- Load demand for the area
- Equivalent sun hour

Frequently utilised correction factors for loads resulting from losses

Correction of loads: It is a given that not every piece of equipment in the vicinity always operates at its highest capacity. Therefore, it makes sense to use 75% of the system's daily Wh, or its maximum feasible load, for designing purposes.

Table 3.19: Correction factor of a stand- alone PV system (Megra, 2018)

	Loss	Efficiency
AC Cable loss	0.01	0.99
Inverter	0.11	0.9
Charge Controller Loss	0.05	0.95
Mismatch	0.01	0.99
Diodes and Connection	0.005	0.995
DC Wiring	0.02	0.98
Soiling	0.04	0.96
System Availability	0.01	0.99
Temp.increase loss	0.05	0.95
Total loss	0.73779	

The peak monthly load demand power consumption of Debrework is 2.01 MW, equating to a daily demand power of 67,000 watts (2.01 MW / 30 days). This corresponds to a daily energy load of 1.608 MWh (67,000 watts * 24 hours), or 1,608 kWh, based on the average daily power consumption of Debrework. Utilizing the following formulas, we calculate the total number of PV modules needed for the feeder line-connected solar system.

$$\text{Re}\,quired\ energy(Er) = \frac{Daily\ average\ consumption\ demand}{Correction\ factor} = \frac{E}{\eta\, overall} \tag{3.14}$$

Where: Er it is required energy, E is Daily energy or demand in watt-hours,
η = Component efficiency.

The research area's average daily consumption demand is equal to 1,608KWh/d the effectiveness of the components contained all from table 4.4 correction factor.

$$\text{energy required} = \frac{1{,}608\text{kwh}}{0.73779} = 2{,}179.5kwh$$

Peak power equal to the required energy divided by average sun hour per day for regarding a certain geographic area.

$$Peak\ power(PP) = \frac{daily\, energy\, requirement}{\min imum\, sun\ peak\, hours\ per\ day} = \frac{Er}{T\min} \tag{3.15}$$

Based on the information gathered earlier, Debrework experiences its minimum

sunshine hour in August 4.93h/d.

$$\text{Peak power} = \frac{2179.5kwh}{4.93hour} = 442.08\text{kw}$$

This size uses a The SunPower Company manufactures the PV monocrystalline module (SunPower 415W P3-COM-1500). because of its specification to minimize the number of modules needed and the amount of space or location where they are implemented. The characteristics of the module are taken under STC "standard test conditions" in the laboratory. Irradiance: 1000 W/m2, cell temperature: 25 °C. And 1.5 solar spectrum air masses (Thuku et al., 2017)**.**

Table 3.20: Basic characteristics of PV modules

Number	Parameter	Rating
1	Maximum power	415 Wp
2	Voltage maximum power point	72.9v
3	Current maximum power point	5.69A
4	Open circuit voltage	8V
5	Short circuit current	6.09A
6	Cells per modulation	128
7	Efficiency	21.9%
8	Area	1.95 m²

In order to accomplish the proposed PV system which is sized to generate a peak power of 442.08kw. the needed number of modules can be obtained by the following equation.

$$\text{Re}\,quariede\ number\ \text{mod}\,ule = number\ series \times number\ of\ \ parallal \tag{3.16}$$

In the size of with a 650 VDC rating, the system DC-link controls the voltage at the inverter's DC side and minimises output current ripple. Consequently, the quantity of PV modules connected in series is determined below equation.

$$number\ of\ \text{mod}\,ule\,in\,series = \frac{DC\ \ voltage}{\max imum\ power\ \ po\text{int}\,voltage} \tag{3.17}$$

$$\text{number of modules in series} = \frac{650\text{v}}{72.9\text{v}} = 9\text{modules}$$

$$number\ of\ \ parallal(strings) = \frac{Total\ Peak\ \ power\ of\ \ PV\ Capacity}{number\ of\ \ PV\ series\ \ \text{mod}\,ule * Max.power\ of\ \ PV\ \text{mod}\,ule} \tag{3.18}$$

$$number\ of\ parallal = \frac{442.08kw}{9 * 415w} = 119 \text{ strings}$$

Thus, total number of PV module becomes: 119*9 = 1,071 modules

So that, electricity produced by a photovoltaic array = Total number of modules*maximum power of module = 1,071 module*415/module = 444,465W or 444.465KW

The total panel area calculated as: Total Area=total module*single module area (3.19)

1,071*1.95 m^2 =**2,088.45m^2=2.08845km^2**

As result, to generate **444.465KW** power at Debrework feeder line, 1,071 modules each having a maximum power of 415 W have been utilised and connected to 9 Modules as series and 119 strings in parallel. As can be show in Figure 4-3.

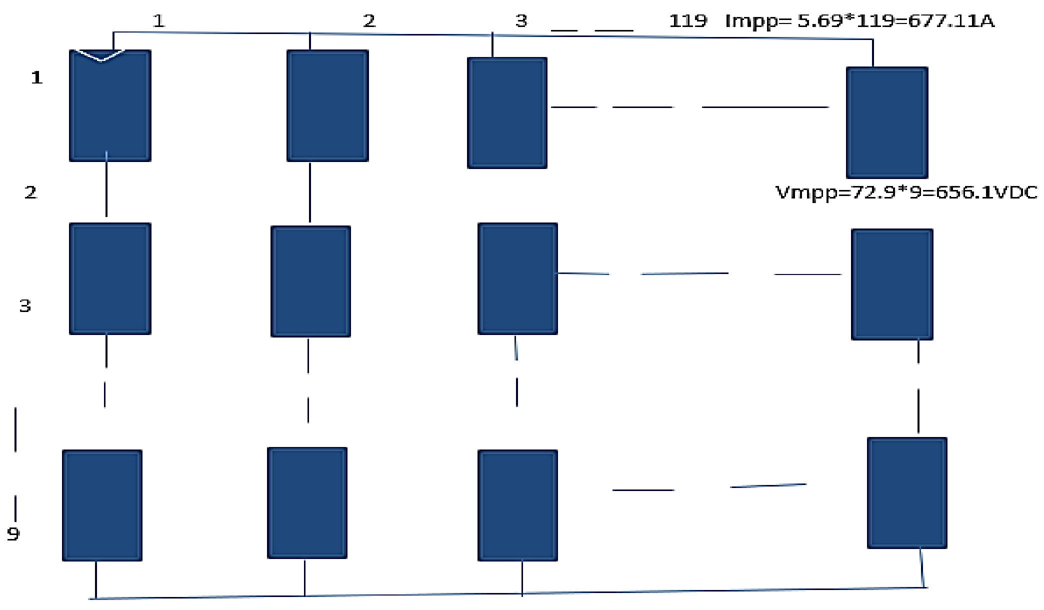

Figure 3.11: Connection of PV array

It is possible to ascertain the PV array's actual maximum voltage and current blow equation.

Vmpv= Number of series modules*Maximum power point voltage (3.20)

Vmpv = 9*72.9= 656.1 VDC

Impv= Number of strings * Maximum power point current (3.21)

Impv = 119*5.690= 677.11A.

After that Actually, the PV array's maximum output power can be calculated

Pdc=Vmpv*Impv (3.22)

$$Pdc= 656.1*677.11 = 444,252 \text{ watt}= 444.252KW$$

It is possible to calculate the maximum short circuit current and maximum open circuit voltage for an array.

$$Voc= \text{number of series module *open circuit voltage} \quad (3.23)$$

$$Voc=9*85.30 = 767.7V.$$

$$Isc=\text{number of parallel strings*short circuit current} \quad (3.24)$$

$$Isc=119*6.09 = 724.71A$$

Inverter sizing: The grid connected system; For safe and effective operation, the inverter's watt rating needs to match or exceed that of the solar PV system. For this size, the total load of Debrework power is 67 kw So that, inverter must be chosen between 25% to 30% higher than the total load.

Inverter Size = 1.3* 444.465kw = **577.8KW** so that**,** the inverter used to greater than **577.8kw**. Among available of the inverter choose **SMA Solar Technology**: inverter especially Sunny Tripower CORE1, thus specification:

- Max. DC power = 110kw
- Vmpp voltage range = 200V to 800V
- Impp input =15A
- Nominal AC voltage = 400V-450V

Based on the results, for each string of modules we utilize one inverter, resulting in a total of **577.8 kW** of inverters being used.

Battery sizing: Deep cycle batteries are the kind of batteries that are suggested for use in solar PV systems. Deep cycle batteries are made especially to be quickly recharged after being quickly depleted of energy or to be cycle charged and discharged for years on end. When using the appliances at night or on overcast days, the battery needs to be big enough to hold enough energy. As an example, consider the battery sizing specifications below:

- System voltage = 650V
- Battery efficiency = 85%
- Inverter efficiency = 95%
- Days of autonomy = 2 day
- Depth of discharged = 80%

$$Battery\ capacity = \frac{Total\ Wh/d * \ day\ of\ \ autonomy}{\eta_{inv} * \eta_{batt} * depth\, of disch\arg * V_{Sys}} \tag{3.25}$$

$$Battery\, capacity = \frac{2{,}179.5kw * 2}{0.95 * 0.85 * 0.8 * 650} = 10.38kAh$$ = **1,0380Ah**

So, from the several batteries on the market, I select Battery Model: Tesla Model S Lithium-ion Battery Pack this model with the specifications:

- nominal voltage =375V
- capacity= 60kwh-100kwh
- Weight = 450kg-540kg and
- Dimension = (W*L*H) =2m*1.2m*1.5cmz

Since, For the minimum energy capacity (60 kWh): Ah=60/375 Ah= 0.16KWh

For the maximum energy capacity (100 kWh): Ah=100/375= 0.27KWh.

So, the ampere-hour capacity of the Tesla Model S Lithium-ion Battery Pack would be approximately 160 Ah to 270 Ah, depending on the energy capacity configuration (60 kWh to 100 kWh). Thus, the chosen battery is linked in series and parallel to produce the necessary system voltage and the computed battery size.

$$Number\ of\ \ battery\ in\ series = \frac{system\, voltage}{Battery\, no\min al\, voltage} \tag{3.26}$$

=650V/375V= **2 Batteries**

$$number\, of\ \ battery\, in\ parallel = \frac{battery\, capacity\, calculated}{Battery\, capacity\, selected} \tag{3.27}$$

=1,0380Ah/270Ah **= 38 Battery string**

Total number of battery = (battery in series*battery in parallel) (3.28)

2*38 = **76 batteries**

As a result, if there is no sun, the chosen battery needs to have a 650 V, 1,0380 Ah capacity and last for two days.

Solar charge controller sizing: The chosen solar charge controller is of the Mpp type, and its size are as follows:

Solar charge controller = total short circuit of PV array *1.3 (3.29)

= 38 string*6.09A*1.3 = **300.85 A**

Table 3.21: A summary of the PV design

Solar irradiance	4.93 hr/yr
System voltage	650V
Total load	1608KWh
Total Wh needed from PV module	2,179.5KW
Total number of PV module	1,071
Number of series modules	9
Number of parallel modules	119
Inverter size	87.1KW
Battery size	1,0380Ah
Number of batteries in series	2
Number of batteries in parallel	38
Charge controller size	300.85A

3.19 Cost Analysis of (PV)

The cost of DG, particularly photovoltaic (PV) systems, is calculated based on current market values. This cost encompasses the expenses associated with solar power, including panel costs, inverter costs), and battery costs The following table shows the price of the solar, inverter, and battery for this work.

Table 3.22: Cost of PV (currently Available in market

Equipment's	Quantity	Unit price $	Total price $
Sun power 415W panel	1071	523.00	160,133
Sunny Tripower CORE1 Inverter	76	5,749.00	436,924
Battery	4	6,000	24,000
Charge controller	2	1160	2,320
Total			623,377

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1 Introduction

Focusing on choosing the optimal location of the DG technology for a particular scenario, this chapter begins by outlining the key selection criteria. It then presents a reliability simulation of the existing Bichena Distribution Substation, comparing scenarios with and without DG integration. The chosen DG technology, along with a detailed reliability analysis using ETAP software and the resulting improvements achieved through DG implementation, are all covered in this chapter.

4.2 Modeling and Design of BDS using ETAP software

Standing out as a pioneer in power system design, analysis, and monitoring worldwide, ETAP software offers a robust suite of tools for electrical engineering analysis and management. Figure 4.1 shows the distribution system receives 230 kV from the grid feed and the transformer, 18.8 MW, at Bichena Distribution Substation. The main transformer steps down from 230 kV to 66 kV, and the two distribution transformers step down from 66 kV to 33 kV and 15 kV, and the customer is supplied by their corresponding feeder.

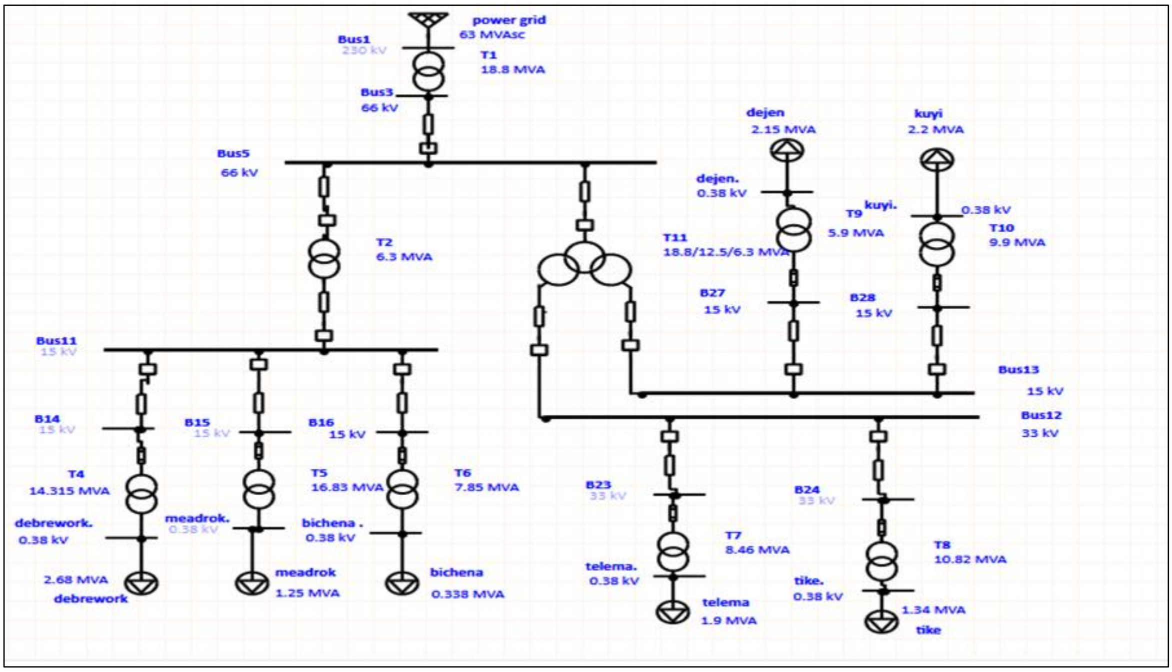

Figure 4.1: Modal and design of BDS using ETAP software

4.3 Selected DG Technology

Building on Chapter Two's exploration of various DG technologies, this chapter focuses on selecting the most suitable option for a specific area. Key factors influencing this decision include the availability of resources in the area, the technology's environmental impact, and its overall cost. Geographical location is essential to determining the accessibility of resources for power generation. The accessibility of renewable energy sources such as wind and solar energy differs greatly across regions, with factors like sunlight hours and wind speed influencing their suitability. The environmental impact of DG technologies varies, with both advantages and drawbacks. A significant factor to consider is the emission profile of these technologies, particularly their contribution of gases such as CO2 and CO to the atmosphere.

Table 4.1**:** Show the level of mission and cost in different DG

Technology	Emission	Cost
PV	No	Moderate
Wind turbine	No harmful emission	Moderate
Fuel cell	Low	High
Micro turbine	Low	Moderate

PV solar is chosen for its abundant renewable resource (sunlight), low operating costs, minimal maintenance requirements, and environmentally friendly nature, with zero greenhouse gas emissions during operation.

4.4 Analysis of Reliability Using ETAP Software

ETAP stands for Electrical Transient Analyzer Programmed, and it's a comprehensive software suite specifically designed for power system analysis, design, and testing. ETAP empowers engineers across various industries to perform a wide range of power system analyses within a single software package. This software can leverage real-world data from operational systems to conduct offline analysis, simulations, energy management studies, and load control optimization. The ETAP analysis incorporates a comprehensive library of power system components, including transmission lines, circuit breakers, transformers, various load types, DG units, the external grid interconnection, and bus bars.

Each piece of equipment in the model is assigned specific electrical and failure data. This data, including electrical ratings (e.g., voltage and current) and failure characteristics (e.g., interruption frequency and duration), is presented.

Table 4.2: Different equipment failure rate and repair duration

Equipment name	Repair duration (Hr.)	Failure rate(f/yr)	Switching time	Voltage level(kv)
External grid	0.12	0.675	1	2
Bus bar	0.01	1.01	1	66
Circuit breaker	0.15	0.015	1	15
Bus bar	0.15	0.015	1	33
Breaker	0.15	0.015	1	230
Fuse	0.15	0.015	1	15
Maine Transformer	120	0.015	1	230
Distribution transformer	200	0.015	1	33
Distribution transformer	200	0.015	1	15
Switch	0.15	0.015	1	15

Since EEU doesn't have its own historical failure data, the failure rates used in this analysis were obtained from various research sources.

Connecting Distributed Generation (DG) to the Debrework feeder: The single-line schematic of the substation depicted in Figure 4.1 serves as the foundation for the subsequent case studies. Two distinct scenarios are executed, In the first part, reliability analysis is simulated using ETAP before DG implementation. In the second phase, reliability analysis simulation is conducted post-DG implementation.

4.5 Condition 1: Before DG installed

The simulation method result of Bichena Substation shows below figure 4.5, the simulation result value yielded for SAIFI, SAIDI, and EENS are 364.0334f/yr,232.6572h/yr, and 2301.898MWh/yr respectively. this value are very similar to the analytical method values obtained that 364f/yr,232.68h/yr, and 2301.898 MWh/yr almost the same. Figure 4-6, 4-7 and 4-8 are shows below ETAP reports simulation result of reliability indices, the load point output reports and EENS plot outputs respectively. Table 4-9 presents the average reliability indices of the substation obtained through the Analytical method, which closely similar with the simulation results for all reliability indices values.

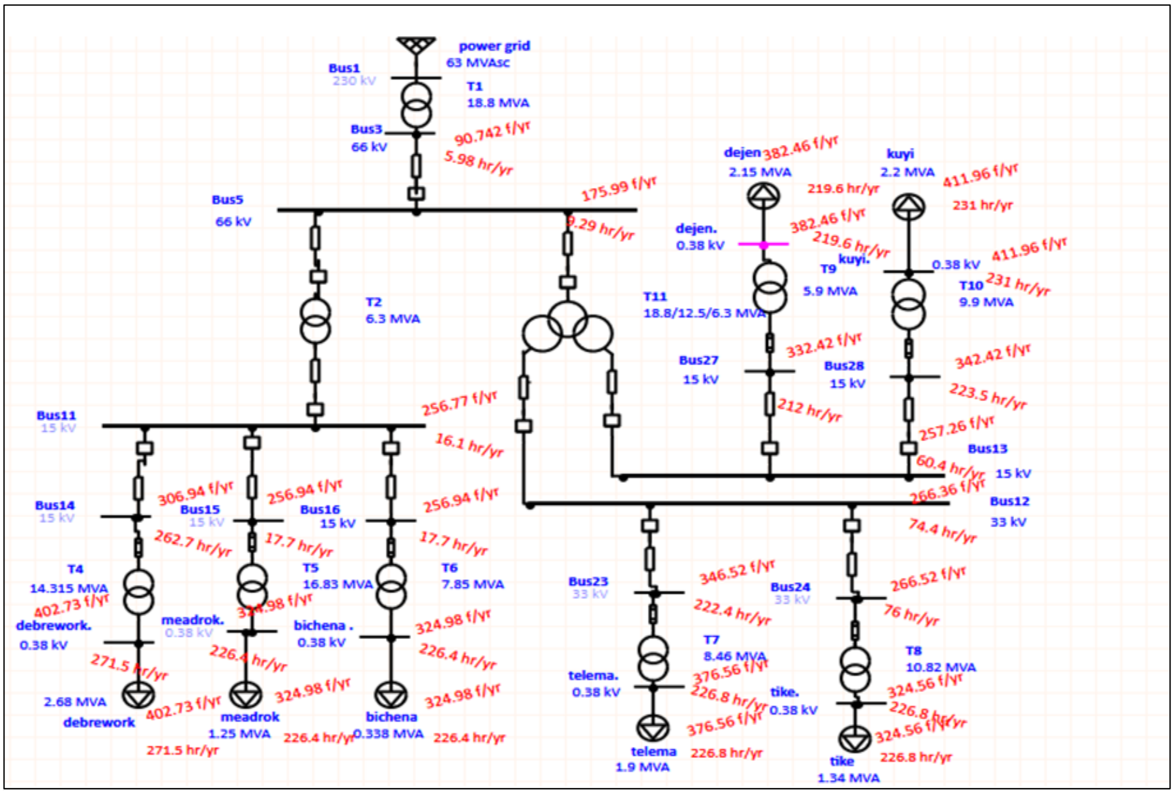

Figure 4.2**:** One line diagram of BDS before DG installed at Debrework feeder

Project: Reliability Enhancement using DG optimal placement | ETAP 19.0.1C | Page: 1
Location: case study Bichena. Amhara | Date: 04-20-2024
Contract: 0941588460 | SN:
Engineer: Almaz Ayalew | Study Case: RA | Revision: Base
Filename: before insert DG | Config: Normal

SUMMARY

AENS	328.8426 MW hr / customer.yr
ASAI	0.9734 pu
ASUI	0.02656 pu
CAIDI	0.639 hr / customer interruption
EENS	2301.898 MW hr / yr
SAIDI	232.6572 hr / customer.yr
SAIFI	364.0334 f / customer.yr

System Indexes

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

Figure 4.3: Simulation result of ETAP report without DG reliability indices

Project: Reliability Enhancement using DG optimal placement | ETAP | Page: 1
Location: Case study Bichena, Amhara | 19.0.1C | Date: 04-20-2024
Contract: 0941588460 | SN:
Engineer: Almaz Avalew | Study Case: RA | Revision: Base
Filename: befor insert DG | Config: Normal

Bus Load Point Output Report

Connected Bus ID	Average Interrupting Rate f / yr	Average Outage Duratio hour	Annual Outage Duration hr / yr	EENS MW hr /
Tike.	324.5614	0.70	226.8220	258.3503
Dejen.	382.4604	0.57	219.5750	321.0703
kuyi.	411.9604	0.56	231.0500	432.0633
Debrework	402.7289	0.67	271.5268	618.5383
Meadrok	324.9810	0.70	226.4234	240.5748
Bichena	324.9810	0.70	226.4234	65.0515
Telema	376.5604	0.60	226.7800	366.2498

Figure 4.4: Simulation result of ETAP report without DG load point output

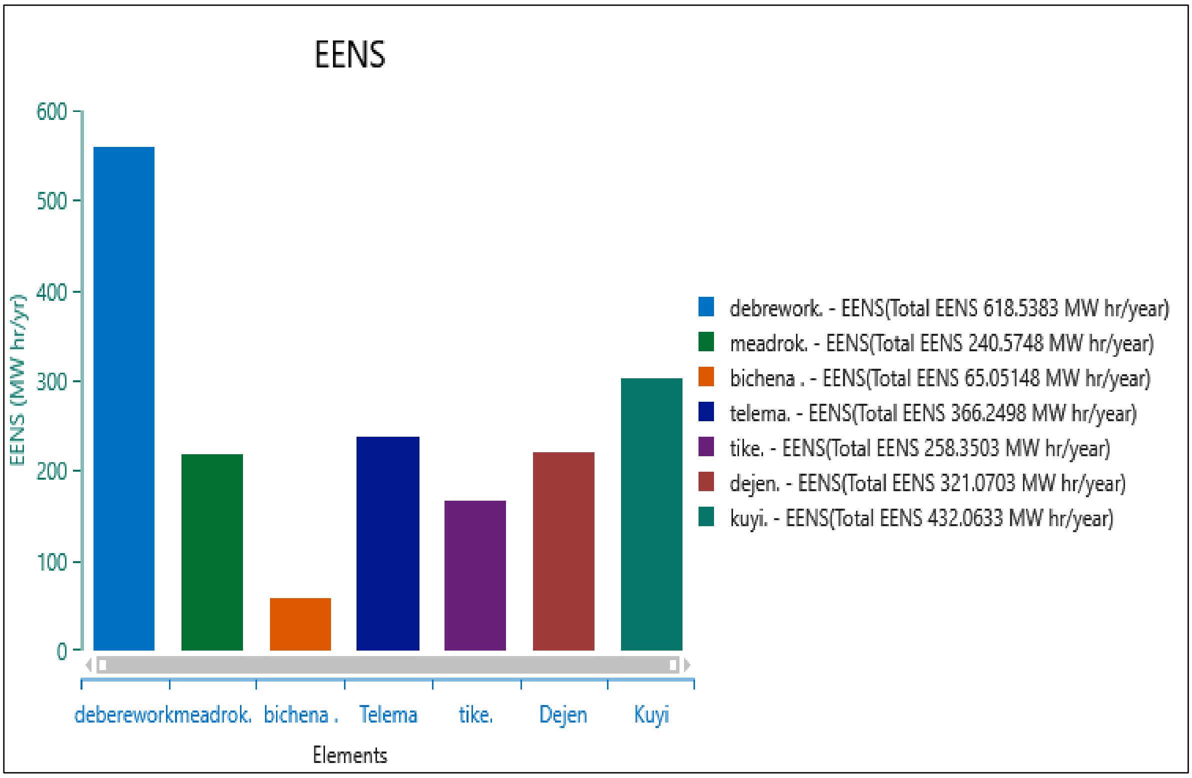

Figure 4.5: Simulation result of without DG EENS plot

Table 4.3: Average reliability indices of both 2014 and 2015 E.C from chapter 3

Feeder name	SAIFI	SAIDI	CAIDI	ASAI	ASUI	ENS(MWh)	AENS(Mwh)
Bichena	324	226.5	0.7031	0.9699	0.03	65.05148	21.724
Debrework	402	271.1	0.7862	0.9622	0.0378	618.538	94.763
Meadrok	323	226.4	0.7009	0.9785	0.0215	240.57	45.4403
Dejen	382	219.6	0.5961	0.9752	0.0248	321.07	42.3296
Kuyi	411	231.6	0.5688	0.9711	0.0288	432.06	43.0937
Telema	376	226.4	0.6021	0.9736	0.0264	366.24	45.6478
Tike	324	226.9	0.7003	0.9829	0.0170	258.35	35.8566
Average	364	232.685	0.6455	0.9733	0.0266	2301.898	328.855

The table above illustrates that the average reliability indices derived from the analytical method in Chapter 3 further elaborate on the discussion regarding reliability indices. Consequently, the analytical method calculations yield results that similar to resemble the simulation results of in Figure 4-6. Specifically, the values for SAIFI, SAIDI, and EENS are 364 f/yr, 232.685 hr/yr, and 2301.898 MWh/yr, respectively.

4.6 Condition 2: After DG installed

Reliability indices after inserting DG at Debrework feeder with the size of Debrework load capacity. The case study demonstrates that the reliability of the power system is positively impacted by the presence of DG on the substation. So that the indices were reduced by DG inserting into the overall system. Figures 4-10, 4-11, and 4-12 shows that blow ETAP reports from the simulation results reliability indices, load point output, and EENS report after installed DG, respectively.

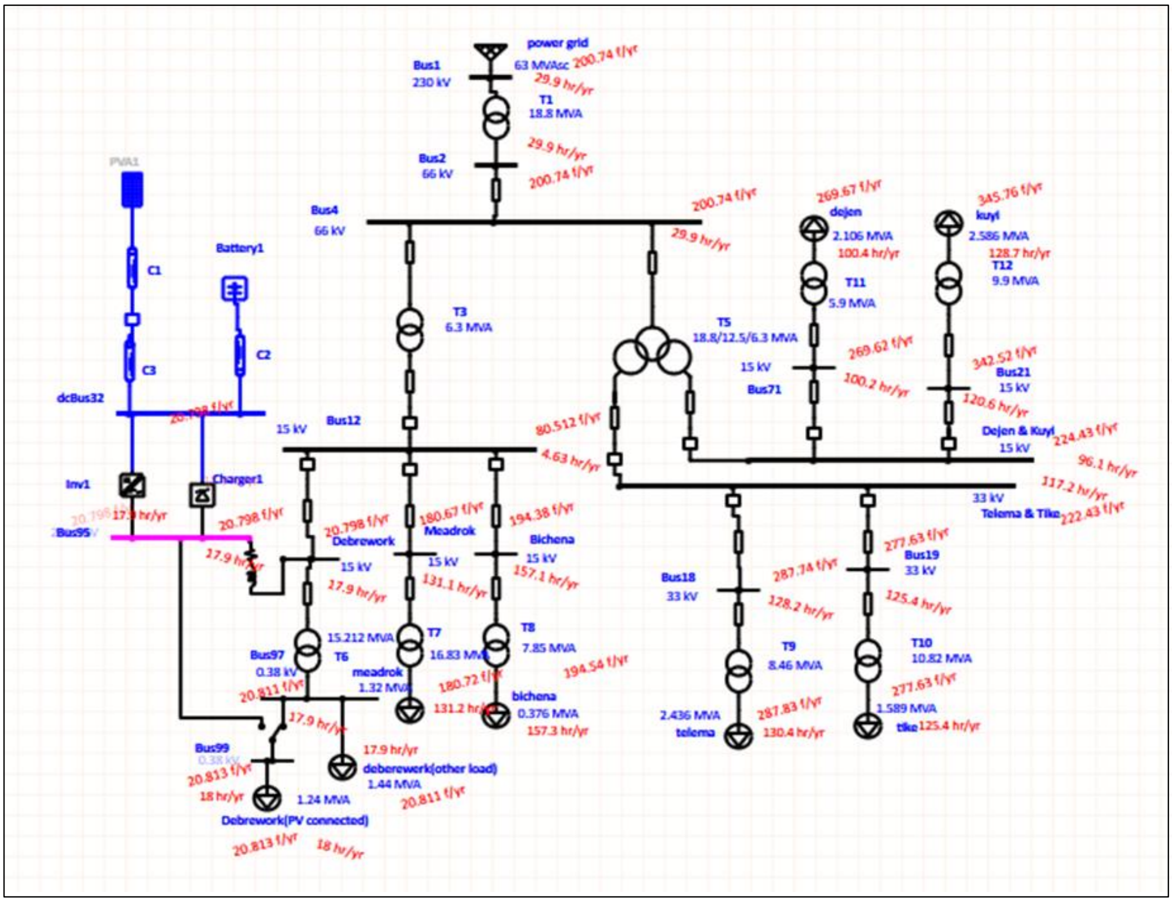

Figure 4.6: Single line diagram of BDS After installed DG at Debrework feeder line

Project: Reliability Enhancement using DG in optimal location
Location: case study Bichena substation, Amhara
Contract: 0941588460
Engineer: Almaz Ayalew
Filename: After DG inserting

ETAP
19.0.1C

Study Case: RA

Page: 1
Date: 04-20-2024
SN:
Revision: Base
Config.: Normal

AENS	125.2581 MW hr / customer.yr
ASAI	0.9895 pu
ASUI	0.01049 pu
CAIDI	0.511 hr / customer interruption
EENS	1127.323 MW hr / yr
SAIDI	91.9093 hr / customer.yr
SAIFI	179.8416 f / customer.yr

SUMMARY

System Indexes

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

Figure 4.7: Simulation result of ETAP report with DG reliability indices

This Figure 4.10 show as Assuming perfect operation of all protective devices and DG units, connecting DG to the chosen feeder (as illustrated in Figure 4.9) is to significantly improve the system's overall reliability as measured by the SAIFI, SAIDI, and EENS indices. The insertion of DG is achived to reduce SAIFI from 364.0334 f/cus.yr to 179.8416 f/cus.yr, SAIDI from 232.6572 hr/cus.yr to 91.9093 hr/cus.yr, and EENS from 2301.898 MWh to 1,127.323 MWh.

ETAP

19.0.1C

Project: Reliability Enhancement using DG optimal placement
Location: Case study Bichena, Amhara
Contract: 0941588460
Engineer: Almaz Ayalew
Filename: After DG inserting

Study Case: RA

Page: 1
Date: 04-20-2024
SN:
Revision: Base
Config.: Normal

Bus Connected Bus ID	Average Interrupting Rate f / yr	Average Outage Duration hour	Annual Outage Duration hr / yr	EENS MW hr /
Deberewerk (other load)	20.8107	0.86	17.9119	22.2807
Meadrok	180.7215	0.73	131.1860	148.2402
Bichena	194.5411	0.81	157.3304	50.3457
Telema	287.8257	0.45	130.4263	249.7663
Tike	277.6281	0.45	125.3859	170.5249
Dejen	269.6748	0.37	100.3683	175.1427
kuyi	345.7614	0.37	128.6510	292.0380
Debrework (PV connected)	20.8127	0.87	18.0119	18.9845

Figure 4.8: After installed DG simulation result Load point output report of 7 outgoing feeders

The simulation results reveal the impact of DG integration on the Debrework feeder. This includes details on the load point output of each feeder line, along with the corresponding changes in reliability indices. The implementation of DG on the Debrework feeder resulted in a significant improvement in reliability indices. Specifically, the System Average Interruption Frequency (SAIFI) decreased from 402.0 f/cus.yr to 20.8107 f/cus.yr, the System Average Interruption Duration Index (SAIDI) decreased from 271.1 hr/cus.yr to 18.0119 hr/cus.yr, and the Energy Not Served (ENS) decreased from 618.538 MWh/yr to 18.9845 MWh/yr.

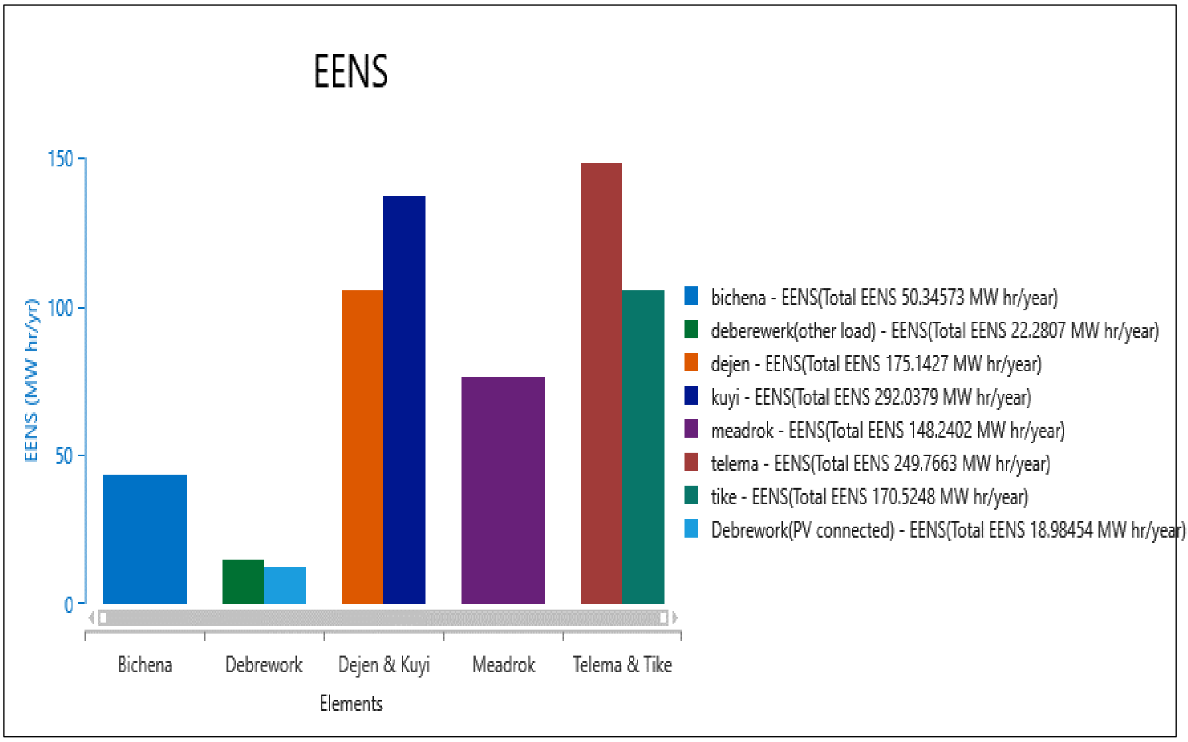

Figure 4.9: Simulation result of with DG EENS plots

The simulation results demonstrate a significant reduction in Energy Not Served (EENS) across all feeder lines after the integration of DG. Notably, the Debrewoerk feeder experiences a particularly substantial decrease in EENS.

4.7 Comparison of ETAP simulation Result with and without DG

The reliability analysis of the summary findings from the ETAP simulation is compared before and after adding DG, as seen in Table 4.10 below.

Table 4.4: Before and After installing PV comparison on reliability analysis of summary results from ETAP simulation

Reliability indices	Debrework feeder before DG	Debrework feeder After DG	% percentage	Bichena Distribution Substation before DG	Bichena Distribution Substation After DG	% percentage
SAIFI(f/yr)	402	20.798	94.8%	364.0334	179.8416	50.6%
SAIDI (hr/yr)	271.1	18.0119	93.4%	232.685	91.9093	60.5%
EENS(MWh/yr)	248.082	22.2807	96.4%	2301.898	1127.323	51%
AENS(MWh/yr)	35.44	3.1829	91%	328.855	125.2581	61.9%

The substation is equipped with indices for both (SAIFI) and (SAIDI) are 364.0334 f/yr and 232.685hr/yr, respectively. And, the candidate Debrework feeder line indices SAIFI and SAIDI are 402f/yr, and 271.1hr/yr respectively. As the result of inserting of DG the substation indices are reduced to 364.0334 f/yr to 179.8416 f/yr and 232.685 hr/yr to 91.9093 hr/yr. and Debrework feeder line also reduced to 402f/yr to 20.798f/yr and 271.1hr/yr to 18.0119 hr/yr.the feeder satisfies the Ethiopian Electric Agency's (EEA) criteria.

The ETAP report's simulation results for the Debrework feeder reliability indices at the base case and after DG installation are displayed in figures 4.7 And 4.11 respectively. It is evident that the reliability of the chosen Debrework feeder and the overall system is effectively decrease as a result of the DG installed at a particular Debrework feeder line. The values for the SAIFI, SAIDI, and EENS of the Bichena Substation determined by analytical methods are 364f/yr, 232.68h/yr, and 2301.898MWh/yr, respectively. this similarly bay simulation method the value obtained are 364.0334f/yr, 232.657h/yr, and 2301.898 MWh/yr are almost the same. The analytical (VSI) technique has several advantages over other techniques when compared, including Active of implementation, better computational time efficiency, non-iterativeness, lack of a convergence problem, and a high precision factor.

4.8 Cost Analysis and Payback period

Cost-effectiveness is determined by the variance in expected interruption cost (ECOST) before and after the implementation of the proposed method.

Cost of Energy not supplied due to interruption

= EENS(Mwhr/yr) *year*tariff(birr/Kwh) (5.1)

= 2301.898 MWh/yr*1yr*2.48birr/Kwh =5,708,707.04 birr or 101,941.1971$

So that, Before the proposed method was applied, 101,941.1971$ was lost due to interruption.

Cost of energy saved due to interruption improvement

=Power saved (Mwhr/yr)*yr* Elec.tariff (5.2)

= 1127.323Mwh/yr*1yr*2.48birr/Kwh = 2,795,761.04 birr or 49,924.3043$.

After applying the proposed method is used. the expected interruption cost (ECOST) is reduced to 49,924.3043$. So that, using the proposed method Saved cost is

$$= (\text{Before use DG} - \text{After use DG}) \quad (5.3)$$

$$= (101{,}941.1971\$ - 49{,}924.3043\$) = \mathbf{52.016.8928\ \$.}$$

This shows that 52.016.8928 $ is saved after using the proposed method. the total average cost of energy no supplied because of power interruption per year before the proposed technique was used. The substation lost a total of 101,941.1971$,

in revenue as a result of EENS for its seven outgoing feeders. 444.465kw of solar power can be produced in total via DG, the price of DG, which included the battery, inverter, charge controller, and solar module, was included the total price is 623,377$ is the overall cost of PV. Payback Period Calculation in overall substation.

$$\text{Payback Period} = \text{Initial Investment} / \text{Annual Saving} \quad (5.4)$$

$$= 623{,}377\$ / 49{,}924.3043\$ = 12.4 \text{ year}$$

While the payback period for the solar panel system is 12.4 years, the long-term benefits extend beyond this timeframe. Solar panels typically boast lifespans exceeding 25 years, meaning they'll continue generating clean electricity and providing cost savings for your energy bills well after the initial investment is recouped

Calculate the total number of months:

12.4 years *12months/year= 148.8 months

Convert the decimal part to days:

0.8month *30days/month = 24 days

So, 12.4 years is equivalent to 12 years, 4 months, and 24 days.

Payback Period Calculation in Debrework feeder:

Payback Period = Initial Investment / Annual Saving

the total price of PV was 623,377$
= 623,377$ / 559,987.224 $ = **1.11year,** 1 year, 13 months, 9 days.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This research investigates the enhancement of reliability in distribution substations. The approach involves strategically inserting DG units into selected feeder lines to improve overall system efficiency. The Debrework feeder reliability as examined in this thesis, does not satisfy EEA standards. Additionally, the Bichena Substation average monthly unsupplied energy is 2301.898 MWh. As a result, EEU losses about 5,708,707.04 Birr annually. Furthermore, based on the analysis, it has been noted that DTEF and DPSC faults happen more frequently than the other kinds of faults. the price of the PV system was 623,377$; DG had 444.465KWh generate capacity,577.8kw invertor, and a 1,0380Ah battery. The Debrework feeder that was weakest, as determined by VSI computation, was linked to DG and following the selection of the DG's optimal location, the DG size is established by choose one of the feeder line from the Bichena Distribution. Therefore, Debrework line load was chosen as the top priority for the DG size among the various lateral load places. the currently system was modeled using ETAP 19.0.1 software.

Generally, the findings of this study demonstrate the optimal location of DG units within a distribution network can significantly enhance its reliability. This conclusion is supported by the observed improvements in key reliability indices. Specifically, integrating DG near load centers within the distribution system resulted in substantial reductions: 50.6% in SAIFI, 60.6% in SAIDI, and 51% in EENS. And from the selected Debrework feeder are 94.8%, 93.4%, and 96.4% reliability improvement was achieved. the case study illustrates that distributed generation can lower customer interruption costs, thereby enhancing the reliability of the system. It is our proposed method was effectively utilized by distribution system.

5.2 Recommendation

A reliability analysis needs to know how many customers are served overall and in each line. the quantity of consumers served the frequency of customer disruptions, the number of loads connected, the quantity and rating of transformers, and so forth. Therefore, power system components (lines, buses, transformers on each feeder, circuit breakers, and disconnectors) and problems that affect them and EEU needs to accurately record the total amount of clients served and disrupted. Determining every load point and all information associated with it showed to be difficult. This thesis analyzes this as challenging. Therefore, it advises EEU to identify every load point and the failure data that goes along with it. Based on the data that was reviewed and studied. It has been noted that earth faults are the main source of distribution network disruptions, with short circuit faults occurring more frequently compared to different fault types. Therefore, it suggests that EEU adopt current limiters as well as reactance relays as a good option. Due to its beneficial effects on the reliability of the system, DG is currently widely deployed. Hence, in addition to being utilized for rural electrification, DG choices based on renewable energy should also be employed as a backup in urban regions. The study area is selected for this research was limited to Debrework feeder line, but the future studies should develop into other feeder lines. I recommend that Promoting the use of PV in power systems in different areas like city, rural area and other sectors.

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APPENDIX

APPENDIX-A: Annually average loads of each feeder line in BDS 2014 E.C and 2015 E.C

Table A.1: Annually of average loads each feeder line in BDS 2015 E.C

Month	33kv and 15kv outgoing feeder monthly load (MW)						
	Bichena	Deber Work	Meadrok	Dejen	Kuyi	Telema	Tike
September	1.35	1.5	1.59	0.98	1.26	0.35	0.27
October	1.35	1.5	1.35	0.825	1.29	0.34	0.33
November	1.35	1.5	1.35	0.9	1.13	0.24	0.18
December	1.44	1.95	1.5	1.05	1.53	0.24	0.18
January	1.2	1.8	1.5	0.9	1.26	0.22	0.17
February	1.35	1.5	1.35	0.9	1.2	0.22	0.175
March	1.44	1.8	1.59	1.05	1.5	0.43	0.41
April	1.5	2.01	1.71	1.29	1.8	0.48	0.46
May	1.35	1.8	1.8	1.05	1.35	0.46	0.46
June	1.5	1.95	1.8	1.2	1.63	0.5	0.6
July	1.6	1.8	1.5	1.21	1.4	0.7	0.65
August	1.56	2.01	1.73	1.45	1.23	0.75	0.59

Table A.2: Annually of average loads each feeder line in BDS 2014 E.C.

Month	Month 33kv and 15kv outgoing feeder monthly load (MW)						
	Bichena	Deber work	Meadrok	Dejen	Kuyi	Telema	Tike
September	1.2	1.5	1.5	1.08	1.17	1.6	0.17
October	0.93	1.35	1.43	0.9	1.02	0.15	0.17
November	1.35	1.5	1.35	0.96	1.05	0.15	0.15
December	1.2	1.5	1.5	0.9	1.05	0.16	0.16
January	1.65	1.8	1.35	1.3	1.38	0.15	0.17
February	1.5	1.5	1.35	0.84	1.2	0.25	0.16
March	1.65	1.8	1.5	1.2	1.5	0.17	0.17
April	1.8	1.95	1.65	1.2	1.44	0.2	0.19
May	1.35	1.5	1.41	1.05	1.26	0.33	0.2
June	1.43	1.62	1.38	0.9	1.35	0.22	0.14
July	1.02	1.1	1.3	1.2	1.02	0.52	0.5
August	1.28	1.38	1.64	1.4	1.21	0.35	0.2

APPENDIX-B: Frequency and Duration of Interruption Data in 2015 and 2014 E.C

Table B.1: 2015 Quarter 1, three-month (**September, October, November**) interruption data on 7 feeders.

	Forced interruption						Operational interruption		Total (force+opera) interruption	
	momentary		sustained		Total					
Feeder Name	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (h)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)
Bichena	24	1:13	7	11:14	31	12:27	33	21:12	64	33:39
D/work	34	2:7	35	86:00	69	88;7	48	45:12	117	134:22
Meadrok	34	1:12	29	55:56	63	58:08	35	22:02	98	81:00
Dejen	39	2:32	29	83:28	68	86:00	20	27:09	88	113:01
Kuyi	44	3:02	23	18:02	67	21:04	18	12:04	85	33:08
Telema	83	1:57	71	180:00	154	181:57	32	31:59	186	213:18
Tike	40	1:23	41	78:09	81	79:32	7	3:02	88	82;34

Table B. 2: 2015 second quarter, 3-month (**December, January, February**,) interruption data on 7 outgoing feeders.

	Forced interruption						Operational interruption		Total (force+opera) interruption	
	Momentary		sustained		Total					
Feeder Name	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (h)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)
Bichena	15	1:23	7	3:37	22	4:06	22	12:27	44	16:33
D/work	40	3:07	48	67:43	88	70:05	41	27:27	129	97:32
Meadrok	21	1:26	9	13:03	30	14:29	23	14:39	53	29:28
Dejen	24	0:05	23	54:55	47	54:06	20	12:23	67	66:29
Kuyi	34	4:05	43	30:16	77	34:21	15	10:00	92	44:21
Telema	53	1:03	51	73:18	104	74:21	22	32:43	126	105:02
Tike	79	5:35	37	67:24	116	72:59	9	7:43	125	80:02

Table B.3: 2015 Third quarter, 3-month (**March, April, May**,) interruption data on 7 outgoing feeders

	Forced interruption						Operational interruption		Total (force+opera) interruption	
	momentary		sustained		Total					
Feeder Name	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (h)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)
Bichena	17	0:33	26	51:25	43	51:58	8	5:22	51	56:08
D/work	67	2:39	90	226:23	157	229:12	44	43:02	201	272:32
Meadrok	43	1:17	35	94:16	78	95:33	16	10:28	94	106:01
Dejen	51	2:06	82	186:02	113	188:08	27	17:3	140	205:38
Kuyi	68	2:58	85	179:26	153	182:24	27	29:33	180	211:57
Telema	78	2:13	56	116:27	113	118:04	29	35:25	163	153:29
Tike	97	2:09	59	221:05	156	223:14	26	33:17	182	256:31

Table B.4: 2015 fourth quarter, 3-month (**June, July, August,**) interruption data on 7 outgoing feeders.

	Forced interruption						Operational interruption		Total (force+opera) interruption	
	momentary		sustained		Total					
Feeder Name	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (h)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)
Bichena	14	0:34	31	56:29	45	57:03	12	8:41	57	65:44
D/work	42	2:06	104	214:48	146	216:54	41	33:48	187	250:02
Meadrok	29	1:09	53	100:13	82	101:22	22	11:37	104	112:59
Dejen	30	1:07	43	166:39	73	167:46	12	20:17	85	188:03
Kuyi	53	2:06	72	223:09	125	225:15	25	22:25	150	247:04
Telema	52	1:02	55	207:02	107	208:04	16	10:06	123	218:01
Tike	68	2:29	27	144:01	95	146:03	7	2:07	102	148:01

Table B.5: 2014 Quarter 1, three-month **(September, October, November)** interruption data on 7 feeders

	Forced interruption						Operational interruption		Total (force+opera) interruption	
	momentary		sustained		Total					
Feeder Name	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (h)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)
Bichena	26	1:06	10	1:06	36	2:12	25	11:22	61	13:34
D/work	47	1:09	65	118:32	112	119:41	22	17:33	134	137:14
Meadrok	28	1:08	21	58:21	49	59:29	28	34:18	77	93:47
Dejen	47	1:01	42	119:38	89	120:39	35	32:23	124	153:02
Kuyi	73	2:02	81	152:22	154	154:24	20	11:06	174	165:03
Telema	110	3:54	45	80:07	195	84:01	27	24:37	222	108:38
Tike	102	4:09	35	74:05	137	78:14	35	20:32	172	98:46

Table B.6: 2014 second quarter, 3-month (**December, January, February**) interruption data on 7 outgoing feeders.

	Forced interruption						Operational interruption		Total (force+opera) interruption	
	momentary		sustained		Total					
Feeder Name	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (h)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)
Bichena	22	0:26	9	9:47	31	10:13	30	26:23	61	36:36
D/work	33	0:59	27	38:02	60	39:19	24	22:36	84	61:55
Meadrok	31	0:84	24	39:21	55	40:05	21	12:25	76	52:03
Dejen	43	0:87	24	64:13	67	65:00	16	15:39	83	80:39
Kuyi	67	1:55	39	84:27	106	86:22	14	11:01	120	97:23
Telema	93	2:31	51	142:32	144	145:03	27	20:07	171	165:01
Tike	60	3:06	50	120:06	110	123:12	15	20:8	125	144:32

Table B.7: 2014 Third quarter, 3-month (**March, April, May**) interruption data on 7 outgoing feeders

	Forced interruption						Operational interruption		Total (force+opera) interruption	
	momentary		sustained		Total					
Feeder Name	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (h)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)
Bichena	18	1:15	33	9:41	51	11:56	26	31:02	77	42:58
D/work	59	2:15	61	136:03	120	138:45	38	58:25	158	196:07
Meadrok	28	1:12	30	69:15	58	70:12	24	14:23	82	84:35
Dejen	28	1:22	29	78:48	57	79:07	34	45:13	91	124:02
Kuyi	61	3:17	68	87:38	129	90:55	27	23:26	151	14:21
Telema	85	2:47	64	107:46	149	110:33	33	44:51	182	155:24
Tike	65	3:04	56	90:8	121	94:24	26	23:02	147	117:26

Table B. 8: 2014 fourth quarter, 3-month (**June, July, August**) interruption data on 7 outgoing feeders.

	Forced interruption						Operational interruption		Total (force+opera) interruption	
	momentary		sustained		Total					
Feeder Name	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (h)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)	Fr. (f)	Dur. (hr)
Bichena	16	0:08	17	53:05	33	53:13	28	16:54	61	70:17
D/work	51	3:45	96	281:07	147	284:52	43	65:58	193	50:01
Meadrok	29	1:04	27	28:12	56	29:16	18	21:13	74	50:29
Dejen	28	12:53	59	109:14	87	122:07	23	24:16	11	146:23
Kuyi	36	1:53	51	138:12	87	140:05	18	8:33	105	148:38
Telema	47	1:08	61	230:27	108	231:35	26	37:00	134	268:35
Tike	37	2:05	43	212:01	80	214:06	18	32:05	98	246:11

APPENDIX -C: Solar Radiation Debrework Data from NASA and PVGIS

Table C-1: Debrework solar radiation from NASA

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	-BEGIN HEADER-														
2	NASA/POWER CERES/MERRA2 Native Resolution Monthly and Annual														
3	Dates (month/day/year): 01/01/2012 through 12/31/2022														
4	Location: Latitude 10.6599 Longitude 38.1659														
5	Elevation from MERRA-2: Average for 0.5 x 0.625 degree lat/lon region - 2403.9 meters														
6	The value for missing source data that cannot be computed or is outside of the sources availability range: -999														
7	Parameter(s):														
8	T2M MERRA-2 Temperature at 2 Meters (C)														
9	T2M_MAX MERRA-2 Temperature at 2 Meters Maximum (C)														
10	T2M_MIN MERRA-2 Temperature at 2 Meters Minimum (C)														
11	ALLSKY_KT CERES SYN1deg All Sky Insolation Clearness Index (dimensionless)														
12	T2M_RANGE MERRA-2 Temperature at 2 Meters Range (C)														
13	ALLSKY_SFC_SW_DWN CERES SYN1deg All Sky Surface Shortwave Downward Irradiance (kW-hr/m^2/day)														
14	-END HEADER-														
15	PARAME	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
16	T2M	2012	17.18	17.37	19.07	19.58	20.23	19.31	15.73	15.48	16.01	14.9	15.48	15.74	17.17
17	T2M	2013	16.99	18.79	19.76	20.48	19.48	17.89	15.06	15.13	15.98	14.8	14.62	14.33	16.93
18	T2M	2014	16.35	17.98	18.92	18.3	18.26	18.25	16.16	15.49	15.64	14.69	14.59	14.36	16.57
19	T2M	2015	15.55	18.2	18.97	20.33	19.26	18.51	17.18	16.06	16.33	15.88	15.65	16.05	17.32
20	T2M	2016	17.45	19.2	20.58	19.79	17.94	17.96	15.62	15.44	16.01	15.09	14.31	14.26	16.96
21	T2M	2017	15.36	17.6	19.33	19.38	18.44	19.62	16.56	15.94	16.24	15.47	14.9	14.54	16.94
22	T2M	2018	16.83	18.01	18.72	18.87	19.6	17.54	15.7	15.47	15.96	15.1	15	15.85	16.88
23	T2M	2019	16.38	18.46	19.23	19.19	19.87	18.94	16.61	15.9	16.08	14.53	15.32	15.23	17.13
24	T2M	2020	16.57	18.2	20.01	19.49	18.99	17.94	15.71	15.62	16.11	14.75	14.23	15.15	16.89
25	T2M	2021	15.35	16.9	18.61	19.05	17.77	18.35	15.23	15.82	16.32	15.17	14.73	15.12	16.52
26	T2M	2022	15.59	17.94	18.76	19.61	20.58	18.19	15.39	15.15	16.19	15.08	14.62	15.17	16.84
27	T2M_MA	2012	26.91	28.8	29.73	29.04	29.66	29.38	22.36	21.03	20.98	21.94	22.52	23.64	29.73
28	T2M_MA	2013	27.45	29.78	30.03	30.55	29.05	27.67	21.72	20.31	21.66	20.49	21.22	22.87	30.55
29	T2M_MA	2014	25.45	27.44	29.02	27.66	25.98	26.05	24.98	21.04	20.76	20.71	21.4	22.6	29.02
30	T2M_MA	2015	25.09	27.65	29.41	29.68	29.28	26.87	24.11	21.77	22.72	22.55	23.2	24.45	29.68
31	T2M_MA	2016	26.37	29.05	29.69	29.69	25.21	26.41	22.21	20.96	21.66	21.15	22.94	24.01	29.69
32	T2M_MA	2017	27.33	27.22	29	29.78	26.41	27.9	22.76	22.27	21.74	21.63	22.33	24.14	29.78
33	T2M_MA	2018	26.7	28.48	28.67	29.24	29.17	25.25	23.47	22.05	21.57	21.7	22.33	24.69	29.24
34	T2M_MA	2019	27.51	28.37	28.22	27.4	29.98	27.94	23.66	22.11	21.33	21.68	21.64	23.37	29.98
35	T2M_MA	2020	25.58	28.51	30.63	29.94	27.4	26.3	22.82	21.23	21.14	20.91	22.03	23.63	30.63
36	T2M_MA	2021	24.05	26.08	29.51	29.85	26.14	27.16	21.96	21.48	21.34	21.5	22.1	24.42	29.85
37	T2M_MA	2022	24.08	26.97	29.58	29.02	29.53	29.23	21.45	20.94	21.55	20.73	21.3	22.52	29.58
38	T2M_MIN	2012	6.38	7.21	9.33	10.34	11.98	11.98	10.01	10.86	11.02	5.69	8.17	7.63	5.69
39	T2M_MIN	2013	6.57	9.23	10.19	10.05	12.57	11.74	9.42	9.89	10.37	7.9	6.48	5.33	5.33
40	T2M_MIN	2014	7.49	8.55	10.72	9.33	11.77	11.84	10.98	10.56	10.45	7.73	6.49	5.18	5.18
41	T2M_MIN	2015	6.36	7.44	9.76	11.38	11.65	11.73	11.75	11.17	11.19	8.9	6.96	7.37	6.36
42	T2M_MIN	2016	8.68	9.69	11.6	11.51	12.51	11.29	10.46	9.9	11.34	7.19	4.65	4.71	4.65
43	T2M_MIN	2017	3.92	9.46	10.37	10.08	11.86	11.59	11.32	10.19	10.29	8	6.87	4.32	3.92
44	T2M_MIN	2018	7.08	7.87	8.3	11.01	11.46	11.44	10.95	8.79	9.35	7.51	6.4	7.47	6.4
45	T2M_MIN	2019	5.74	9.28	11.3	12.21	12.23	12.49	11.48	10.48	10.9	7.48	8.31	7.49	5.74
46	T2M_MIN	2020	7.02	10.01	9.87	10.23	11.8	11.2	10.37	9.41	11.28	7.9	5.8	6.76	5.8
47	T2M_MIN	2021	6.76	7.92	8.79	9.82	10.82	11.57	9.67	10.52	11.08	7.46	6.6	4.08	4.08
48	T2M_MIN	2022	7.36	9.9	9.38	11.08	12.37	10.85	9.85	10.24	10.73	8.07	7.06	7.32	7.06
49	ALLSKY_	2012	0.73	0.75	0.69	0.64	0.63	0.55	0.49	0.51	0.58	0.72	0.7	0.72	0.64
50	ALLSKY_	2013	0.71	0.73	0.66	0.68	0.59	0.55	0.46	0.44	0.58	0.63	0.69	0.73	0.62
51	ALLSKY_	2014	0.69	0.66	0.66	0.63	0.6	0.59	0.51	0.48	0.55	0.66	0.68	0.71	0.62
52	ALLSKY_	2015	0.73	0.72	0.7	0.69	0.61	0.55	0.59	0.52	0.59	0.68	0.67	0.66	0.64
53	ALLSKY_	2016	0.66	0.71	0.66	0.59	0.59	0.57	0.48	0.48	0.56	0.69	0.7	0.74	0.62
54	ALLSKY_	2017	0.77	0.63	0.69	0.66	0.59	0.61	0.52	0.47	0.55	0.62	0.7	0.76	0.62
55	ALLSKY_	2018	0.7	0.69	0.66	0.61	0.61	0.54	0.5	0.48	0.62	0.65	0.66	0.72	0.62
56	ALLSKY_	2019	0.75	0.69	0.65	0.62	0.62	0.58	0.5	0.46	0.52	0.66	0.62	0.69	0.61
57	ALLSKY_	2020	0.7	0.68	0.62	0.62	0.61	0.57	0.43	0.45	0.56	0.66	0.73	0.73	0.61
58	ALLSKY_	2021	0.73	0.66	0.73	0.63	0.61	0.58	0.41	0.49	0.55	0.66	0.68	0.73	0.62
59	ALLSKY_	2022	0.67	0.69	0.68	0.65	0.64	0.57	0.42	0.45	0.52	0.63	0.7	0.65	0.6
60	T2M_RAI	2012	20.53	21.59	20.4	18.7	17.68	17.4	12.34	10.17	9.95	16.25	14.35	16.01	24.04
61	T2M_RAI	2013	20.88	20.55	19.84	20.5	16.48	15.93	12.3	10.42	11.3	12.59	14.74	17.55	25.22
62	T2M_RAI	2014	17.96	18.88	18.3	18.33	14.21	14.2	14.01	10.48	10.3	12.98	14.91	17.42	23.84
63	T2M_RAI	2015	18.73	20.21	19.66	18.3	17.63	15.14	12.36	10.6	11.53	13.65	16.24	17.08	23.32
64	T2M_RAI	2016	17.69	19.36	18.09	18.18	12.7	15.12	11.75	11.06	10.32	13.97	18.29	19.3	25.05
65	T2M_RAI	2017	23.41	17.76	18.62	19.7	14.55	16.31	11.44	12.09	11.45	13.63	15.45	19.82	25.86
66	T2M_RAI	2018	19.62	20.61	20.38	18.23	17.71	13.8	12.52	13.26	12.22	14.19	15.93	17.23	22.84
67	T2M_RAI	2019	21.77	19.09	16.92	15.2	17.75	15.45	12.19	11.62	10.43	14.2	13.33	15.88	24.23
68	T2M_RAI	2020	18.56	18.51	20.77	19.72	15.6	15.1	12.45	11.81	9.86	13.02	16.23	16.87	24.84
69	T2M_RAI	2021	17.28	18.16	20.73	20.03	15.32	15.59	12.29	10.95	10.26	14.04	15.5	20.34	25.77
70	T2M_RAI	2022	16.72	17.06	20.2	17.94	17.16	18.38	11.6	10.7	10.83	12.66	14.23	15.2	22.52
71	ALLSKY_	2012	6.43	7.18	7.03	6.72	6.57	5.64	5.06	5.23	5.91	6.93	6.25	6.15	6.26
72	ALLSKY_	2013	6.28	7.04	6.73	7.11	6.21	5.74	4.73	4.51	5.94	6.16	6.15	6.24	6.06
73	ALLSKY_	2014	6.04	6.35	6.71	6.61	6.27	6.04	5.2	5.06	5.66	6.39	6.13	6.07	6.04
74	ALLSKY_	2015	6.43	6.84	7.21	7.2	6.36	5.64	6.03	5.37	5.97	6.58	6.03	5.59	6.27
75	ALLSKY_	2016	5.8	6.76	6.77	6.22	6.15	5.89	4.95	4.99	5.79	6.66	6.3	6.37	6.05
76	ALLSKY_	2017	6.81	6.08	7.02	7	6.21	6.27	5.33	4.83	5.63	5.99	6.31	6.47	6.16
77	ALLSKY_	2018	6.15	6.53	6.81	6.36	6.35	5.52	5.15	5.01	6.32	6.29	5.86	6.14	6.04
78	ALLSKY_	2019	6.64	6.59	6.59	6.48	6.52	5.92	5.12	4.8	5.31	6.43	5.56	5.87	5.98
79	ALLSKY_	2020	6.18	6.49	6.43	6.52	6.38	5.86	4.44	4.7	5.76	6.34	6.47	6.21	5.98
80	ALLSKY_	2021	6.38	6.36	7.4	6.61	6.34	5.97	4.16	5.07	5.66	6.35	6.08	6.23	6.05
81	ALLSKY_	2022	5.96	6.6	6.97	6.82	6.68	5.83	4.37	4.65	5.29	6.17	6.24	5.53	5.92

Table C. 2: Monthely Solar Radiation of Debrework from (Radiation database:PVGIS-SARAH2)

Latitude (decimal degrees):10.660, Longitude (decimal degrees):38.166

year	month	H(h)_m	Kd	T2m
2013	Jan	181.34	0.31	17.1
2013	Feb	141.36	0.42	17.1
2013	Mar	190.9	0.36	18.3
2013	Apr	182.2	0.42	19.4
2013	May	176.99	0.48	19.4
2013	Jun	167.73	0.48	18.9
2013	Jul	139.03	0.62	16.0
2013	Aug	142.33	0.56	15.5
2013	Sep	185.32	0.44	15.9
2013	Oct	210.35	0.29	17.9
2013	Nov	175.66	0.32	17.3
2013	Dec	159.97	0.34	15.7
2014	Jan	170.17	0.37	16.3
2014	Feb	197.02	0.22	19.2
2014	Mar	186.2	0.36	17.5
2014	Apr	205.08	0.33	19.8
2014	May	187.99	0.43	19.1
2014	Jun	173.29	0.48	18.4
2014	Jul	155.76	0.52	16.2
2014	Aug	154.34	0.53	15.5
2014	Sep	180.32	0.43	15.8
2014	Oct	211.48	0.29	17.4

2014	Nov	177.76	0.32	17.3
2014	Dec	195.81	0.22	17.6
2015	Jan	199.94	0.23	18.5
2015	Feb	208.19	0.21	19.7
2015	Mar	215.38	0.29	19.6
2015	Apr	193.99	0.38	18.8
2015	May	207.62	0.36	20.1
2015	Jun	164.52	0.5	17.9
2015	Jul	158.47	0.55	16.0
2015	Aug	170.13	0.49	15.7
2015	Sep	183.79	0.42	15.7
2015	Oct	216.63	0.26	17.7
2015	Nov	184.9	0.29	17.7
2015	Dec	192.73	0.24	17.5
2016	Jan	184.99	0.29	18.8
2016	Feb	195.02	0.24	20.2
2016	Mar	190.57	0.36	18.7
2016	Apr	215.41	0.3	21.0
2016	May	187.23	0.44	19.8
2016	Jun	159.4	0.52	17.8
2016	Jul	142.17	0.59	15.3
2016	Aug	131.8	0.62	15.0
2016	Sep	188.85	0.41	16.0
2016	Oct	192.54	0.35	16.7
2016	Nov	179.5	0.31	17.1
2016	Dec	187.48	0.26	16.5

2017	Jan	180.38	0.31	17.6
2017	Feb	175.11	0.3	18.0
2017	Mar	198.59	0.35	19.0
2017	Apr	199.11	0.36	19.9
2017	May	200.88	0.37	19.2
2017	Jun	179.08	0.45	19.0
2017	Jul	154.97	0.56	16.6
2017	Aug	160.72	0.54	15.7
2017	Sep	175.17	0.48	15.9
2017	Oct	193.87	0.36	17.4
2017	Nov	176.71	0.32	17.7
2017	Dec	173.63	0.3	16.8
2018	Jan	192.69	0.27	17.7
2018	Feb	188.32	0.25	19.4
2018	Mar	218.23	0.27	19.8
2018	May	198.44	0.4	19.4
2018	Jun	165.07	0.49	18.4
2018	Jul	181.21	0.46	17.1
2018	Aug	166.4	0.52	16.4
2018	Sep	187.93	0.42	16.8
2018	Oct	210.72	0.29	19.3
2018	Nov	180.13	0.34	18.4
2018	Dec	165.43	0.35	17.5
2019	Jan	160.05	0.38	18.4
2019	Feb	187.89	0.28	19.8
2019	Mar	201.15	0.35	21.0
2019	Apr	166.85	0.47	18.5
2019	May	189.62	0.41	18.5
2019	Jun	166.11	0.5	18.3

2019	Jul	142.69	0.58	15.8
2019	Aug	153.59	0.53	15.5
2019	Sep	171.79	0.44	16.2
2019	Oct	193.58	0.3	18.2
2019	Nov	189.85	0.25	17.5
2019	Dec	198.11	0.21	17.1
2019	Jan	208.06	0.21	17.4
2020	Feb	160.74	0.36	17.5
2020	Mar	211.61	0.31	18.9
2020	Apr	206.96	0.31	20.6
2020	May	190.47	0.42	18.2
2020	Jun	176.83	0.46	18.6
2020	Jul	164.21	0.51	16.8
2020	Aug	152.92	0.55	15.8
2020	Sep	174.23	0.44	16.0
2020	Oct	192.23	0.35	18.0
2020	Nov	189.29	0.26	17.9
2020	Dec	200.54	0.21	17.5
2021	Jan	176.54	0.31	17.6
2021	Feb	177.23	0.27	18.8
2021	Mar	205.37	0.32	19.7
2021	Apr	186.84	0.38	19.3
2021	May	192.9	0.41	20.3
2021	Jun	164.01	0.5	17.2
2021	Jul	159.85	0.54	15.8
2021	Aug	157.98	0.54	15.5
2021	Sep	196.79	0.39	16.5
2021	Oct	194.03	0.35	18.1
2021	Nov	167.33	0.34	17.0
2021	Dec	189.46	0.26	18.0
2022	Jan	205.88	0.21	18.6
2022	Feb	179.36	0.3	19.0
2022	Mar	196.41	0.37	18.8
2022	Apr	188.13	0.38	19.0

2022	May	198.65	0.39	20.0
2022	Jun	166.02	0.48	17.7
2022	Jul	162.84	0.54	16.6
2022	Aug	135.18	0.57	15.3
2022	Sep	160.6	0.54	15.9
2022	Oct	202.8	0.3	17.3
2022	Nov	164.14	0.42	17.9
2022	Dec	183.24	0.27	17.7

APPENDIX -D: EEU Tariff Birr/KWh from EEU Data

Table D:1 EEU Tariff Birr/KWh from EEU Data

Tariff amendment		AS of Decmeber.21 onward
Tariff category	KWh/month	Birr/Kwh
1.Residential tariff block		
1.1 1st block	up to 50kwh	0.27300
1.2 2nd block	up to 100kwh	0.76700
1.3 3rd block	up to 200kwh	1.62500
1.4 4thblock	up to 300kwh	2.00
1.5 5th block	up to 400kwh	2.20
1.6 6th block	up to 500kwh	2.4050
1.7 7th block	above 500kwh	2.48100
2.General tariff		
2.1 Flat fee		2.12400
3.Low voltage industry tariff		
3.1 flat fee		1.53100
3.2 Demand charge fee		200.000
4.medium voltage industry tariff.15kv&33kv		
4.1 flat fee		1.19300
4.2 Demand charge fee		147.540
5.high voltage industry tariff above 66kv		
5.1 flat fee		0.92800
5.2 Demand charge fee		87.640
6.street light tariff		
6.1 flat fee		2.12400