Addis Ababa University

College of Technology and Built Environment (CTBE)

School of Electrical and Computer Engineering

Power Reliability Improvement Through Distributed Generation Integration

(Case Study: Adama Industrial Park)

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DECLARATION

I, the undersigned, affirm that this MSc thesis is my original work and has not been submitted for a degree at this or any other university. Furthermore, all sources and materials utilized in the thesis have been duly acknowledged.

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LIST OF ABBREVIATION

AC……………………………Alternating Current

AIP…………………………...Adama Industrial Park

DC……………………………Direct Current

DER…………………………...Distributed energy resources

DG……………………………. Distributed Generator

DigSILENT…………………...Digital Simulation of Electrical Network

ECOST………………………...Expected outage cost

EENS…………………………. Expected Energy Not Supplied

EEPCo………………………...Ethiopian Electric Power Cooperation

EPS……………………………Electrical Power System

GWhr…………………………Giga Watt Hour

HOMER Pro…………………Hybrid Optimization Model for Electric Renewables Professional

HV……………………………High Voltage

I………………………………. Current

IEEE…………………………. Institute of Electrical and Electronic Engineers

IP ……………………………...Industrial Park

IPDC…………………………. Industrial Parks Development Corporation

kV……………………………. Kilo Volt

kW……………………………. Kilo watt

kWh……………………………Kilo Watt Hour

m^2 ……………………………. Meter Square

MPPT…………………………Maximum Power Point Tracking

MW……………………………Megawatt

MWh…………………………. Megawatt hour

NASA…………………………National Aeronautics and Space Administration

NMA …………………………National Metrology Agency

NOCT…………………………Nominal Operating Cell Temperature

NPC…………………………...Net Present Cost

^oC……………………………. Degree Celsius

P_{loss} ………………………….. Power Loss of the Transmission Line

PV……………………………. Photovoltaic

R_{TL}……………………………Resistance of the Transmission Line

SAIDI…………………………System Average Interruption Duration Index

SAIFI………………………. ...System Average Interruption Frequency Index

STC……………………………Standard Test Condition

UTC…………………………...Coordinated Universal Time

ABSTRACT

The traditional energy supply system includes the stages of generation, transmission, and distribution that are all directed towards the same goal of providing reliable, affordable energy to the end-users, thus minimizing the occurrence of power outages and damage to devices. Ethiopia is implementing industrial parks to boost its economy, despite facing challenges such as demand increment, system overload faults, and interruptions due to inadequate nationwide electricity access. This thesis is a case study on the design and techno-economic opportunities of solar and wind energy (DG) to enhance power reliability to AIP as a grid-connected system. The analysis involved various methods, including site visits, interviews, questionnaires, and data from various offices. Solar and wind energy systems were identified, simulated, and optimized using PVsyst and HOMER Pro using the information provided by the National Metrology Agency. The study also evaluated the reliability of the existing system by using customer-side indices (SAIDI, SAIFI, CAIDI, and EENS) over three years. The overall base case AIP feeder SAIFI =178 interruptions/customer/year, SAIDI =319 hours/customer/year, CAIDI = 1.8Hrs./customer interruption, ASAI =96.34%, and ASUI =3.66% which was greater than the standard of Ethiopian Electric Agency (EEAs) per SAIFI =20 and SAIDI 25. Therefore, the reliability of this base case needs to be further improved. At the time of the establishment of AIP, the company requested a total of 48.63 MW from Ethiopian power, but only one feeder was allocated for 9 MW. After one year, another 9 MW feeder was added to the previous one, and Sunshine Wool Textile PLC and Kingdom Ethiopia Linen PLC were allowed to operate separately through this feeder. In addition to the feeder, however, a power interruption has taken place. Conversely, if we produce at capacity, then the techno-economics of this generation will be approximately the same as if we were only to produce 100% of 48.63 MW with no place for solar or wind energy being able to provide 48.63 MW. The PVsyst simulation indicates that for a grid-connected 10 MW polycrystalline solar power plant, 1634 strings of 18 modules each in series will be required to achieve a total area of 57,070 m² (29,412 modules total). As for a wind farm, a 15 MW wind farm is designed as ten separate 1.5 MW units. The preferred hub height of approximately 70 meters gives an acceptable balance between the energy production and the costs of the tower and foundation. The wind speed at this height is about 7.08 m/s. The techno-economic analysis applied at 100% full capacity of 48.63 MW would imply that there would be no place where solar/wind could produce that 48.63 MW. The PVsyst simulation predicted that a 10 MW polycrystalline grid-connected photovoltaic (PV) plant would be made up of 1,634 strings with 18 origin units in series. The 10 MW photovoltaic system will consist of 29,412 solar panels and will cover approximately 57,070 square meters for the installation of the panels. The layout of the 15 MW wind park comprises 10 turbines of 1.5 MW each. A height of 70 meters is suggested as a compromise between power generation and the costs of the foundation and tower construction. A height of 70 meters is proposed as a middle ground between power production and the expenses of the supporting structure and tower construction. Wind speed at 70 meters is estimated to be approximately 7.08 m/s. A particular solar PV was selected using HOMER, based on the local solar radiation to create a workable result. A favorable assessment of the wind energy potential was also made. HOMER has determined the optimal system to comprise a new photovoltaic array of 10000 kW and 10 wind turbines of 1500 kW each. The optimization results for the hybrid power model with a grid-connected. For this grid-connected system, the cost of energy (COE) obtained the result of $0.0379, and the percentage of renewable energy contribution is 96.2%. The net present cost (NPC) is $64.6M. The summary of the Economic analysis indicates that the Internal rate of return of the project stands at 8.7, and the Internal Return on the investment is 5.9. The simple payback period consists of 10 years, and the discounted payback period consists of 9 years. DG integrates into the AIP feeder, resulting in simulation values of the reliability indices SAIFI, SAIDI, and ENS, which are 5.22 interruptions per customer per year, 8.55 hours per customer per year, and 155.9 MWh/year, respectively. As a result of the presence of DG, the reliability indices SAIFI, SAIDI, and ENS are reduced by 97.11%, 97.33%, and 97.33%, respectively. Based on the results of the study, DG integration effectively improves the reliability of the AIP feeders.

Keywords: Wind energy, Ethiopia, AIP, HOMER Pro, PVsyst, Solar

CHAPTER ONE

1. INTRODUCTION

1.1 Background

The general arrangement of energy provision involves the steps of generation, distribution, and then transmission to the final consumers. Power plants can generate between 11 and 25 kilovolts of electricity. This voltage is then raised by step-up transformers to the necessary level for main transmission. Substations form connections between different parts, like transformers and lines, and these parts do the switching. A transmission facility operates with voltages of between 66kV and 400kV (or greater) and can move a significant amount of power in excess of 220kV from generation plants to high load centers through cables that operate at those voltages. A number of voltages used in the transmission networks in the UK are 275kV and 400kV, whilst many transmission networks within the United States have voltages of 345kV, 500kV, or in some instances, even 765kV. Super grids are those networks that operate at extremely high voltage levels. A sub-transmission network that operates at 132 kV or lower is then fed by this grid. In Ethiopia, networks operate at 400 kV, 230 kV, 132 kV, 66 kV, and 45 kV high voltage transmissions. On the other hand, there are 33 kV and 15 kV for medium voltage distribution providing supply to consumer services at 380 volts in three phases, being it at 220 volts per phase. [1]

The main goal of any power company is to generate energy that is reliable and cost-effective for customers. Careful planning & reliable supply of electricity will help subscribers avoid high costs associated with power outages. One of the main components in achieving this is the development & implementation of a distribution system that will operate in the most efficient manner and have the least impact on subscribers & their associated loads.[2] The need for reliable power system operation is seen as one of the highest priorities in the electrical systems industry and is especially critical in the distribution sector of the electrical system. When reliability is low, results can include an increase in blackouts, power outages, reduced efficiency of appliances, burnt out light bulbs, and damage to electrical and/or electronic equipment. System security and adequacy are two categories of reliability. When there is adequate generation of electric power, sufficiency is related to meeting consumer demand. Security refers to the power system's capacity to respond to transients and instabilities that arise in the system.[3] having a reliable supply of electricity is essential for the operation of any firm. In most developing countries, however, electricity supply is highly not reliable.[4]

In general, if a system or piece of equipment operates without failure during service time, it is considered to be performing well. Reliability assessment is the most important factor in designing and planning distribution systems that should operate economically with minimal interruption of customer loads.

There are several ways to evaluate a power distribution network's reliability. The most often used metrics in the literature are an expected outage cost (ECOST), expected energy not supplied (EENS), system average interruption frequency index (SAIFI), and system average interruption duration index (SAIDI).[5]

Distributed Generators (DG) utilizing environmentally friendly energy sources, like wind, small hydro, and solar became a serious part of future smart grid/ micro grid concepts. These energy sources meet both the increasing demand for electrical power and environmental regulations. Photovoltaic energy is one of the foremost popular renewable sources since it is clean, inexhaustible requires little main tenancy, and is distributed throughout the world. Normally DG is a small-sized active power generator of 1 kW to 100 MW that's connected at the distribution level. [6] Distributed Generation (DG) is likely to be very important in the electricity system for homes, businesses, and factories. Nowadays, the distributed generation (DG) is connected to the distribution system; many issues may cause technical impacts on the distribution system. Reliability is one of the problems that is interesting based on studies and research papers related to this subject. therefore, in the study area more solar energy and wind energy.

This research mainly focuses on the power reliability improvement of the distribution system of Adama Industrial Park, integrating distributed generation.

1.2 Statement of the Problem

The primary issue electric power utilities in developing countries currently face is a rapid increase in demand for electricity. Component outages in distribution systems are the root cause of many faults that interrupt end customers' supply. In Ethiopia, power reliability is a major issue. Since Adama is the preferred location for a few of the industrial parks in Ethiopia, a considerable share of the electrical power supply is directed towards the town. Due to this fact, Adama Industrial Park has been another load center of Ethiopian electric power. In the study area, distribution system problems account for most interruption issues. The power interruptions and instability become serious problems in the case study area. Therefore, it is necessary to improve the distribution networks' reliability.

Currently, the maximum consumption of electricity at Adama Industrial Park (AIP) is 18.5132MW.[7] the park's electricity usage is much below the anticipated level due to a number of factors, and it is not operating at full capacity. Power consumption at the park has been drastically lower, yet there are still almost daily power cuts. Being an industry park with continuous operation planned for it, the situation is such that the grid power supply is inadequate and, therefore, diesel engines are used. The frequent use of diesel generators to fill the power gap at AIP could create a problem as they are in direct contradiction to the eco-industry's philosophy. One option would be to find out the exact amount of power needed by the park and build a grid-connected renewable power station accordingly. Industrial parks due to the variety of difficulties in accurately analyzing the input parameters for the particular site location can serve as a fundamental focal point for this topic's analysis. This paper aims to address this gap by designing solar and wind energy-based power plants for AIP and also exploring potentials for improving the power reliability of the system.

1.3 Objective

1.3.1 General Objective

The main objective of this study is to design a cost-effective and environmentally friendly DG for Adama Industrial Park with the aim of improving the power reliability of the power supply.

1.3.2 Specific Objective

The specific goals of this investigation were to:

- Collect current load data, interruption data, and relevant power ratings of the distribution substation.
- Evaluate the data to see the level of power reliability and also the power needs of the site.
- Identify major causes and effects of the power interruptions.
- Evaluate the reliability indices of the Adama Industrial Park.
- Design and correctly size DG to improve the power reliability of the system.
- Evaluate the techno-economic performance of the DG using Homer Pro software.
- Draw relevant conclusions and recommendations from the result of the investigation.

1.4 Scope of the Research

This research covers studying the current power system reliability problems of the Adama Industrial Park, their causes, and the improvements gained by the design of the available size of distributed generators at the present Adama Industrial Park. The resources of solar design and sizing results are shown using the PV SYST V7.3 simulation, as well as the wind design of the ETAP model. Homer Pro also simulates the techno-economic of DG.

1.5 Significance of the Study

This research is expected to have the following benefits:

- Show concrete data and research ways of reducing the poor reliability of the power supply.
- Provide the Adama industrial parks with a full research report that contains the design, optimization, and techno-economics results of grid-connected distributed generation (solar and wind energy) for further implementation.

1.6 Methodology

The methodology of this thesis starts with the problem identification and reading helpful literature. The problem identification is the first step towards solving the site problem. The study goes through a literature survey on power reliability improvement through distribution generation integrations and comes up with ideas for mitigating the problems.

The following methodology is followed to achieve the objectives of this thesis:

1. Site Selection

Adama Industrial Park is selected as a case study area where power interruption problems are highly pronounced. It is also well known that energy resources and space are available at that site for wind and solar energy to improve power reliability.

2. Literature reviews

In this thesis, the literature from several journal articles, reports, simulation tools, conference papers, and books on power reliability improvement and study have been reviewed.

The literatures comprise reviews of: -

❖ From the past and recent published and unpublished documents regarding the theoretical background of power systems, reliability analysis, role of protection system, and DG benefits in distribution systems and

- ❖ Power reliability improvement through DG-related works on electric power distribution systems.

3. **Data Collection and Analysis**
   - ❖ Site visit and observations
   - ❖ Technical data collection from the site office
   - ❖ Gather relevant data from the Awashe Melkasa substation and Adama Industrial Park and check the data collected.
   - ❖ Assess power reliability indices and compare them with the international standards to identify the level of power reliability gaps.
4. **Design and simulation**

The design and modification of the suggested system are simulated by Pvsyst and Dig Silent Software. Also, Dig Silent/Power Factory software is used to simulate the size and magnitude of DG and feed it to the main grid as a standby in order to improve reliability in the base case. Homer Software's simulation of DG's optimization and techno-economics.

1.7 Outline of the Research

The thesis is structured as follows;

Chapter 1 presents the introduction of a thesis, background, problem statements, objectives, and motivation for DG integration and finally, it presents some reviewed publications on DG. **Chapter 2** describes the basics of distributed generation (DG), different types of distribution technologies, beneficiaries of DG, applications of DGs, and impacts of DGs on overall power systems.

Chapter 3 presents the interruption duration and frequency data of the AIP feeder, collected from Awash II Distribution Substation, as well as the Power Demand and Supply Status data of AIP.

Chapter 4 presents the design of the research area, the DG size, and simulation results, all of which are tailored to the thesis's objectives. The system's economic feasibility will also be assessed to confirm any prospective financial benefits.

Chapter 5 describes the results, the recommendations, and future projects of the study.

CHAPTER TWO
2. THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

The system becomes more available and more reliable when DG is integrated into the distribution system. Improper location and sizing of DGs in distribution networks can also lead to increased system complexity and coordination issues with the protection system. One new power system trend being employed to meet the rising energy demand is distributed generation.

DG is the strategic deployment of modest generating at or close to utility customers' homes across the electricity utility service area, connected to the distribution or sub-transmission system to reduce service costs.

This chapter focused on a review of different literature related to the improvement of reliability through the integration of DG. Research done in this area of power system reliability analysis or reliability improvement using distributed generation and reliability analysis methods has been discussed.

2.2 Electrical Power Systems

An electric power system consists of a network of interconnected processes that produce, transmit, and distribute electrical energy to end users, including residential, commercial, institutional, and industrial consumers. The distribution system relays power between the transmission system and the end-user facilities. At substations, where the distribution and transmission systems are connected, transmitted power is stepped down to the utility voltage level before being delivered.[8]

The main components of an electrical power system are [9]

- Generation system
- Transmission system and
- Distribution system.

Generation System

Electro-mechanical conversion systems transform mechanical energy into electrical energy to create electricity. The mechanical energy is typically supplied by heat energy or the force of flowing water. More non-fossil fuels, such as wind, solar, tidal, geothermal, and biogas, are being utilized to produce electricity. Hydropower is the most popular non-thermal mechanical energy source for generating electricity. Synchronous generators are used in the majority of power plants to transform mechanical energy into electrical energy. In wind power systems, induction generators are rarely used. In the generation system, electricity is typically produced at a low voltage, between 11 and 35 kV.

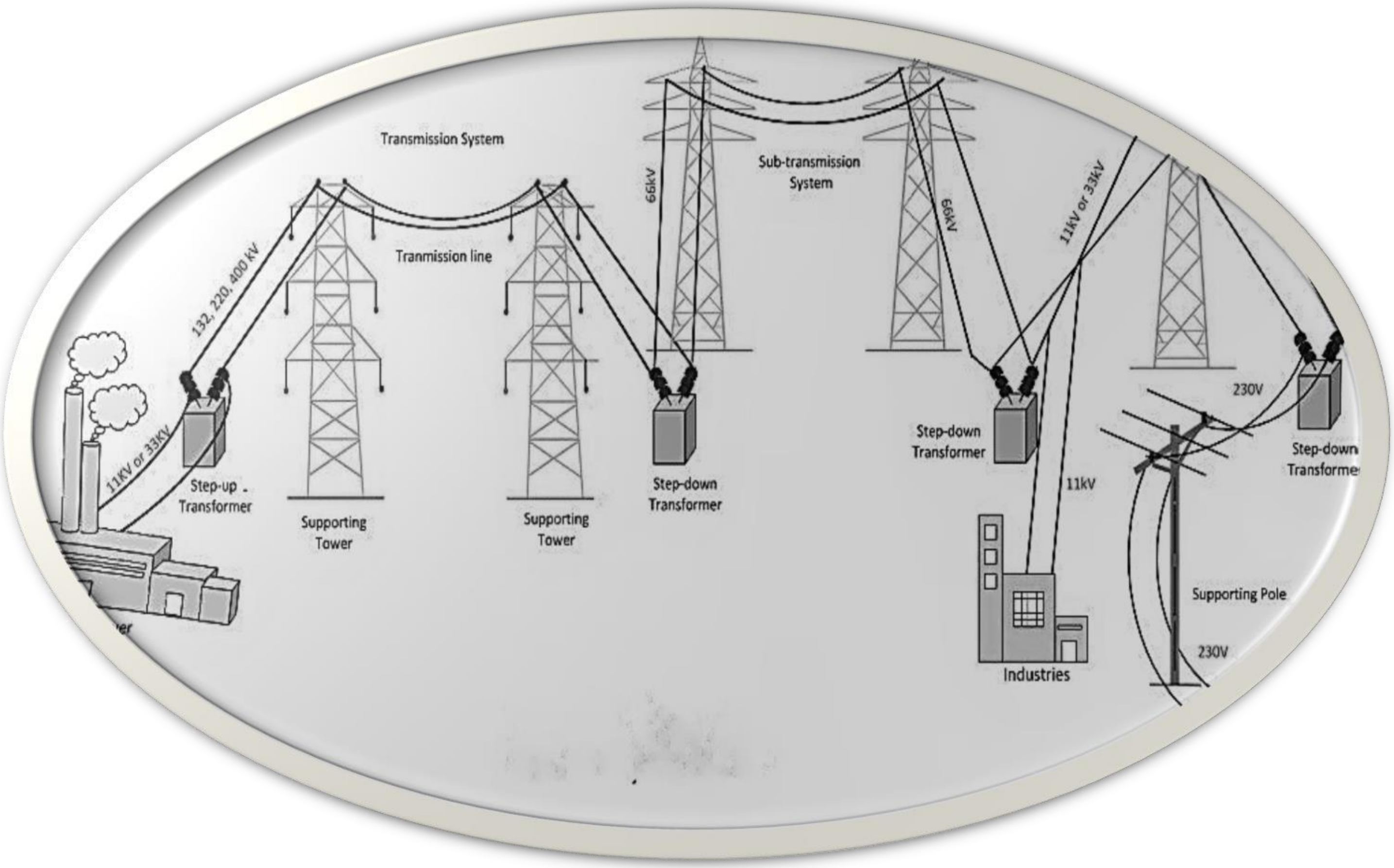


Figure 2- 1 Power System Structure

Transmission System

In generating stations, energy is produced in large quantities and subsequently transported across great distances to load or demand sites. All of the system's producing units and significant load centers are connected via the transmission system. It serves as the power system's structural core.

Transmission lines function at the greatest voltage levels, typically 275 kV and beyond, since the power loss in a transmission line is proportional to the square of line current ($P_{loss} = R_{TL}|I|^2$). To give several options for the electricity to get from the generators to the load locations, transmission networks often include a mesh structure. The system's reliability is increased as a result. Substations are where high voltage (HV) transmission cables arrive at terminate. These substations may supply power directly to huge industrial users. Here, the voltage gets reduced before feeding into the sub-transmission network. Basically, the voltage is lowered before it goes to the next grid. Step-down transformers hook up the high-voltage place to the distribution place. Usually, the voltage for this part is around 66–132 kV. The sub-transmission system may provide direct service to a few large industrial consumers. A grid is created by connecting nearby electricity systems at transmission levels through transmission lines. The grid is made up of various levels of the transmission network and several producing resources.

Distribution System

As shown in Fig. 2.2, the distribution is the last phase of power transfer to each consumer. In most cases, the distribution network has radial connections. 11 kV to 33 kV is the typical range of the distribution voltage. Primary feeders provide small industrial clients at this voltage level. The secondary distribution feeders supply 415/240V supplies for residential and commercial properties. It is common for small generating facilities near load centers to be directly connected to the distribution or sub-transmission system.

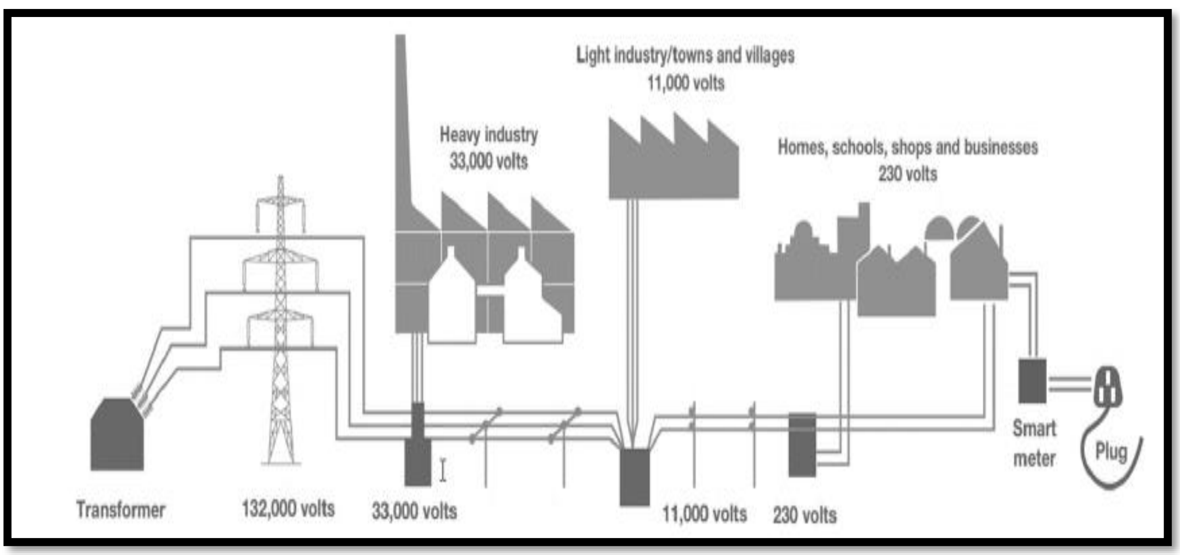


Figure 2- 2 Typical Distribution System Structure

2.3 Electrical Power System Reliability Analysis

An electric power system is intended to address system load requirements, as well as to provide a reasonable degree of continuity and quality assurance. Reliability is usually defined as the capacity of a system to supply a sufficient amount of electrical energy. Power system reliability is a very wide notion that encompasses all elements of the system's capacity to meet customer demands.[10]

The issue may be reasonably divided into "system reliability" categories, as seen below.[11]

Adequacy: is typically defined as the system's capacity to supply sufficient facilities to satisfy customer demand. These facilities encompass those facilities that are needed to produce adequate amounts of energy, and the transmission and distribution networks that are needed to convey the energy to the final points of customer loads. Adequacy is thus considered to be related to the conditions that are still, without any interruptions in the system states. Security: It is believed to have something to do with the capability of the system to react to internal upheavals.

Security: therefore, is concerned with the response of the system towards any interruptions. These are thought to incorporate instances that will influence the system both locally and globally and the loss of valuable transmission and generation.

2.4 Electrical Power Distribution System Reliability Analysis

The main factor that can be used to improve consumer reliability is the enhancement of distribution reliability as it can contribute to approximately 90% of all the customer reliability problems.[12] Consequently, the reliability of distribution stands as an important issue in the electric power sector, significantly affecting electricity costs and closely dependent on customer satisfaction levels.

2.5 Reliability Evaluation Methods

There are two methods such as analytical and simulation. This is primarily explained by the fact that although analytical models and techniques have proven to be adequate to give the planners and designers the data needed to make objective decisions, simulation normally takes time during processing. This is starting to shift and there is increased interest in a more detailed modeling of the behavior of the system. This means that the Monte Carlo simulation should be considered.[11]

2.5.1 Analytical Method

The mathematical models overcome the problem of dependability by performing analytical methods. Depending on the given input data and system structure, particular results are obtained in the computation. Block diagrams, event trees, fault trees, cut sets, state enumeration, and Markov modeling are some of the more common methods used. In recent times, it has been proposed that reliability sets can be used in calculations. Their common problem is that they will always have to make estimates and simplify their assumptions.[13]

2.5.1.1 Series Structure

A radial system consists of a number of series components, including transformers, breakers, lines, switches, and end-customers. A chain of being is not any stronger than its part; it applies to the series structure in that both components must be intact in order to be able to operate the system, in the parallel structure, both components must fail in order to be able to stop operating the system. Figure 2.3 in this case indicates that all the parts are series-linked, and the following equations are necessary to calculate the fundamental indices:[14]

Figure 2- 3 Series Structure (System) For Two Components

- The expected failure rate of the system, λ_s (fr/yr)

$$\lambda_s = \lambda_1 + \lambda_2 + \lambda_3 + \cdots = \sum_{i=1}^{\infty} \lambda_i \qquad (Eq.no.\ 2.1)$$

- The average outage time the system, r_s (hr)

$$r_s = \frac{\lambda_1 r_1 + \lambda_2 r_2 + \lambda_1 r_1 \lambda_2 r_2}{\lambda_1 + \lambda_2 + \lambda_3 + \cdots \lambda_i} \qquad (Eq.no.\ 2.2)$$

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

$$r_s = \frac{\sum_{i=1}^{\infty} \lambda_i r_i}{\sum_{i=1}^{\infty} \lambda_i} = \frac{U_s}{\lambda_s} \qquad (Eq.\ no.\ 2.3)$$

- The average annual outage time of the system, U_s (Hr/yr)

$$U_s = \lambda_s * r_s \qquad (Eq.no. 2.4)$$

Where, λ_i = is the failure rate at node i

r_i = is the outage time at node i

2.5.1.2 Parallel Structure

As seen in Figure 2.4, the failure modes of the load point in a parallel system include overlapping outages, meaning that to interrupt a load point, two or more components must be out of service simultaneously. Since it is expected that the failures are independent and that restoration calls for either replacement or repair, the following formula were employed to calculate the overlapping outage indices.[14]

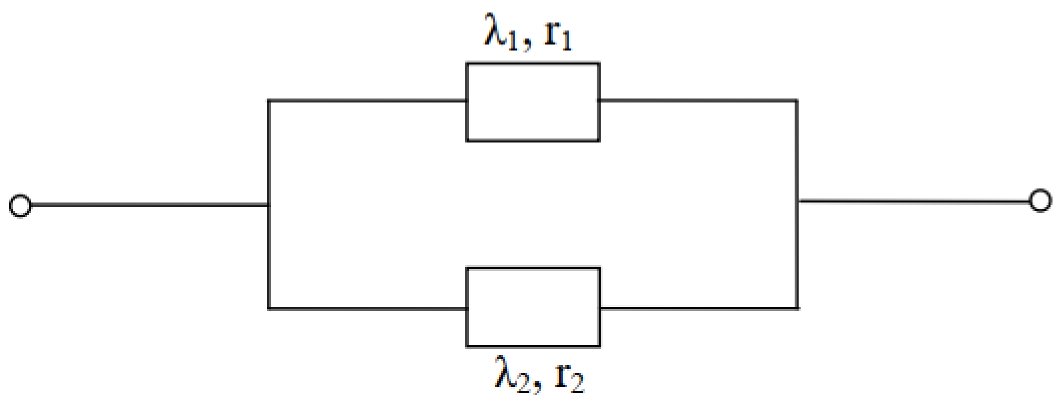


Figure 2- 4 Parallel Structure (System) For Two Components

The calculations involved in the parallel system shown in Figure 2.4 above are given in the equations

- Average failure rate of the system, λ_s

$$\lambda_s = \frac{\lambda_1 * \lambda_2(r_1 + r_2)}{1 + \lambda_1 * r_1 + \lambda_2 * r_2} \qquad (Eq. no.\ 2.5)$$

But $\lambda_1 * r_1\ and\ \lambda_2 * r_2 \ll 1\ \lambda_s = \lambda_1 * \lambda_2(r_1 + r_2)$

- Average annual outage time of the system U_s,

$$U_s = \frac{r_1\lambda_1 r_2\lambda_2}{(1 + r_1\lambda_1)(1 + r_2\lambda_2)} = r_1\lambda_1 r_2\lambda_2 \qquad (Eq. no.\ 2.6)$$

- Average outage time of the system r_s,

$$r_s = \frac{u_s}{\lambda_s} = \frac{r_1\lambda_1 r_2\lambda_2}{\lambda_1 * \lambda_2(r_1 + r_2)} = \frac{r_1 * r_2}{r_1 + r_2} \qquad (Eq. no.\ 2.7)$$

2.5.1.3 Markov model

A Markov model is quite popular in quantitative reliability analysis, and that is suitable to give a fair idea about the reliability analysis principle. Based on Markov models, a simple formula can be developed that can be used to calculate the reliability of the radial distribution network[14]

- Failure frequency (λ)
- Repair time (r)

Markov Modeling is employed to analyze the maintain ability, availability, and dependability of networks. A system is made up of several units that can be in a state of failure or operation at any given time. The failure or success rates of individual units determine how well the system functions as a whole. The system may thus be either in one of two states: The condition in which the system is operating at even though it has a failure unit or units.

- A system is said to have the opportunity fully operational when every system unit operates properly.
- A failed state occurs when one or more failure units cause the system to malfunction.

This kind of model ensures an obvious representation of all system states and the transition between them. Its primary drawback, though, is how challenging it is to draw a diagram for a big power system with numerous components. The current number of states equals 2^n when there are n units in existence.[15]

2.5.2 Numerical or Monte Carlo Simulation

Monte Carlo simulation makes use of random number generators to imitate the occurrence of random events. Thus, two Monte Carlo simulations with identical inputs will usually yield different outputs. Repeated simulations will ultimately yield a range of outcomes from which the variance, mean, and other statistical measures can be calculated; hence, this volatility is usually welcomed. When a Monte Carlo simulation is used to evaluate the dependability of a distribution system, it usually examines system behavior over a predetermined amount of time (like a year). usually, several simulations are required because every simulation will yield unique findings.

A Monte Carlo simulation provides many benefits over an analytical simulation. One is that a Monte Carlo simulation can yield a distribution of potential outcomes in addition to the anticipated value. An additional benefit is the simplicity with which component parameters may be modeled as random variables with probability distribution functions instead of constant values. Additionally, complicated system behavior, including nonexclusive events, cascade failures, conditional probability, and so on, is easier to represent with a Monte Carlo simulation. An analytical simulation has disadvantages in comparison to those of a Monte Carlo simulation. Computational intensity is likely to be the most significant one. Generally, hundreds of random years need to be simulated by a Monte Carlo simulation, whereas only one of the predicted years needs to be modeled by an analytical simulation. Another weakness is imprecision. Even with such a large number of simulations, Years later, somewhat different results of repeated Monte Carlo simulations will still be reached. It is more difficult to compute gradients, conduct sensitivity assessments, and assess the effects of little changes on big systems due to this lack of accuracy. Sequential and non-sequential Monte Carlo simulations are the two primary types.[12]

2.6 Distribution System Reliability Indices

Statistics that aggregate reliability data for a certain group of loads, components, or customers are called reliability indices. Most of the reliability indices are means of some measure of dependability of the entire system, operating area, feeder, or substation service territory. The relevant definitions of the indexes of reliability presented are based on the recently approved IEEE trial usage guide P1366, also. Despite the fact that utilities in general have not adopted this standard, it provides a document that can be applied to assess various utility operations.[12]

The underlying objective of a distribution system is to supply electrical energy at the customer load points with the help of a substation. In distribution system reliability tests, three basic load point indices are normally employed to measure load point reliability. These are the average outage duration, average failure rate, and average outage duration per year.[16]

2.6.1 Customer-Oriented Indices

For a continual interruption, the System Average Interruption Duration Index (SAIDI) is the most frequently used performance metric. For a specific time period, this index calculates the average customer's total interruption duration. Though it can be computed daily or for any other time period, SAIDI is typically computed on a monthly or annual basis.

Every interruption that occurs during the period is multiplied by its duration to determine the customer minutes of interruption, which is how SAIDI is calculated. The total customer minutes is then calculated by adding the customer minutes from each interruption. In order to find the by the following formula,

1. System Average Interruption Duration Index (SAIDI)

$$SAIDI = \frac{Sum\ of\ all\ customer\ interruption\ duration}{Total\ number\ of\ customers\ served} = \sum \frac{(U_i N_I)}{NT} \qquad (Eq.no.\ 2.8)$$

2. System Average Interruption Frequency Index (SAIFI)

The index of the frequency of interruptions to the functions of the system is known as the System Average Interruption Frequency Index (SAIFI), which indicates the average number of service interruptions a customer of the system will encounter through one year of system operation or study period.

$$SAIFI = \frac{total\ number\ of\ customer\ interruptions}{Total\ number\ of\ customers\ served} = \frac{\sum_i \lambda_i N_i}{\sum_i N_i} \qquad (Eq.no.\ 2.9)$$

3. Customer Average Interruption Duration Index (CAIDI)

It is the average time when restore service to the average customer after a long failure occurs. Then it is the sum of customer interruptions divided by the sum of interruption time.

$$CAIDI = \frac{Sum\ of\ customer\ interruption\ durations}{Total\ number\ of\ customers\ interruptions} = \frac{\sum_i U_i N_i}{\sum_i \lambda_i N_i} = \frac{SAIDI}{SAIFI} \qquad (Eq.no.\ 2.10)$$

where Ni is the total number of customers at load point i, and Ui is the annual outage time at load point i.

4. Customer Average Interruption Frequency Index (CAIFI)

The average annual number of interruptions per customer is measured by the CAIFI. It is simply calculated by dividing the total number of interruptions by the number of customers impacted.

CAIFI = Total number of sustained interruptions in a year per total number of consumers affected or

$$CAIFI = \frac{Total\ number\ of\ customer\ interruptions}{Total\ number\ of\ customers\ affected} = \frac{\sum_i N_o}{\sum_i N_i} \qquad (Eq.no.\ 2.11)$$

5. **Average Service Availability Index (ASAI):** It shows the percentage of a customer's time that power is supplied over the duration of a year or the specified reporting period.

$$ASAI = \frac{Customer\ hours\ of\ available\ service}{customer\ hours\ demanded} = \frac{\sum_i N_i * 8760 - \sum_i U_i N_i}{\sum_i N_i * 8760} \qquad (Eq.no.\ 2.12)$$

6. **Average Service Unavailability Index (ASUI)**: This index serves as the average service availability index's (ASAI) complementary value.

$$ASUI = 1 - ASAI = \frac{Customer\ hours\ of\ unavailable\ service}{customer\ hours\ demanded} \qquad (Eq.no.\ 2.13)$$

2.6.2 Load or Energy-Oriented Indices

1. Energy Not Supplied Index (ENS): The total energy that the system is unable to supply is represented by this index. Additionally, it is provided by

$$ENS = \sum_i L_{aver}\,(i)U_i$$

Where, $L_{aver}(i)$ is the average load given by:

$$L_a(i) = L_P(i) * L_F(i) = \frac{Ed(t)}{t}$$

L_P is peak load demand, L_F is the load factor, and Ed is the total energy demand in the period of interest.

2. Average Energy Not Supplied Index (AENS): The average amount of energy that the system does not supply is represented by this index.

$$AENS = \frac{Total\ energy\ not\ supplied}{Total\ number\ of\ customers\ served} = \frac{\sum_i L_a(i)U_i}{\sum_i N_i} \qquad (Eq.no.\ 2.14)$$

3. Average Customer Curtailment Index (ACCI): This index shows the total amount of energy that the system is unable to supply to each impacted customer.

$$ACCI = \frac{Total\ energy\ not\ supplied}{Total\ number\ of\ customers\ served} = \frac{\sum_i L_a(i)U_i}{\sum_i N_o} \qquad (Eq.no.\ 2.15)$$

Where: La (i) represents the average load, No represents the quantity of consumers impacted.

2.7 Reliability Cost and Worth

The cost of reliability is the amount of money required to reach a particular degree of sufficiency. The value that dependability adds to society, the utility, and consumers is the result of increased system investment and increased reliability. Fig. 2.5 can be used to show the reliability cost/worth notion. The graph illustrates how, in general, greater system costs correspond with higher investment costs for facilities and equipment that offer higher reliability. The combination of these two expenses is what society will pay. The best goal degree of dependability is shown by a minimum point on the resultant total cost curve. To determine this ideal position, a reliability worth/cost analysis is carried out.[17]

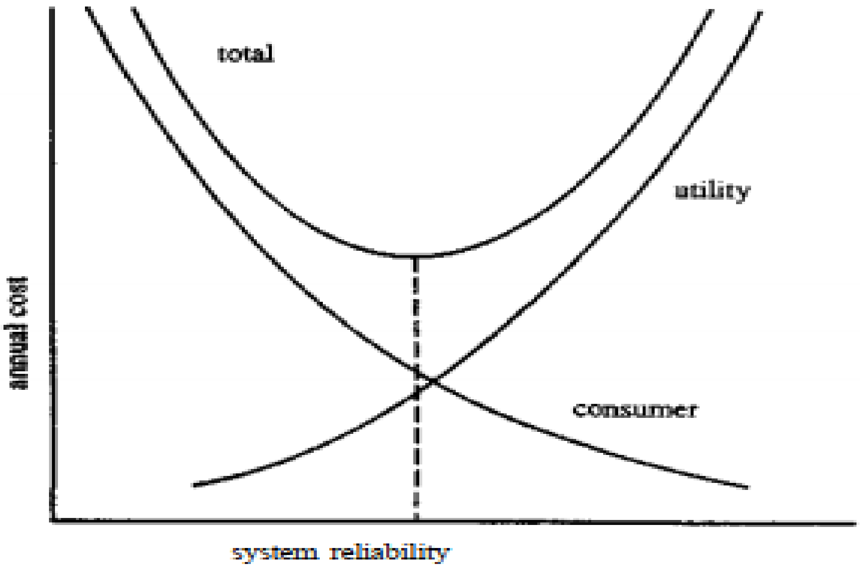


Figure 2- 5 Cost as Function of System Reliability

2.8 Distributed Generation (DG)

Distributed generation (DG) is when power is produced at a location near load centers using alternative resources, which produce the energy. It is connected to the utility grid system at the Point of Common Coupling (PCC) so as to restrict the growth of the existing electric transmission system. Because of the financial advantages, environmental concerns, need for dependability, etc., power systems are rapidly expanding in the field of distributed generation. DG utilization is expanding quickly at the distribution level in today's reorganized electricity system. This may be attributed to the evident benefits such as enhanced supply dependability, optimized voltage profile, and decreased transmission loss. With a few exceptions (biomass combustion), using renewable energy sources has become more important as it encourages sustainable living and does not pollute. Small-scale applications using renewable resources can be utilized in places where there are few large-scale generating plants, or big-scale applications when huge conversion systems are employed and the resource is abundant. In recent years, practitioners and scholars have given the problems with power quality a great deal of attention. Increasing the quality of delivered power has become crucial for electric companies in the modern era due to factors like more sensitive electrical devices, side effects of modern equipment, rising demand for high-quality electricity, producers' tendency to prioritize customer satisfaction, and consumers' ability to evaluate power qualities. There are several aspects of power quality, including voltage sag and swell, reliability, and long and brief interruptions.

Concern about voltage and frequency stability grows with the integration and utilization of Distributed Generation (DG) technologies, such as unpredictable renewable energy sources, which can optimize the penetration of green energy in the utility network. Furthermore, in poor utility network systems, voltage swings and distortions are also common. Voltage harmonics are produced by power electronics converter ripple currents, which may also affect utility voltage waveforms.[18]

2.8.1 Definition of Distributed Generation

DG usually refers to power generation equipment that is located near the load, about a few kilowatts to tens of megawatts, environmentally sound and efficient.[19] Several definitions are given by various organizations such as the US. DOE, EPRI, and IEEE for distributed generation.[20]

Definition by US Department of Energy (US DOE): Distributed generation - small, modular electricity generators sited close to the customer load can enable utilities to defer or eliminate costly investments in transmission and distribution (T&D) system upgrades, and provide customers with better quality, more reliable energy supplies and a cleaner environment.

Definition by Electric Power Research Institute (EPRI): EPRI's DG definition round around integrating distributed energy resources. It establishes that the new system would also be able to flawlessly integrate an array of locally installed, distributed power generation as power system assets. The energy information gateway is capable of having distributed power sources with a maximum capacity of 20 MW on both the supply and demand sides as important resources that can be efficiently dispatched, make good use of the existing capacity, and provide reliability. Moreover, according to another EPRI definition, the category of distributed resources encompasses not only small generation (1kW to 50MW) but also the full range of energy storage devices which are generally installed close to the bulk of consumers or at distribution and sub-transmission substations.

Definition by Institute of Electrical and Electronic Engineers (IEEE): IEEE's Standard for Interconnecting Distributed Resources with Electric Power Systems defines distributed generation as a part of distributed resources that consist of electric power generation facilities that are connected to an area EPS (electrical power system) through a point of common coupling. This implies a few other definitions. Facilities that supply electricity to a load, which may include generating units that serve local EPSs are known as EPS areas. Every Local EPS is completely contained within a single building or collection of buildings. The term "point of common coupling" refers to the location where a Local EPS is connected to the Area EPS. Lastly, distributed resources are electric power sources that are not directly connected to a bulk power transmission system, according to IEEE. and energy storage and generator technologies are part of the DR.

2.8.2 Benefit of DG in the Distribution System

The benefits of applying DG in the existing distribution system have an economic, technical, and environmental point of positive although benefits ultimately count in terms of money over the technical advantages. The benefits are in three groups: economic, technical, and environmental as shown in the following table.[21] [22]

Table 2- 1 The Benefit of Distributed Generation

Technical part	Economical part	Environmental part
• Active power loss reduction • Voltage profile improvement • Reliability and power quality Improvement. • Relieves transmission and Distribution congestion • Enhances system reliability and security.	• Reduces operation and maintenance costs • Optimal energy price. • Enhances productivity • Increases overall efficiency by reducing fuel costs. • Low operating costs due to peak shaving.	• Emission reduction. • Reduction in wastage generation. • Water use and discharge.

2.8.3 Types of DG Technologies

There is Various DG technologies have been used in power systems, and some of them have been used for a long time and some are newly emerging. the classification of DG technology see as follows figure.[23]

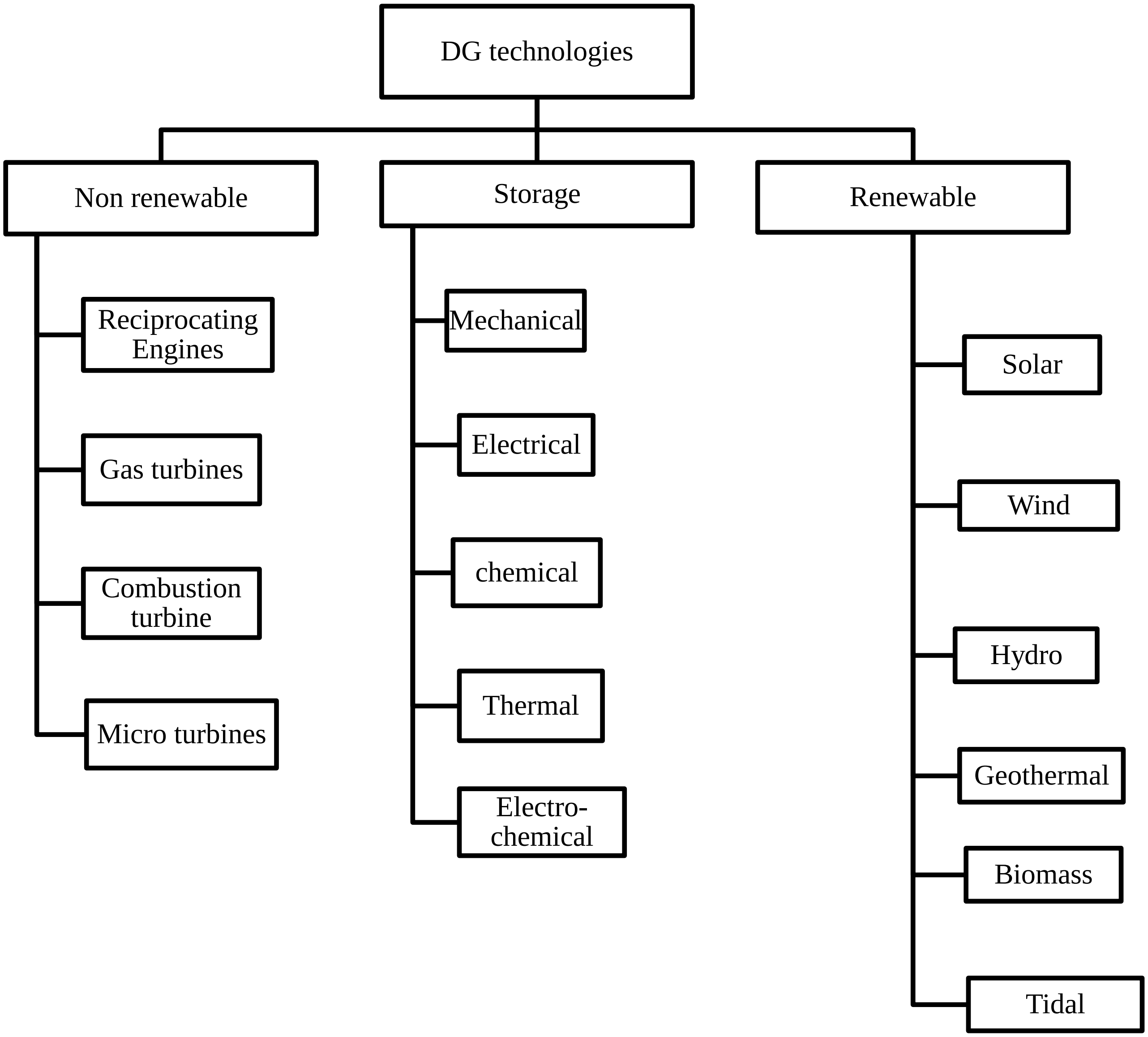


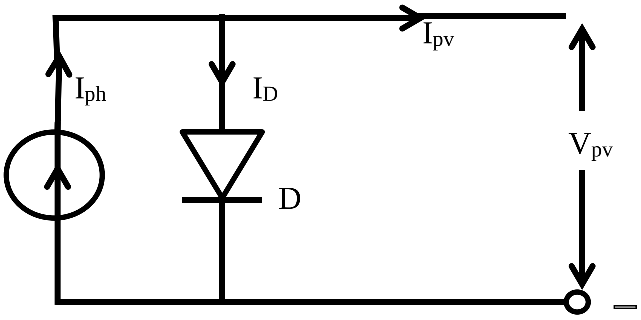
Figure 2- 6 Types of DG Technologies

This section discusses some of the present markets for DG technologies: photovoltaics, wind power, fuel cells, and microturbines.

2.8.3.1 Photovoltaic System

Photovoltaic System Solar photovoltaic technology is a method that utilizes the photovoltaic effect of a semiconductor material to directly turn solar energy into electrical energy. A photovoltaic generation system can be split into two categories: standalone photovoltaic systems and grid-connected photovoltaic systems.[24]

The PV technology requires the integration of semiconductor cells or wafers with the p-n diode at the top surface of each major area. The PV effect generates direct voltage and current when the light strikes the cell. In order to obtain sufficient voltage and current, a number of cells are combined and made into modules.[25]



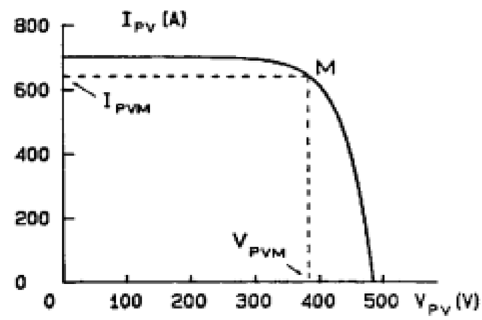


Figure 2- 7 PV Cell Equivalent Circuit and V-I Characteristic

The simplified equivalent circuit of Fig (a) is adequate for the representation of the PV cell. The output current is a function of solar radiation, temperature, wind speed, and coefficients particular to the cell technology. The form of I_{pv} as a function of the array output voltage V_{pv} (V-I characteristic of the array), is given in Fig. (b). When the array is operating at point M on the V-I characteristic, the maximum power output is achieved.

2.8.3.2 Wind Turbines

There is a vast array of designs for wind turbines that are based on the quantity of power they can generate or the pace at which they can produce it. The ideal range of wind speeds for wind turbine design is usually determined by the turbine's maximum output. It will be simpler to locate an appropriate wind turbine in areas with less harsh wind conditions. Wind turbine power is extremely erratic, hence production units or storage facilities managed by the balancing responsible party are usually required to maintain balancing.[26]

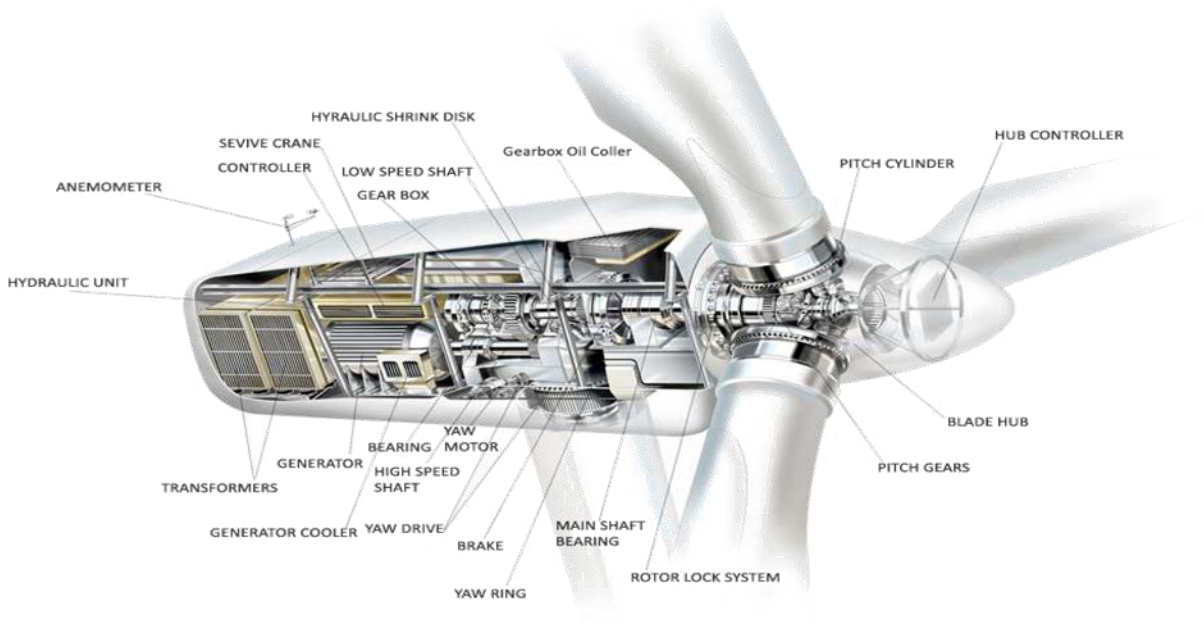


Figure 2- 8 Diagram of a Typical Wind Turbine [27]

Wind power produces energy using the air flows that naturally occur in the Earth's atmosphere. Wind passes through turbine blades, converts the wind energy into mechanical energy that moves an electricity generator. There are three major categories of wind turbines. Wind turbines may be classified into three main categories. These are

i. Utility-scale wind: These wind turbines can produce above 100 kW of energy. Usually, power systems operators or electric utilities provide and inject them into the electrical power grid.
ii. Distributed (or little) wind: These wind turbines have a capacity of less than 100 kW for producing power. Typically, they are not wired into the power system. Homes, small enterprises, farms, and other relevant end-use applications directly employ them.
iii. Offshore wind: Located largely on the continental shelf, these wind turbines are situated in vast bodies of water.

Because there are only a few locations where wind power may be generated economically, wind power potential differs by area. In addition to the overall average fluctuation in wind power observed at various locations, there is a significant amount of intermittency since the available power fluctuates dramatically with wind speed. There are disadvantages to wind energy. Since wind turbines have increased to nearly 80 meters above the ground, concerns among many individuals are on the beauty of the surrounding environment. Bird mortality and noise are a couple of other issues. However, by strategically placing the wind turbines, some of these worries can be avoided.[28]

Due to the declining fossil fuel reserves and the growing awareness of people about the necessity of creation of energy sources that would not harm the environment, wind energy became a subject of numerous researches. Wind power reached hydropower, solar, and geothermal energy in terms of sustainability metrics, which account for the lowest relative emissions of greenhouse gases, the least amount of water used, and the greatest positive social consequences. In 2022, the estimated total wind power capacity will be 906 GW, with an additional 77.6 GW expected. Approximately 36% of the built capacity of renewable energy would come from solar photovoltaic and wind energy, according to the Indian government's newly established 2030 target of 450 GW/yr.[29]

2.8.3.3 Fuel Cell

Fuel cells are electrochemical devices that, in a very clean and efficient manner, convert chemical energy coming from fuels into electrical energy. Thus, they provide an environmentally friendly power generation with a very small impact. The thermodynamic limits of heat engines, such as the Carnot efficiency, do not apply to fuel cells since they do not require the intermediary processes of heat production and mechanical labor that are typical of most traditional power-generating systems. Furthermore, fuel cells provide electricity with less pollution since combustion is avoided. Fuel cells require constant replenishment of oxidant and reductant to operate continuously, in contrast to batteries. There are several similarities between electrolyzers and fuel cells. Certain fuel cells may function as electrolyzers in reverse, producing reversible fuel cells that can store energy.[30]

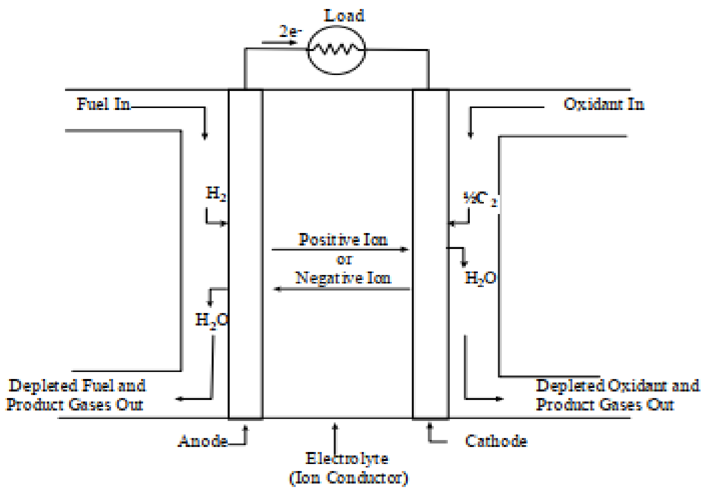


Figure 2- 9 Schematic of an Individual Fuel Cell

The anode, or negative electrode, of a fuel cell, receives fuel continually, while the cathode, or positive electrode, receives an oxidant, usually oxygen from the air, continuously. At the electrodes, electrochemical reactions produce a complementary electric current that transfers heat to the electrolyte and produces an electric current through the load. While a fuel cell and a standard battery have many similarities, they also differ in key areas. Fuel cells can be classified based on the type of electrolyte used and temperature. Here a general classification based on the type of electrolyte used is presented. Six different types of fuel cells are used for various applications, depending on their essential working nature. They are:[31]

Solid polymer electrolyte type fuel cells

They are also known as proton exchange membrane fuel cells or solid polymer electrolyte fuel cells. PEM fuel cells operate at relatively lower temperatures in the 50 o C to 100 o C range. The major desirable qualities of them are their low operating temperatures, large power densities, start-up versatility (flexibility), and high efficiencies, whereas their drawbacks are that they can not work without clean fuel, that cogeneration can only be used in lighting and water heating in chilly climates, and the kind of fuel cell they use is subject to carbon monoxide catalyst pollution.

Direct Methanol fuel cell (DMFC)

DMFCs employ polymer membrane electrolytes just like in PEM fuel cells. The input of liquid fuel as input by DMFC avoids the need for a fuel reformer. Controlling the flow of liquid fuel and catalyst poisoning are two of these kinds of limitations**.**

Phosphoric Acid fuel cell (PAFC): operating at higher temperatures roughly 200 ^{o}C because of which the waste heat they produce may be efficiently used for cogeneration, increasing their efficiency even more. Additionally, PAFC has a limited tolerance to carbon monoxide contamination; however, high operating temperatures may cause material breakdown and slow startup.

Alkaline-type fuel cell (AFC)

AFC is known for being used in space shuttles to generate power and create drinking water as a byproduct. Although they are prone to and against carbon contamination, they are capable of achieving high efficiencies, which makes them very likely to be used in non-terrestrial applications.

Molten Carbonate type fuel cell (MCFC)

MCFC operates at temperatures as high temperature of 650 ^{o}C, which allows the waste heat generated to be used for high-quality cogeneration. In addition to, the carbon monoxide serves as part of the fuel for the molten carbonate fuel cell, meaning that they are not affected by carbon monoxide contamination. The fact that the corrosive working environment reduces cell durability is a drawback.

Solid Oxide fuel cell (SOFC)

SOFCs operate at high temperatures, which qualifies them for fixed uses like big power plants. Waste heat can be utilized for internal fuel reforming, space heating, and water heating in cogeneration systems. The many kinds of fuel cells are summarized in Table 2.2.

Table 2- 2 Types of Fuel Cell

Features / ***Types***	Electrolyte	Operating Temperature	Catalyst	Fuel used	Efficiency	Application
PEMFC	Proton exchange membrane or solid polymer	50-100^{O} C	Platinum	Pure hydrogen	45%	Portable and stationary power, automotive
DMFC	Proton exchange membrane	50-90^{o} C	Platinum	CH_3OH	40%	Portable power, transportation
AFC	Potassium hydrogen (KOH)	100-200^{O}C	Platinum Ni/NiO_X	Pure hydrogen	50-65%	Space application, transportation, portable power

PAFC	Phosphoric acid	180-220^{O}C	Platinum	Pure hydrogen	~40% and ~85% with co*generation	Stationary power generation co-generation
MCFC	Potassium, Lithium and Sodium carbonates	~650^{O}C	Ni/LiNiO$_X$	H_{2}, CH_4, CO	50%-55% and ~85% with co-generation	Stationary power generation, cogeneration
SOFC	Solid oxide	600-1000^{O} C	Ni	H_{2}, CH_4, CO	50%-60% and 80-85% with co-generation	Stationary power, portable power, cogeneration

2.8.3.4 Micro Turbines

A microturbine is a machine that converts thermal energy to mechanical energy by passing gas through it. The fuel used in microturbines is usually a gas that has been pre-compressed by the compressor in order to occupy the combustion chamber of the microturbine. The turbine is made to rotate and the compressor and generator are also mounted on the same base as the turbine in the most standard construction of the micro turbine. This is seen in Figure 2.10.[32]

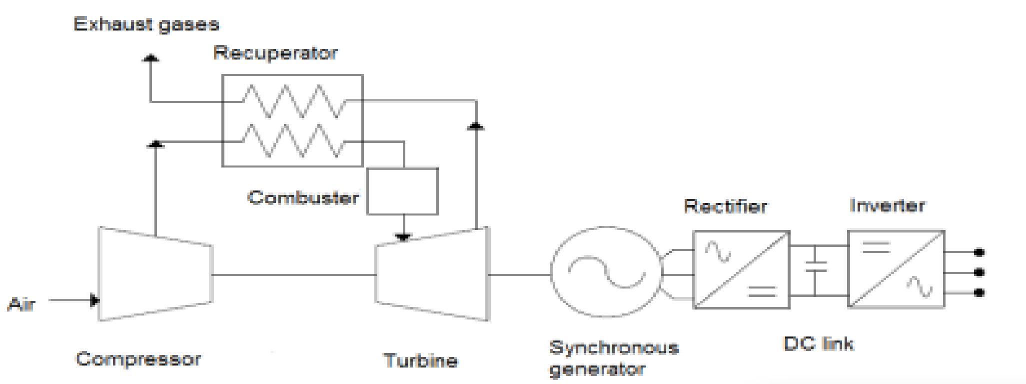


Figure 2- 10 Schematic Diagram of a Micro-Turbine

the output voltage of micro-turbines can only be converted to DC, then to AC, and vice versa, before being connected to the power grid or utility, which is the main advantage of micro-turbines in that they operate efficiently and emit low levels of pollution. But the disadvantage of it is the cost of maintenance and experience in this field. Rarely have micro-turbines been operating sufficiently long to generate a credible database in the field. Moreover, the means of distribution and management of numerous microturbines and the methods of selling the remaining energy have not been implemented to date.

2.9 Application of Distributed Generation

Due to weather-related problems, accidents, human mistakes, etc., the power system is vulnerable to failures and disruptions. The dependability of the power supply is guaranteed by having the DG as a backup source, which is essential for business and industry. There is room to increase the system's overall dependability. By employing switch operations, DG may be utilized to continuously supply parts of the load feeders. Distributed generation (DG) has an important application as a source of additional energy to feed back into the electrical power network during periods of peak usage, when demand exceeds supply. During these times, distributed generation (DG) can assist the main electric power grid in meeting customer service demands by providing additional energy to customers who are requesting energy above their normal consumption rates. With DG's help, load shedding can be prevented. [33] The DG can be used as a standby for consumers that cannot tolerate interruption of service e.g. hospitals. The DG can also be used as a stand-alone to supply power to customers that are not connected to the grid.

2.10 Impact of DG in Distribution System Reliability

The extent of the impact of Distributed Generation (DG) installations in the original radial distribution systems without any power generation on them greatly depends on the distribution system and the DG characteristics. Utility and customer voltage and power flow conditions may be affected by such an impact which can be either positive or negative. One method of impact assessment is to examine the behavior of an electric power system with and without DG. [34]Power system behavior with DG, has led to changed reliability parameters and power flow. The electric power generation through random placement in a network has three main impacts on distribution system reliability: increased reliability, financial gains, and reduced environmental pollutants. [35]The reliability of the power distribution system is a major issue during planning and operating. Reliability of a system is determined by utilizing reliability indices suggested by the IEEE guide such as SAIFI, SAIDI, CAIFI, CAIDI, ASAI, ASUI, ENS, etc. [36]

2.11 DG Integration in the Power System

For integration to be successful, DG must "coordinate" well with system design and operating procedures. This means that the workings of the transformer, grounding, output waveforms, protective relays, control processing, and other technical aspects must be similar to the functioning and distribution systems designs. In such a manner, unless good coordination is realized, at least, the value of the DR transmission and distribution support will be diminished. On the other hand, more undesirable effects are possible. Among these are: degradation of an electric power system's efficiency, power quality, and reliability. In practice, the worst case may see significant damage to customer loads and power system components as well as the creation of safety hazards. Thus, "negative" transmission and distribution support benefits may result from a poorly integrated DG.[37]

2.12 Literature Review

This section reviews different literature related to this thesis. Power reliability improvement by using distribution generation integration has been done by different researchers. Some of the works done in this area are summarized below.

K. IDOWU ET AL. This research uses a 3 MW distributed generator to enhance the reliability of the distribution network in Port Harcourt, Rivers State, Nigeria. The overall goal of the distributed generator plan is to improve general network performance that could offer reliable power that would satisfy customer demand.[38]

I.K. Tarsi, A. Sheikholeslami, T. Barforoushi, and S.M.B. SadatiIn this study, an analytical method for examining how distributed generation (DG) affects distribution network reliability is suggested. In our method, we have suggested a mathematical model that uses the duration and frequency methodology to assess the reliability indices. We have also examined the frequency and average duration of states using the islanding probability concept. In this regard, the likelihood of islanding in a distribution feeder with two DG units is considered.[39]

A. C. Neto and M. G. da Silva, in this research, the study of distributed generation (DG) to enhance the restoration capabilities of distribution networks; that is, DG may remove network restrictions (feeder loading or voltage drop) during the restoration process. As a result, during the indices linked to the restoration time, DG might enhance the reliability of network restrictions (voltage loss or feeder loading). A method for calculating the effect of DG on distribution network reliability indices is presented in this research. Given the fact that the DG can be linked with an isolated feeder (isolated operation) or a feeder with tie-lines (interconnected operation), this effect is considered.[40]

In this research, **G. Sengi and E. Ntagwirumugara** have modeled and evaluated a distributed generation (DG) system powered by solar energy as one way of alleviating the challenge of power reliability viability of the suggested solution has been evaluated by assessing the initial and life-cycle costs of the investment. The rate was conducted in an economic analysis through the unsold energy and electricity rate. The reliability indices are calculated, and each feeder's modeled solution is computed by PV Syst software. The mode is then simulated by ETAP, and the simulation results show that reliability can be improved up to 76%.[41]

Evtaleny Mauboy studied additional lithium-ion batteries as one of the possible methods for increasing the reliability of the power system associated with wind generation. This work will aid in the planning of battery storage systems and is expected to contribute significantly to enhancing the stability of wind energy generation with storage systems. The outcomes demonstrate the simulation system's increased stability when it comes to wind generation and battery use.[42]

Tefera Mekonnen Azerefegn, this research discusses the feasibility of integrating PV and wind power systems with the existing, unstable grid and diesel generator systems to supply essential loads for industrial parks located in three different areas of Ethiopia. The main highlight of the study was how to deliver a consistent supply of cost-effective, environmentally-friendly materials. Using HOMER Pro software, modeling and techno-economic analysis of grid-connected PV/wind/diesel systems were conducted by examining four distinct scenarios while accounting for unplanned outages. The data collected for the study included load fluctuation, grid interruption, and meteorological information specific to the study locations.[43]

Mekdes Paulos Mulat, the primary research question of this thesis is the techno-economic viability of the potential of Kombolcha Industrial Park (KIP) as an off-grid solar and wind energy facility through the case study framework. Using the gathered data as input, HOMER software was used to predict the solar and wind potential. Using HOMER, the economic and emission reduction aspects were also assessed. One of the best options of the technology mix was to generate the required 2.8 MW of electrical power by combining 69% (1.8 MW) of PV modules with 31% (1.0 MW) of wind turbines, with a cost of energy of USD 0.198/ kWh. However, this costs around USD 19 million. It has a much cheaper cost of USD 6.65 million is requires 2.8 MW using only PV modules with battery and a cost of energy of USD 0.07/kWh. There are V-shaped ceilings in each of the seven park shelters. Producing 24 tCO_2e in total estimated emissions annually.[44]

CHAPTER THREE

3. DATA COLLECTION AND ANALYSIS

3.1 Introduction

In this chapter distribution system reliability analysis requires interruption duration, interruption frequency, loads connected, total number of customers served, and so on. Therefore, this chapter presented the collected failure data and basic electrical data of power system equipment which are necessary for reliability analysis. These data are analyzed to identify the current reliability status of the AIP and to distinguish the main problems of interruption.

Here different types of collected data are analyzed. While analyzing data there are differences. Procedures are to be followed depending on the type of data collected.

3.2 Method of Data Collection

The data was collected by using Google Earth, metrological data, IPDC data regarding AIP, interviews for companies, and site visits of AIP. After the collection of data, the next step is analyzing the data using Excel.

The data gathering methods on the site are illustrated in Table 3.1. The Major sources of the data are Adama Industrial Park (AIP), National Metrology Agency of Ethiopia, (NMA), and Ethiopian Electric Power (EEP).

Table 3- 1 Procedures of Data Collection

Method of data collection		
1. Primary source	Qualitative data	Quantitative data
	▪ Interviews ▪ Observation ▪ Questionnaires	▪ Structured observation ▪ Analysis of existing statistics
2. Secondary source	Information or data collected from government offices	
Data collected from various officers		

Adama industrial park (AIP) visit	• For the AIP layout and rooftop area of the sheds • Site Observation • Power Demand and Supply Status in Adama Industrial Park • Questionnaire or Interview with the investors or companies residing there
National Metrology Agency (NMA)	Data inquiry of metrological data such as Solar radiation, Rainfall, and Wind sped for the Adama area.
Ethiopian Electric Power (EEP)	• Data for Awash II Distribution Substation • Power Interruption Data of Adama Industrial Park

3.3 Data for Awash II Distribution Substation

Table 3- 2 Awash II Substation Data

Name substation	Transformer Quantity	Voltage level (kV)	Capacity of Transformer (MVA)
Awashe II Substation	1	132/33/15	31.5
	1	132/15	25

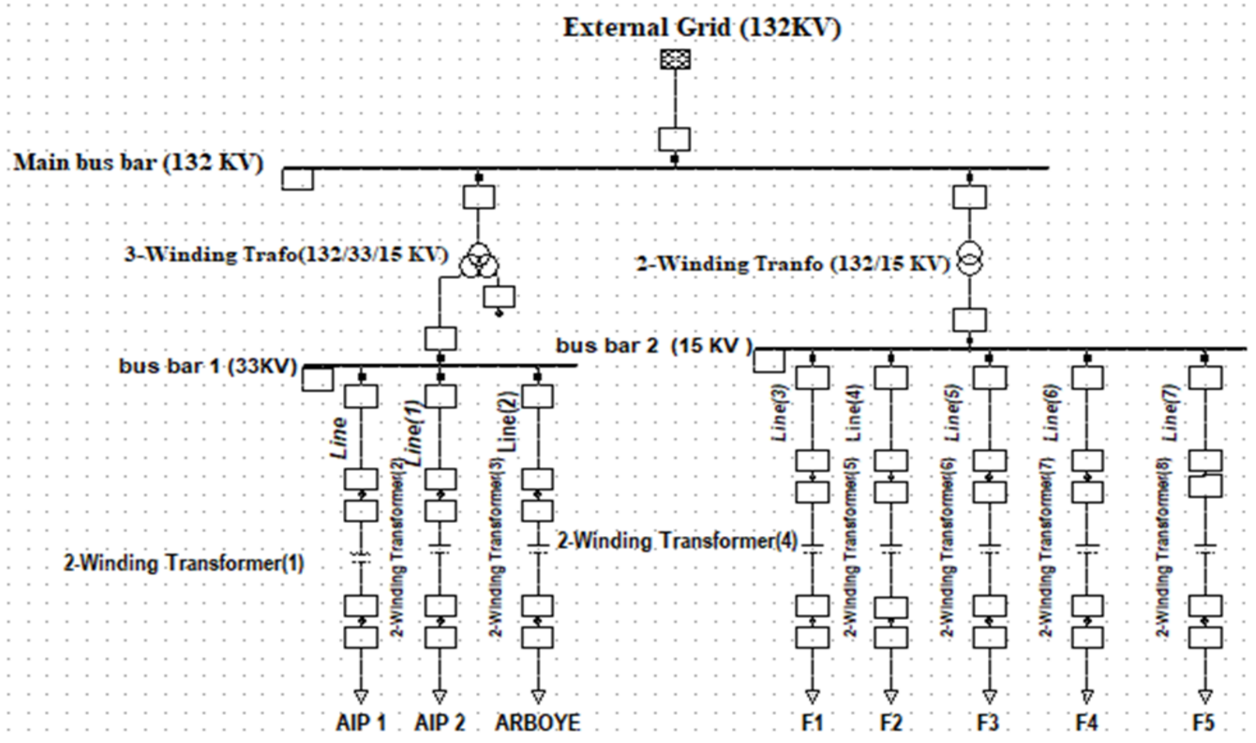


Figure 3- 1 One - Line Diagram of Awash II Distribution Substation

3.4 Power Demand and Supply Status in Adama Industrial Park

Table 3- 3 Power Demand and Supply Status in Adama Industrial Park

N		Name of Private IP Developer/ Investor	Requested power from EEP(MW)	Actual /used/ power (MW)	Plot of land in m^2
1	Feeder-2	Sunshine Wool Textile PLC	5	5.301	800,000
2		Kingdom Ethiopia Linen PLC	7	4.901	320,000
3	Feeder -1	Antex Textile PLC	12	3.074	61,000
4		Charter Ventures Apparel Ethiopia PLC	1.28	0	11,000
5		Eagle Pack Packaging PLC	1.3	0	11,000
6		GTA Garment and Trim PLC	0.64	0.4403	3,000
7		YKK Garment PLC	0.64	0.1895	5,500
8		ZLD/Zero Liquid Discharge	18.5	3.88	57,000
9		JUTON paints	0.64	0.6036	5,500

10		Commercial and auxiliary buildings (rental office, clinical buildings, police station buildings, fire station buildings, power room buildings, solid waste buildings, logistics buildings, water supply pump station buildings, water supply pump station tanker)	1.63	0.1237	6,286.18
		Total	48.63	18.5131	1,280,286

3.5 Major Cause of Power Interruption at AIP

The most commonly identified issues in Adama Industrial Park include earth faults, short circuits and overcurrent. A number of short circuit faults can occur due to line-to-line (phase to phase), line-to-ground (phase to neutral) and double line-to-ground (phase to ground and neutral) conditions. Mostly line to line and line to ground fault are common causes for short circuits. The earth fault or ground fault is any failure of a connection in the circuit conductors with the earth. Such faults can cause circulating currents and energize the housing equipment at dangerous voltage.

These major faults are classified into two main categories:

i. Temporary and

ii. Permanent faults

i. Temporary Faults

The power supply is interrupted and restored in less than 5 minutes, then the customer is said to have experienced a momentary (transient) interruption. Temporary faults account for the majority of faults in distribution systems. These faults can occur for many reasons: but include falling trees, animal contact, vehicles, lighting, and weather as the main contributors. Temporary faults can be easily solved, with little or no intervention from the system itself. Many are self-clearing, such as a branch or animal contact that burns and falls off, conductors slapping together in severe wind, or insulation flashover due to contamination. When the instantaneous reclosing occurs, it will produce a brief de-energization period of the line; during this time, the arc, or the contact path, disappears and thus also eliminates the fault path. After re-energization of the circuit, the system is once again able to operate normally.

ii. Permanent Faults

Permanent or sustained interruptions are long-duration interruptions that last longer than five minutes. Permanent faults, on the other hand, are those that cannot be solved with reclosing action and will not self-clear. Equipment malfunction, cable failure, downed lines, or persistent tree contact can all produce permanent faults. It is important to point out, that some tree contact can cause permanent faults, such as a tree falling on a line.

Permanent faults (interruptions) can be classified as planned and unplanned outages. The planned outages occur for construction, maintenance, or repair purposes. On the other hand, unplanned interruptions occur due to fault clearing, unwanted operation of the protection system, or due to inadvertent initiation of the opening operation of a switching device by a human.[35]

According to the data collected from the Awash II Distribution substation, the causes of nonmonetary (unplanned) interruptions in the AIP feeder are; Permanent Earth Fault (PEF), Permanent Short Circuit (PSC), Temporary Earth Fault (TEF) and Temporary Short Circuit (TSC). The reasons for these unplanned interruptions are a result of faults and failures which make a component to be unavailable to perform its function. In addition, the two major factors that affect the reliability of power distribution systems are capacity shortages and Faults and failures.

The overall nonmonetary or unplanned interruption in the AIP feeder is described as follows.

1. **Permanent Earth Fault (PEF):** In the Adama Industrial Park feeder, around 49% of duration interruption and 50% of frequency interruption occur on permanent earth faults. This issue occurs when an electric conductor makes a conducting connection with any grounded or potentially grounded conducting material. Electricity flows are always looking for a method to get to the earth. In a ground fault, electricity typically finds its way to the earth by a channel that was never planned, such as a person's body. The earth fault, which is a plant engineering issue that damages electrical installations and, more importantly, puts people in danger, is caused by a loss of insulation between a live conductor and an exposed conductive part. As a result, people may come into contact with an exposed conductive part that is not normally live but may have a dangerous potential to ground due to the fault.
2. **Permanent Short Circuit:** About 3% of frequency interruptions and 2% of duration interruptions in the Adama Industrial Park feeder are caused by permanent short-circuit faults. The most typical way to characterize the source of a power outage is as a permanent short circuit. This happens when an electric current in an electrical circuit follows a route that

differs from the planned one. When this occurs, an overabundance of electricity can cause explosions, fires, and damage to the circuit. These short circuits also happen when the insulation of the utilized wiring decreases. A short circuit can also occur due to the presence of an external conducting material (such as water) that is introduced accidentally into the circuit. Electrical batteries can explode if they are subjected to a large current through the system. Again, short circuits can even occur when electric motors are forced to operate when the moving parts are jammed. This can result in an abnormal buildup of current, ultimately leading to a short circuit.

3. **Distribution Line Overload:** Overcurrent accounts for about 32% of duration interruptions and 33% of frequency interruptions in the Adama Industrial Park feeder. Existing power systems have become overloaded as a result of the ongoing rise in demand for electric power. Line voltage variations are frequently caused by overloading. Line voltage issues can also be caused by inadequate power generation and distribution systems. Voltage fluctuations may result from improperly built power-regulating equipment. Even voltage can be caused by loose or corroded connections at the electric service user's end. The voltage may also be impacted by the same circumstances on the distribution power lines. Inadequate infrastructure is the cause of many voltage fluctuation issues.

we can calculate the percentage of duration and frequency by taking the contribution of each type of fault and the total sum.

Table 3- 4 Percentage Duration (hours per year) of each Fault Type

Causes	PEF	TEF	POC	TOC	PSC	Operation
Duration (Hr.)	413	0.45	266.7	0.5834	20.3	144.06
Percentage of Duration (%)	49	0	32	0	2	17

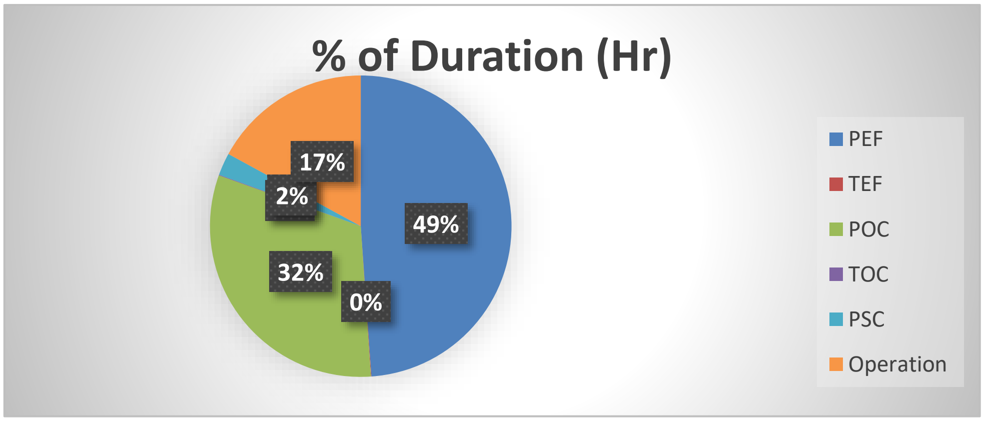


Figure 3- 2 Percentage Duration per year of each Fault Type

The pie chart shows that the permanent earth fault (PEF) accounts for 49%, the permanent overcurrent (POC) for 32%, operation and maintenance for 17%, and the permanent short circuit (PSC) for 2% of the interruption duration.

Table 3- 5 Percentage of Frequency (interruption per year) of each fault type

Causes	PEF	TEF	POC	TOC	PSC	Operation
Freq (Int/Yr.)	250	10	166	13	17	47
Percentage of Frequency (%)	50%	2%	33%	3%	3%	9%

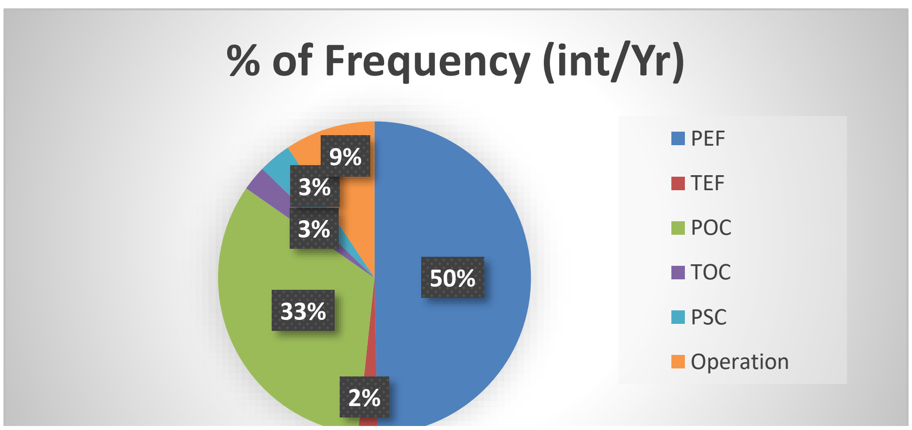


Figure 3- 3 Percentage of Frequency (interruption per year) of Each Fault Type

Figure 3.3 indicates that the causes of interruption to service were permanent earth fault with 50%, permanent overcurrent with 33%, Operation and Maintenance with 9%, permanent short circuit with 3%, transient overcurrent with 3%, and transient earth fault with 2%.

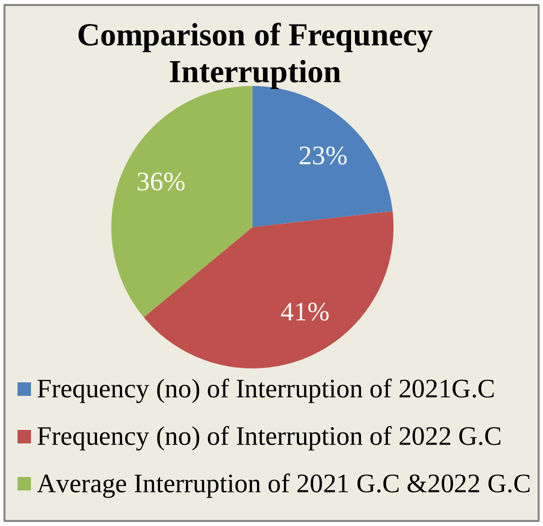
3.6 Duration and Frequency of Interruption for AIP Feeder

The AIP feeder is far from the main Awashe Melkasa distribution substation to 25 km, and both feeders cross different types of trees, including seedlings. In the year 2023, that is, higher frequency and duration interruptions are present, as shown in table 3.7 below. In the Awashe Melkasa substation, a monthly power interruption of the AIP feeder was recorded, and in the report, three years (2021, 2022, and 2023) of data are taken from this substation of 33 kV outgoing feeders. The power interruption report includes the duration and cause of each monthly power outage.

Table 3- 6 Frequency & Duration of Monthly and Total Outages of AIP Feeders in 2021 G.C. and 2022 G.C.

Month	Frequency (no) of Interruption of 2021G.C	Frequency (no) of Interruption of 2022 G.C	Average Frequency of Interruption of 2021 G.C &2022 G.C (int/Yr.)	Duration of Interruption(hr.) of 2021G.C	Duration of Interruption (hr.) of 2022G.C	Average Duration of 2021 G.C &2022 G.C
September	16	12	14	11.2317	22.7189	16.9753
October		36	36		54.4393	54.4393
November	8	10	9	29.8822	16.7502	23.3162
December	6	14	10	2.9165	20.2513	11.5839
January	10	16	13	18.9145	12.2511	15.5828
February	4	15	9.5	20.5165	2.8171	11.6668
March	3	23	13	3.9166	19.217	11.5668
April	18	12	15	38.9494	28.877	33.9132
May	2	9	5.5	2.1165	18.0002	10.0583
June	9	16	12.5	6.5499	40.8005	23.6752
July	15	17	16	29.3662	55.9507	42.6584
August	13	3	8	41.6024	0.7333	21.1679
Total	**104**	**183**	**161.5**	**205.9624**	**292.8066**	**276.6042**

As shown in Table 3.6 there is an average of 161.5 frequency of interruption per year and 13.5 frequency of interruption per month occurs in the AIP feeder. An average of 276.6hr. duration of interruption per year and 23.05 hours duration of interruption per month occurs in the feeder.



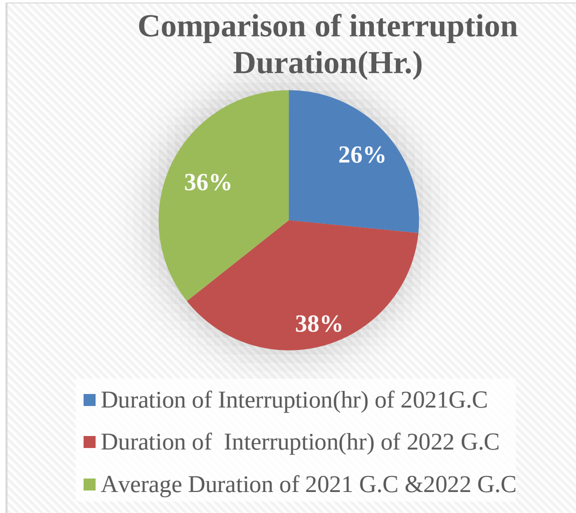


Figure 3- 4 Interruption of Frequency and Duration Year With the Years 2021 and 2022 from AIP Feeder

But after the date of 1/7/2014 E.C added another feeder (AIP2) in the Adama industrial park.

Table 3- 7 Monthly and Total Outage Frequency and Outage Duration of AIP2 Feeders in 20122G.C to 2023G.C

Month	Frequency of interruption (no) of 2022 to 2023G.C	Duration of interruption. (hr.) of 2022 to 2023G.C
March	22	32.284
April	15	50.601
May	19	58.0345
June	28	59.2341
July	32	110.6304
August	10	22.6169
September	25	26.9671
October	9	25.2502
November	10	12.5823
December	18	32.7656
January	26	8.2314
February	20	16.5659
Total	**234**	**455.7634**

Hence, the AIP feeder-2 experiences an annual frequency of interruption of 234 and a monthly frequency of interruption of 19.5 along with a yearly duration of 455.76 hours and a monthly duration of 37.98 hours in feeder-2; this signifies that there is a complete power outage in AIP feeder per day for an average of 1.266 hours.

3.7 Reliability Indices Calculation

As per the explanation provided in Chapter Two, the reliability indices of the existing AIP feeder can be estimated for the base scenario through the application of equations (2.1) to (2.15). Reliability indices for the years 2021, 2022, and 2023 were derived from the data given in Tables 3.6 and 3.7. The reliability indices for the year 2021 G.C., 2022G.C, 2023G.C, and the average indices are shown in Table 3.8.

Table 3- 8 Reliability Indices of AIP Feeder

Year	SAFI	SAIDI	CAIDI	ASAI	ASUI	ENS(MWh)
2021	104	205.9624	1.98	0.976	0.024	1983.11
2022	183	292.8066	1.6	0.967	0.033	2819.3
2023	234	455.7634	1.95	0.948	0.052	4388.3
Average	173.667	318.178	1.843	0.964	0.036	3063.57

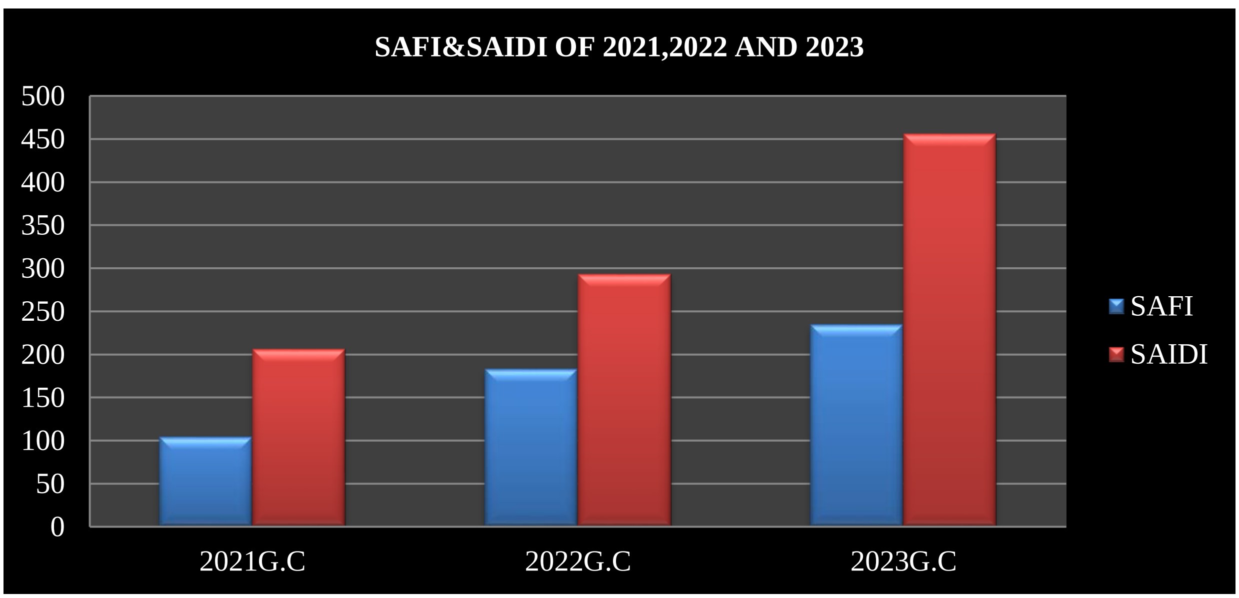


Figure 3- 5 Comparison of SAIFI and SAIDI of AIP Feeder

As shown in Figure 3.5, seen from the figure that SAIDI, or system average interruption duration index, and SAFI, or System Average Interruption Frequency Index have shown increasement from 2021 to 2023.

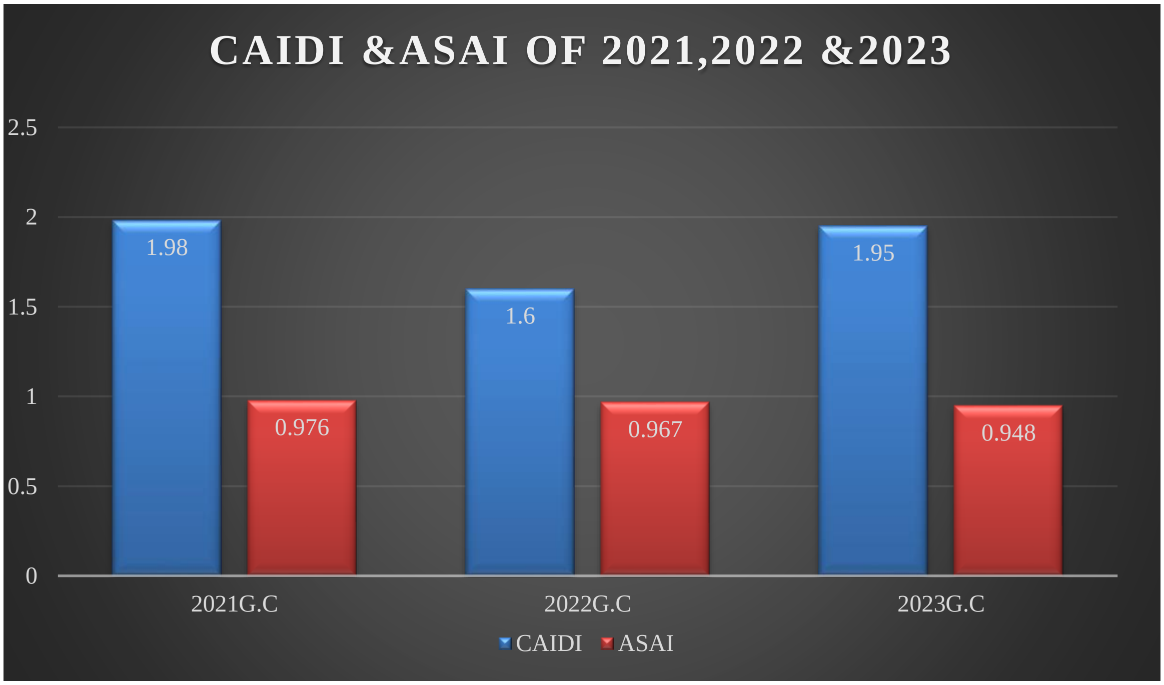


Figure 3- 6 Comparison of CAIDI and ASAI of AIP Feeder

The total average calculated reliability indices of the Adama industrial park can be seen in Table 3.8 and SAIFI, SAIDI, CAIDI, ASAI, ASUI, and EENS values were equal to 173.667 Inter. / customer/yr, 318.178 (hrs/cust/yr), 1.843Hrs./customer interruption, 0.964(96.4%), 0.036(36%), and 3063.57 (MWh/yr) respectively.

3.8 Comparison of Overall Reliability Indices Result with EEA Standard

- Table 3.8 shows the overall system of SAIFI is 173.67 interruptions per year or 14.45 interruptions per month. As we've seen, the standard SAIFI values set by the Ethiopian Electrical Agency shouldn't rise by 20 interruptions per consumer per year. Therefore, the system's current values are far higher than the Ethiopian Electrical Agency's (EEA) standards. The result shows that the AIP feeder has a serious reliability issue.
- The overall SAIDI of the system values is 318.18 hours per customer per year which indicates that every customer has no power for about 318.18 hours per year or 26.51 hours per month. Therefore, from the present case study, which is a great reliability problem as per (EEA), the SAIDI values should not exceed 25 hours per customer per year.
- The average service availability index (ASAI) is the fraction of time that a customer has received power during the reporting period. The power supply of the overall system is

96.4% available, as shown in Table 3.8. However, this value is not still good enough since the ASAI value should be greater than 99.98% as per the EEA's standard.

- Energy not supplied (ENS) for each feeder indicates unsold or unserved energy. The AIP feeder system's total unsold energy was 3063.57MWh, as seen in Table 3.8 above.

Table 3- 9 Overall System Reliability Indices

Indices	Units	Value
SAIFI	Inter. / customer /yr.	173.667
SAIDI	Hrs. / customer. /yr.	318.178
CAIDI	Hrs./customer interruption	1.843
ASAI	%	96.4
ASUI	%	3.6
ENS	MWh/yr.	3063.57

3.8 Comparison of Reliability Indices with Benchmark Standards

Reliability benchmarks are the guidelines against which the analyzed or determined reliability is deduced. The purpose of reliability benchmarks is to describe the minimum average reliability. performance, by feeder type, for a distribution network and supply a basis against which a distribution network service provider’s reliability performance may be assessed. The benchmarks were calculated using the IEEE Guide for Electric Power Distribution Reliability Indices – IEEE Standard 1366-2003. [41]

Table 3- 10 Benchmark of Reliability Indices with IEEE Standard 1366 and Different Countries [34], [42]

Country	SAIDI (hr./customer/ year)	SAIFI (int./customer/year)	CAID (Hrs./customer interruption)	ASAI (%)
IEEE Standard 1366	1.50	1.10	1.36	99.9999
United States	4	1.5	2.05	99.91
Austria	1.2	0.9	1.87	99.97
Denmark	0.4	0.5	1.17	99.981
France	1.03	1	0.97	99.97

Germany	0.383	0.5	0.83	99.999
Italy	0.97	2.2	1.77	99.9991
Netherland	0.55	0.3	1.25	99.97
Spain	1.73	2.2	1.9	99.968
UK	1.5	0.8	1.67	99.964
Ethiopia	25	20	1.25	99.98
AIP	318.178	173.667	1.843	96.4

In a benchmark, the basic reliability indices of SAIDI, SAIFI, CAID, and ASAI for nine developed countries are shown in Table 3.10 and then compare the calculated reliability indices of the case study with the standards.

In Table 3.10, AIP has a SAIDI value of 318.178 hours/customer/year, SAIFI of 173.667 interruptions/customer/year, CAIDI of 1.843 hours/interruption, and ASAI of 96.4%. This study area has a high value of SAIDI and SAIFI, which means the longer duration of outages and frequency of occurrence. The value of ASAI also shows that the availability of the system is very low, and comparing this with the average reliability indices computed, as it is seen in the calculated values, the substation has worse performance and needs to be improved upon to increase its reliability indices.

The lower number for SAIDI, SAIFI, and CAIDI indices indicates better reliability performance, while a higher value of index number indicates worse performance. so, comparing the system indices such as SAIDI, SAIFI, CAIDI and ASAI value of AIP with the benchmark shows in Table 3.10 that worse performance.

CHAPTER FOUR

4. DESIGN AND SIMULATIONS

4.1 Description of the Study Area

The Adama Industrial Park (AIP) is in Adama township, about 100 km from the federal capital, Addis Ababa with an area of 365 hectares of land the first phase, which has 19 manufacturing sheds, was built on 102 hectares of land, costing 147 million dollars was commissioned by the Industrial Parks Development Corporation. It started operations in October 2018. Phase one of AIP is expected to create about 25,000 new jobs and generate about USD40 million in annual export revenue. The park is focused on textile and garment manufacturing and currently depends on hydro-powered electricity. The Adama Industrial Park demanded 18.5 MW from Ethiopia Electric Power. But, only one feeder with 9 MW was provided. After one year, a 9 MW feeder was added, and Sunshine Wool Textile PLC and Kingdom Ethiopia Linen PLC were made to be supplied independently through this feeder. The feeder installation, however, has already caused power reliability problems almost at all times. As a result, the power necessity of the park would be covered completely by the renewables, namely solar and wind energy. The power provision to Adama Industrial Park would depend on renewable sources if we produce 51.4% of the total electric demand, i.e., 48.63 MW, with 25 MW from the joint solar and wind sources. However, if we generate 100% of 48.63 MW, the techno-economics will be high, and there will be no place for solar and wind power to generate 48.63 MW.

4.2 Design PV System Sizing

In this study, a 10 MW grid-connected PV power plant will be designed utilizing polycrystalline, the most popular PV technology for plants of this scale.

4.2.1 Location and Site Visit

The geographical location and satellite view of AIP can be described as follows.

- **Geographical Data of AIP:** Latitude is 8.51354(N) and Longitude is 39.30608(E)
- **Satellite View of AIP:** As can be seen from Figure 4.1 the AIP can be seen as a top view holding the current 19 sheds and other two sheds Private IP Developer (Kingdom Ethiopia Linen PLC and Sunshine Wool Textile PLC) built.

Figure 4- 1 Satellite View of AIP

4.2.2 Solar Resource and Meteorological Data

Adama is one of the cities with the highest solar radiation. Its Specific photovoltaic power output of that site is 1858 kWh/kWp and yearly direct normal irradiation is 2049.5 kWh/m². [45] Solar radiation data is collected from the National Metrology Agency of Ethiopia.

Table 4- 1 Average Solar Insolation Data in kWh/m^2/day of Adama [46]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Solar irradiation (kWh/m^2/ day)	6.37	6.5	7.04	6.4	6.41	6.02	4.72	5.34	5.4	6.24	6.13	6.11

The map of the global horizontal irradiation of Adama based on annual average sunshine reported on 22 Sep 2022, provided by the Solar GIS database, and the Global horizontal irradiation is 2209.8 kWh/m², is shown in Figure 4.2[45].

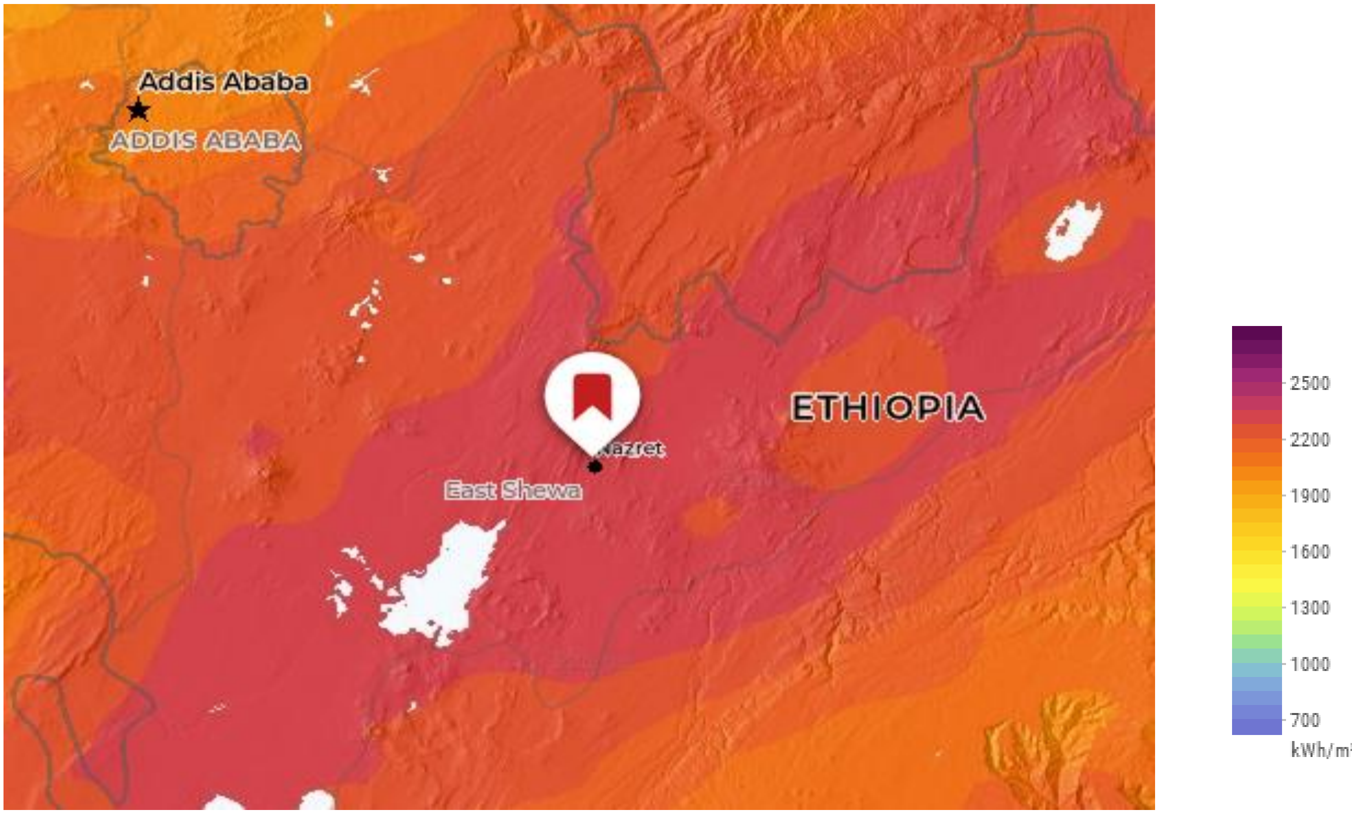


Figure 4- 2 Global Horizontal Irradiation of Adama

4.2.3 PV Plant Component Selection

1) PV module

When it comes to solar panels, the following factors need to be considered.[47]

a) **Solar Panel Cost:** For sure, it is the first variable that most probably everyone takes into account when comparing solar panels by price. The cost of a solar panel is determined by several factors such as power rating (in watts), physical size, brand name, material, durability (or warranty), and possibly obtained certifications.

b) **Solar Panel Quality:** This considers the solar panel's construction process as well as the quality of the materials utilized in its construction. Manufacturers produce panels differing in quality produced, price, and power yield.

c) **Energy Efficiency:** The efficiency of solar panels is considered to be the proportion of the light received that is converted into electricity, and this is directly related to the amount of electricity your system will generate. It is thus, the more efficient the panel (also the more expensive) the better. However, always going for the largest and most efficient solar panel might turn out to be a wrong decision because your expenditure could be more than what you need for energy.

d) **Temperature Coefficient:** The heating effect once solar panels are installed significantly affects their performance. It is better to reduce this percentage per degree Celsius as they age faster in the heat.

e) **Durability:** This can be an indication of the manufacturer's confidence in its creations. Solar panels often have a 25-year warranty (as long as the firm runs). If the manufacturer doesn't provide a lengthy warranty, you could assume that their product is bad and that they are unwilling to accept returns. In this instance, use caution to avoid being duped by an attractive price since you could regret it later. of course, it is important to properly maintain your solar panels to increase their lifespan.

f) **Size:** This factor takes into account the wattage capacity of the system in relation to its dimensions. The installation of solar panels must generate enough electricity to cater for all the devices in need, as well as space for the mounting. The total area of the solar panel is determined by the solar cell type and the output of the entire system (larger solar panels are usually indicators of higher wattage).

g) **Solar Cell Types Utilized:** The solar panel's composition dictates the efficiency, and the cells used determine the type. Highly efficient, monocrystalline silicon cells are compact in size but have already made their way into the sunny side of the panel market with their excellent heat resistance. Polycrystalline (or multi-crystalline) silicon cells are the most widely used in residential installations; however, they come with lower efficiency and a larger area requirement compared to crystalline silicon cells. The selection of the PV modules is done from Jinko Solar's range, which is an Indian firm with a sea of popularity in the photovoltaic sector. The two modules chosen are of the same make, the only distinction being that one is made of monocrystalline and the other is polycrystalline. Power output for both 72-cell panels under Standard Test Conditions is 340 W, and the efficiency is 17.52%. The fundamental specifications of the selected panels are presented in Table 4.2.

Table 4- 2 Price and Technical Data of the PV Modules

Manufacture	Jinko solar	Jinko Solar
Model number	JKM340M-72-V	JKM340PP-72
Solar panel type	Monocrystalline	Polycrystalline
Operating (Nominal) voltage	24 V	24V
Number of cells	72 cells	72 cells
Manufacturer	10years	10 years
Performance warranty	25 years	25 years
Frame material	Anodized Aluminum	Anodized Aluminum
Maximum Power (P_{max})	340W	340W
Maximum Power Voltage (V_{mp})	38.7V	38.2V
Maximum Power Current (I_{mp})	8.79A	8.91A
Open-circuit Voltage (Voc)	47.1V	47.5V
Short-circuit Current (Isc)	9.24A	9.22A
Module Efficiency STC (%)	17.52%	17.52%
Operating Temperature (℃)	-40^{O}C ~ +85^{O}C	40^{O}C ~ +85^{O}C
Maximum system voltage	1500VDC(IEC)	1000/1500VDC(IEC)
Maximum series fuse rating	20A	20A
Power Tolerance	0 ~+3%	0 ~+3%
Temperature coefficients of Pmax	-0.38%/^{O}C	-0.38%/^{O}C
Temperature coefficients of Voc	-0.29%/^{O}C	-0.31%/^{O}C
Temperature coefficients of Isc	0.048%/^{O}C	0.06%/^{O}C
Nominal operating cell temperature (NOCT)	45±2^{O}C	45±2^{O}C

2) Solar Inverter

String inverters perform the function of converting the direct current (DC) produced by photovoltaic (PV) panels into alternating current (AC) that is compatible with the electrical grid and can be supplied to it.

Figure 4- 3 SG1000 Solar Inverter

Table 4- 3 Price and Technical Data of the Solar Inverter [Alibaba.com]

MODEL SG1000		
Input (DC)	Max. PV input voltage	1000V
	Min. PV input voltage /startup input voltage	460v/500v
	MPP voltage range for nominal power	460V-850V
	No. of independent MPP inputs	1or 2
	Max. number of DC inputs	8-16
	Max.PV input current	2244A
	Max. DC short-circuit current	2920A
Output (AC)	Nominal AC output power (@ 50 ^{O}C)	1000 kW
	Max. AC output power at pf=1(@45 ^{O}C)	1100 kW
	Maximum AC apparent power (@45 ^{O}C)	1100kVA
	Maximum AC output current	2016A
	AC voltage range	252-362V
	Nominal grid frequency	50Hz/45-55Hz,60Hz/55-65Hz
	THD	<3% (at nominal power)
	DC injection	<0.5% in
	Power factor at nominal power /adjustable power factor	>0.99/0.8leading -0.8lagging
	Feed-in phase /connection phase	3/3
Efficiency	Max. Efficiency	99.0%
General	Dimension	2991*2591*2438mm
	Weight	4.3T

Data	Isolation method	Transformer less
	Ingress protection rating	IP54
	Auxiliary power supply	220Vac,2Vac5/Optional:380Vac, up to 15kVA
	Operating ambient temperature range	-35 to 60^{o}C (50 ^{o}C derating)
	Allowable relative humidity range	0-95%

- To calculate the required number of inverters in the AIP site the following formula is used

$$\text{No. of inverter} = \frac{plant\ capacity(MW)}{Rated\ \ AC\ output\ of\ selected\ inverter\ (kW) * Inverter\ efficiency} \qquad (Eq. no.\ 4.1)$$

So, $no. of\ inverter = \ 10MW/(\ 1000kW * 0.99)\ =\ 10.10 \approx 10$

4.2.4 System Sizing

For solar PV systems to operate reliably and perform better, be safer, and last longer, proper system design and element sizing are essential. According to SMA, the system is going to be sized step by step as per the following procedure.

a) Calculate the Power Dimensions of the PV Plant
   - Determine the inverter AC active power and DC input power
   - Define the nominal power rate (NPR)

b) Calculate the Voltage Dimensions
   - Calculate voltage dimensions at the module position
   - Calculate voltage dimensions at the string position

4.2.4.1 Power Dimensions of the PV Plant

A. Determining AC Active Power

Under optimum weather conditions, AC active power sent to the grid is determined by the planned output AC power of the inverter (1 MW), the power factor (cosα), the apparent power of the inverter, and the AC voltage of the grid. The following formula determines the AC active power.

$$U_{AC} = \ U_{app} \cos\alpha \qquad (Eq. no..\ 4.2\ )$$

Where: U_{AC} = AC active power

$U_{app} = Apparent\ power\ of\ the\ inverter$

$\cos\alpha = power\ facter$

$$U_{AC} = 1100\text{kVA} * 0.99 = 1089kW$$

Solar panels generate direct current (DC) which voltage is determined by the particular design and the quantity of sun radiation. An inverter changes the DC power into standard AC voltage. Central inverters are commonly used for large-scale applications due to their high efficiency and ease of installation.[48]An inverter size for a grid-scale PV system is determined by the array-to-inverter rate (nominal power rate), which is usually 100% to 125%, depending on the load the inverter can supply and the maximum watt-peak generated by the PV modules.[49]

B. Determine the DC Input Power of the Inverter

The DC input power of the inverter and its efficiency determines the DC input power. required to achieve the desired AC active power that will be fed into the grid. Also, is necessary to mention that the PV array voltage influences the efficiency of the inverter, decreasing with high input voltages.

The following formula determines the DC input power.

$$U_{DC} = \frac{U_{AC}}{\eta} \qquad (Eq.no..\ 4.3)$$

Where: $U_{DC} = DC\ input\ power\ of\ inverter$

$U_{AC} = AC\ active\ power$

$\eta = inverter\ efficiency$

The maximum efficiency of the selected inverter is 99%

$$U_{DC} = \frac{1089\text{kW}}{0.99} = 1100kW$$

C. Nominal Power Rate (NPR)

This ratio describes the relation between the DC power of the inverter and the DC power of the PV array. Is important to avoid oversizing the inverter because its performance is maximum at a certain amount of absorbed power and decreases when this power is small compared with the nominal.

$$NPR = \frac{U_{DC}}{P_{PV\ arr}} \qquad (Eq.no.\ 4.4)$$

Where: $NPR =$ Nominal power rate

$U_{DC} = DC\ input\ power\ of\ inverter$

$$P_{PV\ arr} = PV\ array\ power, but\ \ P_{PV\ arr} = \frac{plant\ capacity(MW)}{no. of\ invereter} = \frac{10MW}{10} = 1000kW$$

$$NPR = \frac{1100kW}{1000\text{kW}} \approx 1.1$$

To summarize the results obtained in the power dimensioning of PV plant the following table.

Table 4- 4 Power Dimensioning of PV Plant

AC active power	1089 kW
DC input power of the inverter	1100kW
Nominal power rate (NPR)	1.1

4.2.4.2 Voltage Dimensions

Temperature is affected negatively by the electrical performance of PV panels. This parameter is more the voltage than the current, as can be seen in the figure below. Because of that, items like the module voltage or the string current have to be calculated considering the climate data of the PV location.

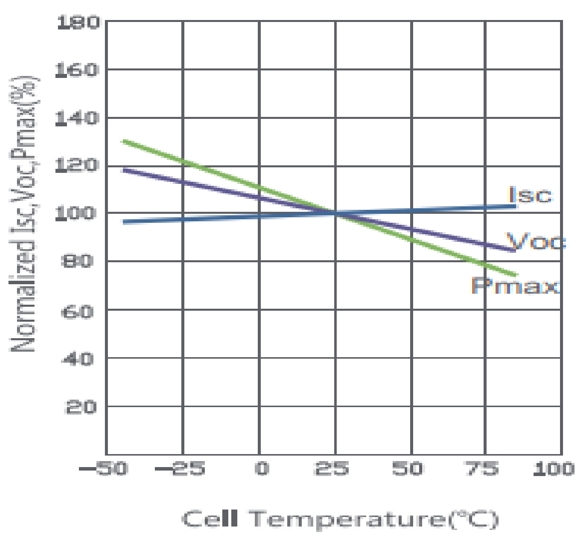


Figure 4- 4 Temperature dependence of Isc, Voc, and Pmax

1. **Maximum Open Circuit Voltage**

The open circuit voltage decreases with temperature, as shown in Figure 4-4. The maximum open circuit voltage of the module is calculated based on the lowest ambient temperature that is expected that the module will operate under in the time that the module produces the highest expected voltage. Maximum open circuit voltage is determined at lowest temperature by use of equation 4.5.

$$V_{maxMO} = V_{mppMO(minT)} = V_{ocM}\left(1 + \frac{T_{min}\Delta T}{100\%}\right) \qquad (Eq. no. 4.5)$$

Where: V_{maxMO} = maximum PV module voltage

T_{min} = temperature coefficient at minimum expected temperature

V_{ocM} = open circuit voltage of the PV module

ΔT =Temperature variance between STC and the minimum expected temperature

According to the meteorological data received from NASA Power Access Data Viewer, the mounting site has experienced a minimum temperature of 6.47℃ and a maximum temperature of 34.78℃ within 20 years.

$$V_{maxMO} = V_{mppMO(6.47℃)} = 47.5V\left(1 + \frac{(-0.31\ \%/℃)(6.47℃ - 25℃)}{100\%}\right) = 50.2V$$

2. **Minimum MPP Voltage**

The module's minimum voltage is calculated using the highest temperature at the installation site when the modules produce the lowest expected voltage. This is less efficient because, as a photovoltaic module becomes hotter, it becomes less efficient, resulting in lower voltage production.

$$V_{minMOD} = V_{mppMOD(maxT)} = V_{mpp}\left(1 + \frac{T_{max}\Delta T}{100\%}\right) \qquad (Eq. no. 4.6)$$

Where: V_{minMO} = Minimum PV module voltage

V_{mpp}= The voltage of the PV module at maximum power

ΔT = Temperature variance between STC and the maximum expected temperature

T_{max}=Temperature coefficient at the maximum expected temperature

$$V_{minMOD} = V_{mppMOD(34.78℃)} = 38.2V\left(1 + \frac{(-0.31\ \%/℃)(34.78℃ - 25℃)}{100\%}\right) = 37V$$

3. **Maximum PV Module Current**

In the above figure, 4-4 current is less dependent on temperature than voltage, instead of that the maximum PV module current in short-circuit conditions had been calculated considering the maximum expected temperature that can be expected at the installation place.

$$I_{maxstr} = I_{scMOD(maxT)} = I_{sc}\left(1 + \frac{T_{max}\Delta T}{100\%}\right) \qquad (Eq.\ no.\ 4.7)$$

Where: I_{maxstr} = Maximum string current

I_{sc} = Short-circuit current of the PV module

T_{max} = Temperature coefficient at maximum expected temperature

ΔT= The temperature difference between STC and the maximum expected temperature

$$I_{maxstr} = I_{scMOD(34.78℃)} = 9.22A\left(1 + \frac{(0.06\ {}^{\%}/_{℃})(34.78℃ - 25℃)}{100\%}\right) = 9.2753A$$

To summarize the results obtained in the voltage dimensions of the PV plant the following table

Table 4- 5 Voltage Dimension of PV Plant

Maximum open-circuit voltage (V)	50.2V
Minimum MPP Voltage (V)	37V
Maximum PV Module Current (A	9.2753A

4.2.4.3 String Dimensions

If a PV module string's voltage is higher than the inverter's maximum input voltage, yield losses may result.

1. **Maximum Number of PV Modules Per String**

$$n_{maxMODSTR} \le \frac{V_{mppmaxINV}}{V_{maxMOD}} \qquad (Eq. no.\ 4.8)$$

Where: $n_{maxMODSTR}$ = Maximum number of PV modules per string

$V_{mppmaxINV}$ = Maximum MPP voltage of the inverter

V_{maxMOD} = Maximum PV module voltage

$$n_{maxMODSTR} = \frac{850V}{50.2V} = 16.9 \approx 17\ modules$$

On the other hand

$$maximum\ total\ number\ of\ panels\ in\ series\ per\ string\ in\ an\ array$$
$$= \frac{Max. MPP\ voltage\ of\ inverter\ (V)}{Open\ circuit\ voltage\ of\ PV\ panel(V)}$$
$$= \frac{850V}{47.5V} = 17.89 \approx 18\ modules$$

2. **Minimum Number of PV Modules Per String**

Additionally, the string voltage must be maintained above the minimum MPP voltage of the inverter to avoid yield losses due to insufficient MPP tracking.

$$n_{minMODSTR} \geq \frac{V_{mppminINV}}{V_{minMOD}} \quad (Eq.no.\ 4.9)$$

Where: $n_{minMODSTR}$ = Minimum number of PV modules per string

$V_{mppminINV}$ = Minimum MPP voltage of the inverter

V_{minMOD} = Minimum PV module voltage

$$n_{minMODSTR} \geq \frac{460V}{37V} = 12.433 \approx 12 Modules$$

3. **Maximum and Minimum String Voltage**

The maximum and minimum string voltage can be calculated by using the following formulas;

$$V_{maxSTR} = n_{MODSTR} * V_{maxMOD} \quad (Eq.\ no.\ 4.10)$$

$$V_{minSTR} = n_{MODSTR} * V_{minMOD} \quad (Eq.\ no.\ 4.11)$$

Where: V_{maxSTR} = Maximum voltage per string n_{MODSTR} = Number of modules per string

V_{minSTR} = Minimum voltage per string V_{maxMOD} = Maximum PV module Voltage

V_{minMOD} = Minimum PV module Voltage

$$V_{maxSTR} = 18 * 50.2V = 903.6V$$

$$V_{minSTR} = 18 * 37V = 666V$$

4. **Maximum and Minimum Number of Strings**

String size is important because too many panels on one string can damage the inverter. Alternatively, if you have too few panels per string, your inverter may shut off during the hottest days of the year, causing you to lose out on generating power. [50]The maximum numbers of strings depend on the maximum input current of the inverter, and the minimum depends on the PV array power. They are calculated by using the following equations:

$$n_{maxSTR} = \frac{I_{maxINV}}{I_{maxSTR}} \quad (Eq.\ no.\ 4.12)$$

$$n_{minSTR} = \frac{P_{pvArr}}{P_{maxMOD} * n_{MODSTR}} \quad (Eq.\ no.\ 4.13)$$

Where:

n_{maxSTR} = Maximum number of strings I_{maxINV} = Maximum input current of the inverter

n_{MODSTR} = Number of modules per string P_{pvArr} = PV array power

I_{maxSTR}= Maximum string current n_{minSTR} = Minimum number of strings

P_{maxMOD} =Maximum PV module power

$$n_{maxSTR} = \frac{2244A}{9.2753A} = 241.93 \text{ Strings}$$

$$n_{minSTR} = \frac{1000KW}{0.340KW * 18} = 163.4 \text{ Strings}$$

Summarizes the results obtained after calculating the string dimensions of the PV plant in the following table

Table 4- 6 String Dimensions of PV System

Maximum number of PV modules per String	18
Minimum number of PV modules per String	12
Maximum string voltage (V)	903.6
Minimum string Voltage (V)	666
Minimum number of strings	163.4
Maximum number of strings	241.93

Therefore, generally, the necessary module for the PV plant system is given by:

$$n_{modules} = n_{mod\ per\ str} * n_{str} * n_{inv} \qquad (Eq.\ no.\ 4.14)$$

$n_{modules}$ = 18 ∗ 163.4 ∗ 10=29,412 modules

4.2.5 Yearly Energy Production of the PV System

To make a first estimation of the PV plant DC energy production of each inverter, the following formula has been used:

$$E_{DC} = P_{DC} * n_{inv} * \ Peak\ sun\ hour \qquad (Eq.\ no.\ 4.15)$$

Where: E_{DC}= DC energy production of the inverter

P_{DC}= DC power of the inverter

n_{inv} = number of inverters installed

A peak sun hour refers to the amount of solar radiation a location receives on average every day. It describes the number of hours when the average intensity of sunlight is 1,000 W/m^2.yearly irradiation in the PV installation area is 2209.8 kWh/ m^2.

$$Peak\ sun\ hour = \frac{yearly\ irradiation\ \left({kWh}/{m^2}\right)}{1000\ {W}/{m^2}} = \frac{2209.8\ \left({kWh}/{m^2}\right)}{1000\ {W}/{m^2}} = 2209.8\ h$$

$$E_{DC} = 1100kW * 10 * 2209.8\ hr = 24{,}307.8\ MWh/year$$

Calculating the yearly AC energy produced includes considering the inverter efficiency:

$$E_{AC} = E_{DC} * \eta_{INV}$$

$$E_{AC} = 24{,}307.8\ MWh/year * 0.99$$

= 24,064.7 MWh/year

4.3 Simulation of Grid–Connected PV System

The main calculations required to determine the PV system's size are displayed in the above topic. However, a software simulation must be created to produce more precise results. The program on which the simulations of the project are done is PVsyst. Using this software, the user can make a more precise project design, that is, a comprehensive study and analysis of the project, or one can make a simple pre-sizing to make a quick study of a PV installation. Fig. 4.5 shows the stages that are involved in designing a simulation. The process that must be followed to simulate a design using PVsyst is shown in the step-by-step diagram below.

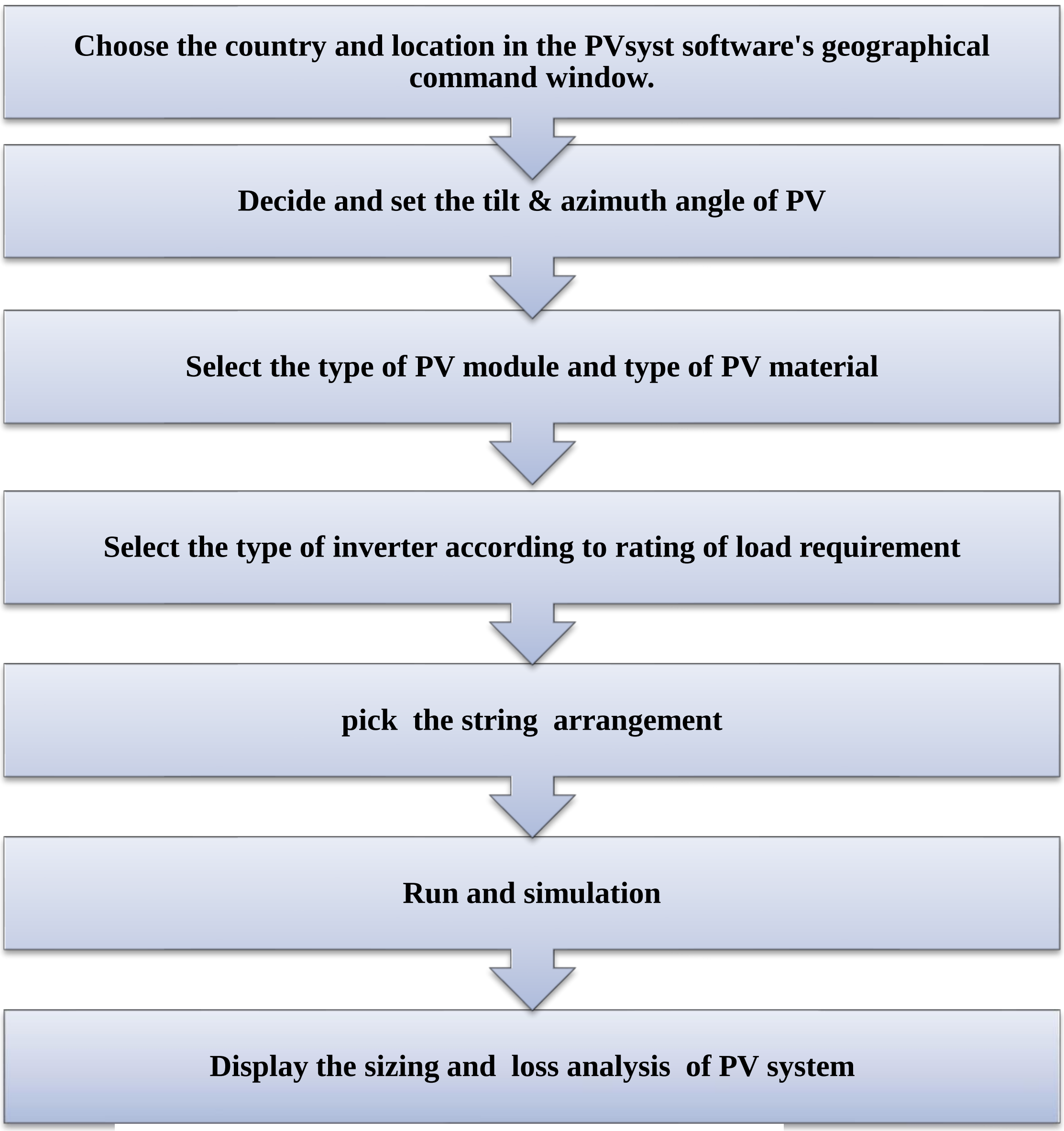


Figure 4- 5 Steps to Analysis PVsyst

In this design, the system is a grid-connected solar PV system that consists of a PV panel, inverter, grid, and load as shown in Fig 4.6. This system is selected to reduce the cost of the whole system by avoiding battery backup.

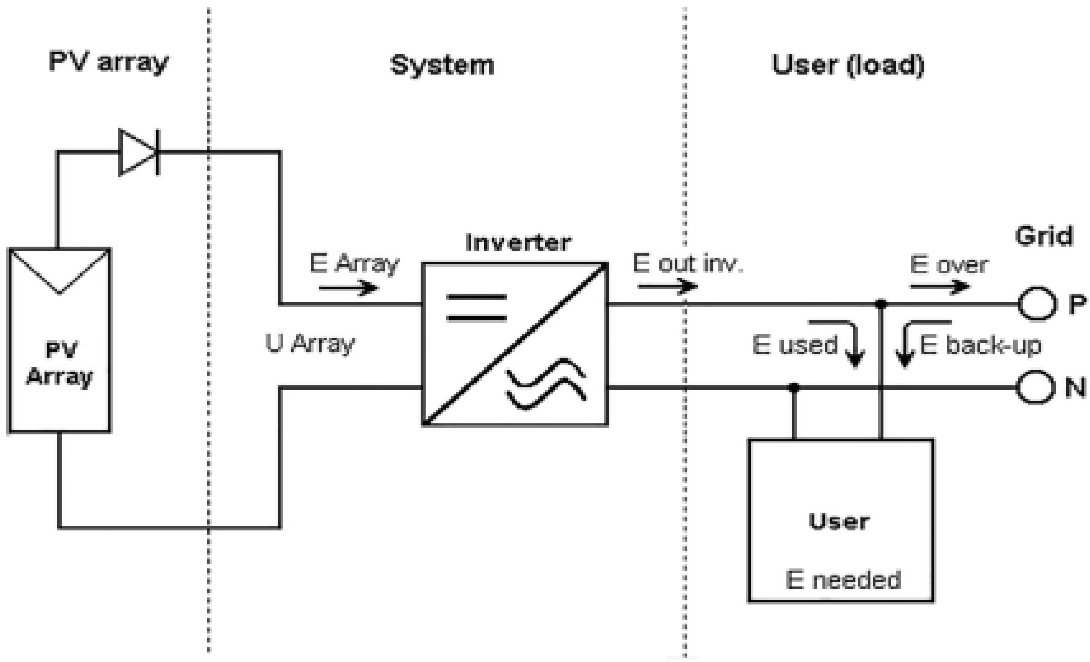


Figure 4- 6 Block Diagram of Grid-Connected PV System

The layout and important settings for the project are displayed in Figure 4.7. For study areas, the tilt angle was set at 8°, JinkoSolar 340 Wp 32V Si-poly PV modules and Sungrow 1000 kW 460-850V inverters were selected. The planned power input was 10 MW. In Figure 4.8, the arrangement of PV modules with strings and the inverter is shown.

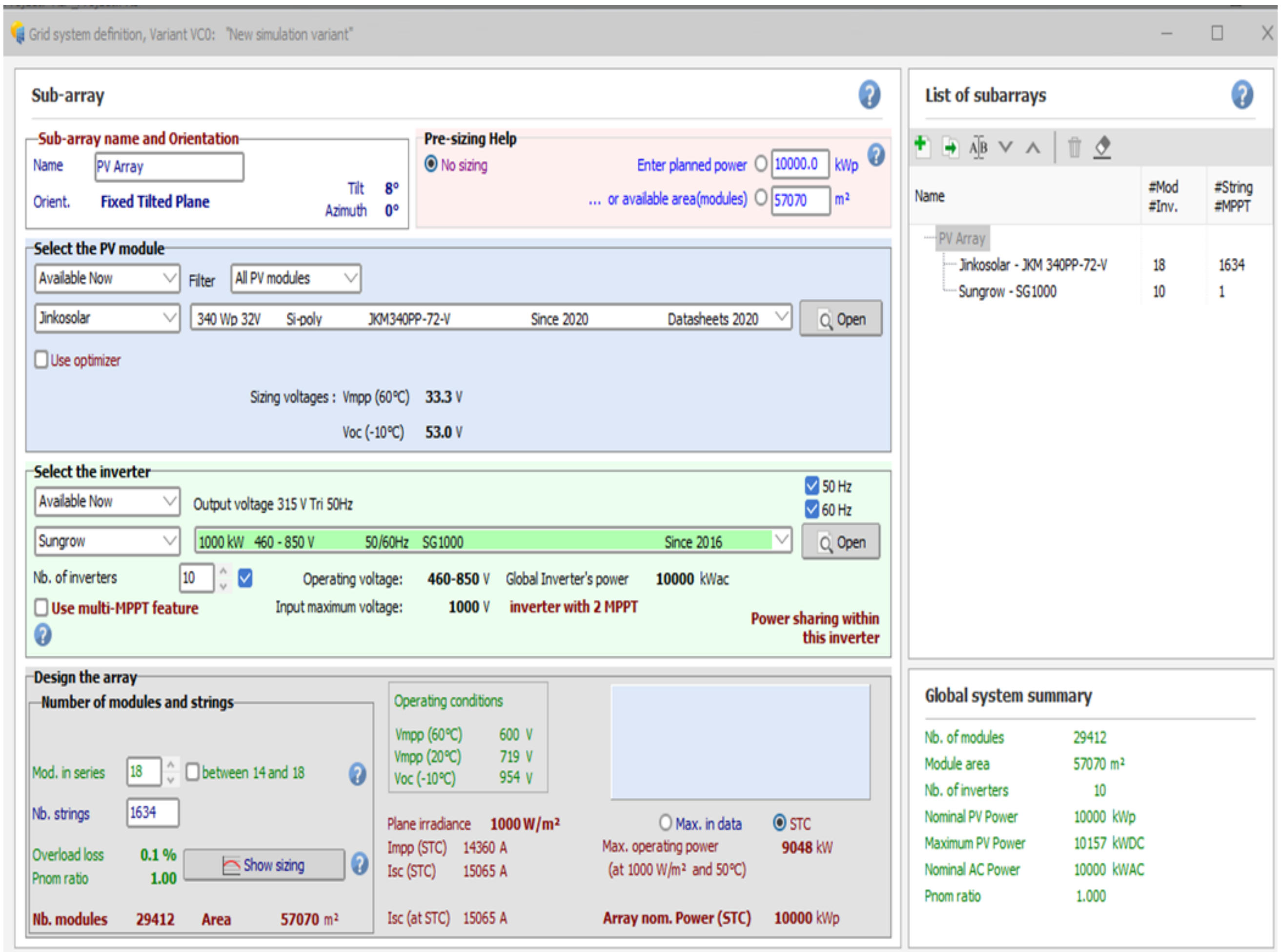


Figure 4- 7 Sizing of 10MW PV System in AIP Using Pvsyst Software

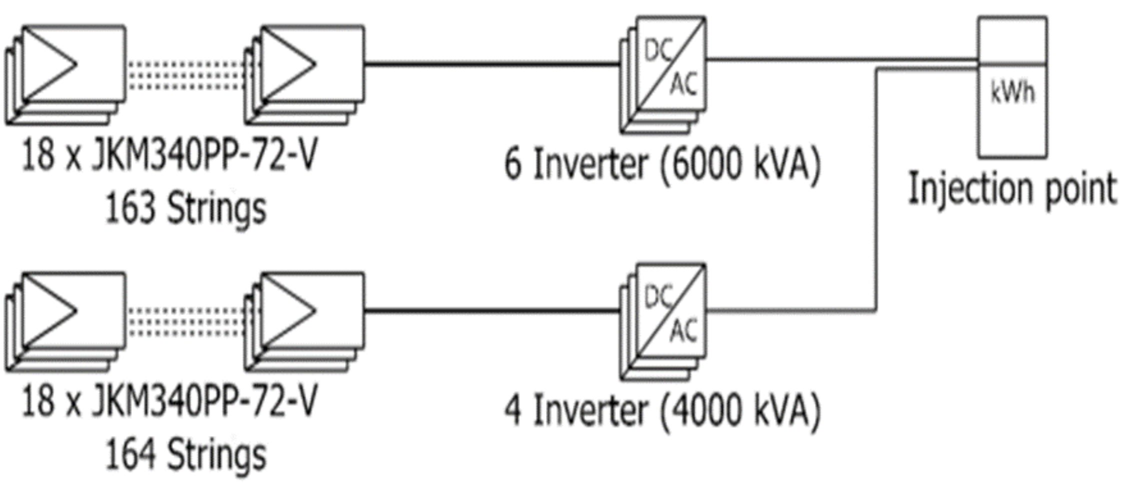


Figure 4- 8 Single-Line Diagram of PV System

4.3.1 Simulation of Polycrystalline Technology

The PVsyst software simulates a grid-connected photovoltaic system of a 10 MW power plant. It is discovered during the simulation that the required modules and inverters are 29,412 modules and 10 inverters, respectively. 18 PV modules are arranged in series together, and they are a string. For the placement of the modules, a 57,070 m² area will be required.

General parameters

Grid-Connected System		**No 3D scene defined, no shadings**			
Orientation #1				**Models used**	
Fixed plane		**Sheds configuration**		Transposition	Perez
Tilt/Azimuth	8 / 0 °	No 3D scene defined		Diffuse	Perez, Meteonorm
				Circumsolar	separate
Horizon		**Near Shadings**		**User's needs**	
Free Horizon		no Shadings		Unlimited load (grid)	

PV Array Characteristics

PV module		**Inverter**	
Manufacturer	Generic	Manufacturer	Generic
Model	JKM 340PP-72-V	Model	SG1000
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	340 Wp	Unit Nom. Power	1000 kWac
Number of PV modules	29412 units	Number of inverters	10 units
Nominal (STC)	10.00 MWp	Total power	10000 kWac
Modules	1634 string x 18 In series	Operating voltage	460-850 V
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.00
Pmpp	9048 kWp	Power sharing within this inverter	
U mpp	630 V		
I mpp	14360 A		
Total PV power		**Total inverter power**	
Nominal (STC)	10000 kWp	Total power	10000 kWac
Total	29412 modules	Number of inverters	10 units
Module area	57070 m²	Pnom ratio	1.00
Cell area	51535 m²		

Array losses

Array Soiling Losses		**Thermal Loss factor**		**DC wiring losses**	
Loss Fraction	3.0 %	Module temperature according to irradiance		Global array res.	0.74 mΩ
		Uc (const)	29.0 W/m²K	Loss Fraction	1.5 % at STC
		Uv (wind)	0.0 W/m²K/m/s		
Module Quality Loss		**Module mismatch losses**		**Strings Mismatch loss**	
Loss Fraction	-0.8 %	Loss Fraction	2.0 % at MPP	Loss Fraction	0.2 %
IAM loss factor					
ASHRAE Param.: IAM = 1 - bo (1/cosi -1)					
bo Param.	0.05				

Figure 4- 9 Simulation parameters of a 10MW grid-connected PV system (polycrystalline)

In Fig. 4.10, three main parameters were evaluated based on the main simulation results. The first parameter is the total amount of energy produced from the 10 MW photovoltaic system on an annual basis, which is referred to as produced energy, i.e., 19,237.2 MWh/year. The second parameter is the specific production on an annual basis per installed kWp, which is 1924 kWh/kWp/year. The third parameter is the yearly average performance ratio (PR) of 85.44%.

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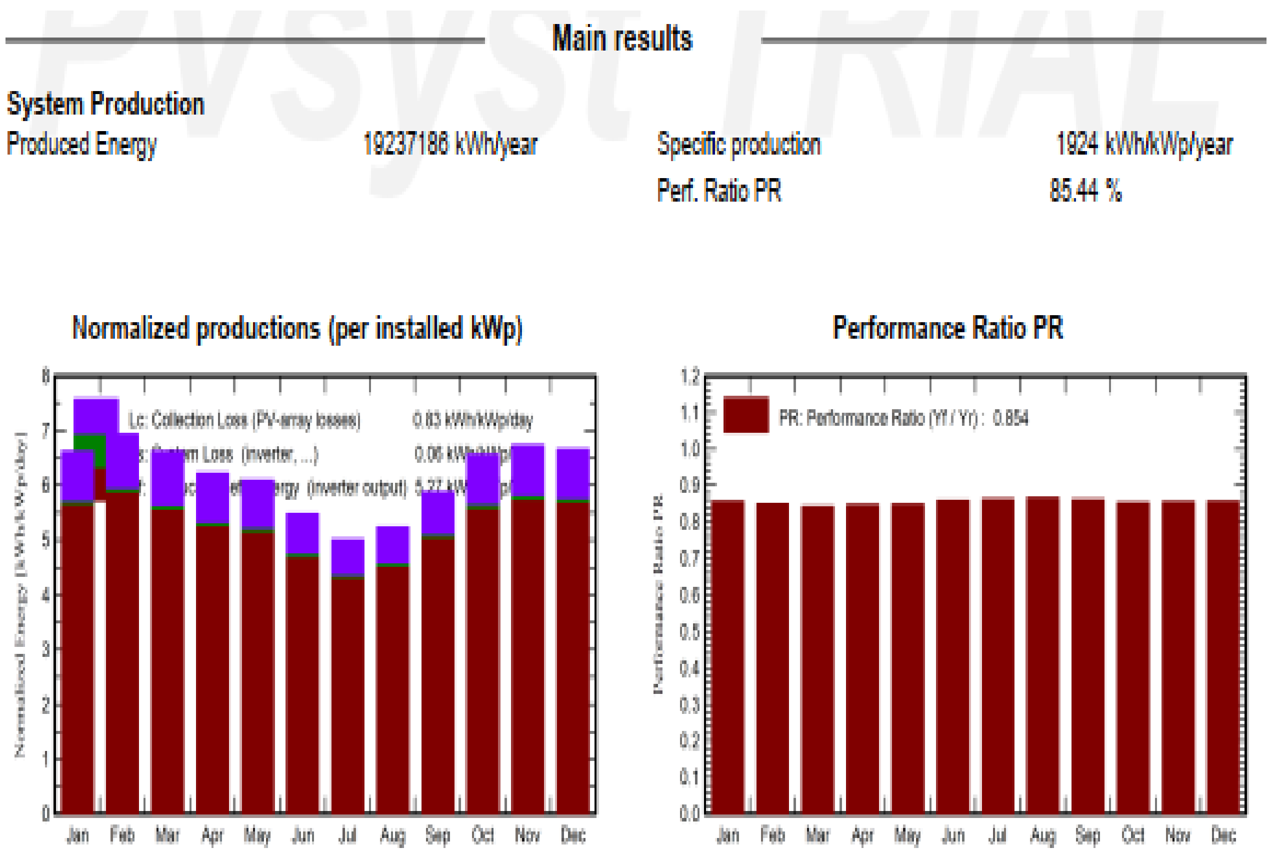

Figure 4- 10 Normalized Energy Productions Per Installed kWp & Performance Ratio

The energy output of a PV array cannot be identical to the energy injected into the grid. The PV array generates energy in the form of DC that must be converted to AC energy to supply the grid. A certain amount of energy is lost during this process due to the loss of AC wiring. In December, the PV plant produced and added 1769.4 MWh of energy to the grid. The lowest amount of AC energy that is injected into the grid is 1358 MWh, which is in July. Detailed information about the AC energy that is injected into the grid is shown in Figure 4.11.

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	188.5	41.23	18.48	205.2	193.5	1777360	1757310	0.856
February	184.0	40.60	20.05	194.3	184.0	1669381	1650431	0.849
March	202.1	56.73	21.54	205.4	194.4	1750033	1729892	0.842
April	189.3	61.50	21.46	186.8	176.5	1602058	1582540	0.847
May	197.2	58.59	21.26	189.2	178.5	1624116	1604573	0.848
June	173.1	59.70	19.45	164.5	154.8	1431542	1413582	0.859
July	162.1	66.03	18.21	155.3	146.0	1358021	1340156	0.863
August	166.2	68.20	18.09	162.3	153.1	1424501	1406766	0.867
September	175.2	62.40	18.57	176.4	167.0	1537486	1518675	0.861
October	195.6	51.77	18.75	203.5	192.8	1757403	1735909	0.853
November	188.1	39.90	18.32	202.1	191.5	1749696	1727949	0.855
December	188.5	37.20	17.84	206.5	194.9	1790101	1769403	0.857
Year	2209.8	643.85	19.33	2251.4	2126.9	19471700	19237186	0.854

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

Figure 4- 11 Yearly generation output using PVsyst

The arrow loss diagram is obtained from the simulated studies, which help in analyzing the various losses that are to be encountered while installing a PV plant, or constraints to be considered. The arrow loss diagram is seen in Fig. 4.12, the various losses that come about within the system. The horizontal plane will absorb 2210 kWh/m' of total solar radiation.

However, the collector's effective irradiance is 2127 kWh/m². This causes an energy loss of 0.4% as a result of the irradiance level. Electrical energy is generated when this effective irradiance strikes a photovoltaic module or array. The array nominal energy at standard testing conditions (STC) following PV conversion is 21,394.7 MWh. The efficiency of the PV array at STC is 17.63%. The annual array virtual energy at MPP is 19,471.7 MWh. The various losses that occur at this stage are 6.2% losses due to temperature, 2.2% losses due to module array mismatch, and

1.1% ohmic wiring losses. Available energy on an annual basis at the inverter output facility is 19,237.2 MWh, and the same is injected into the grid.

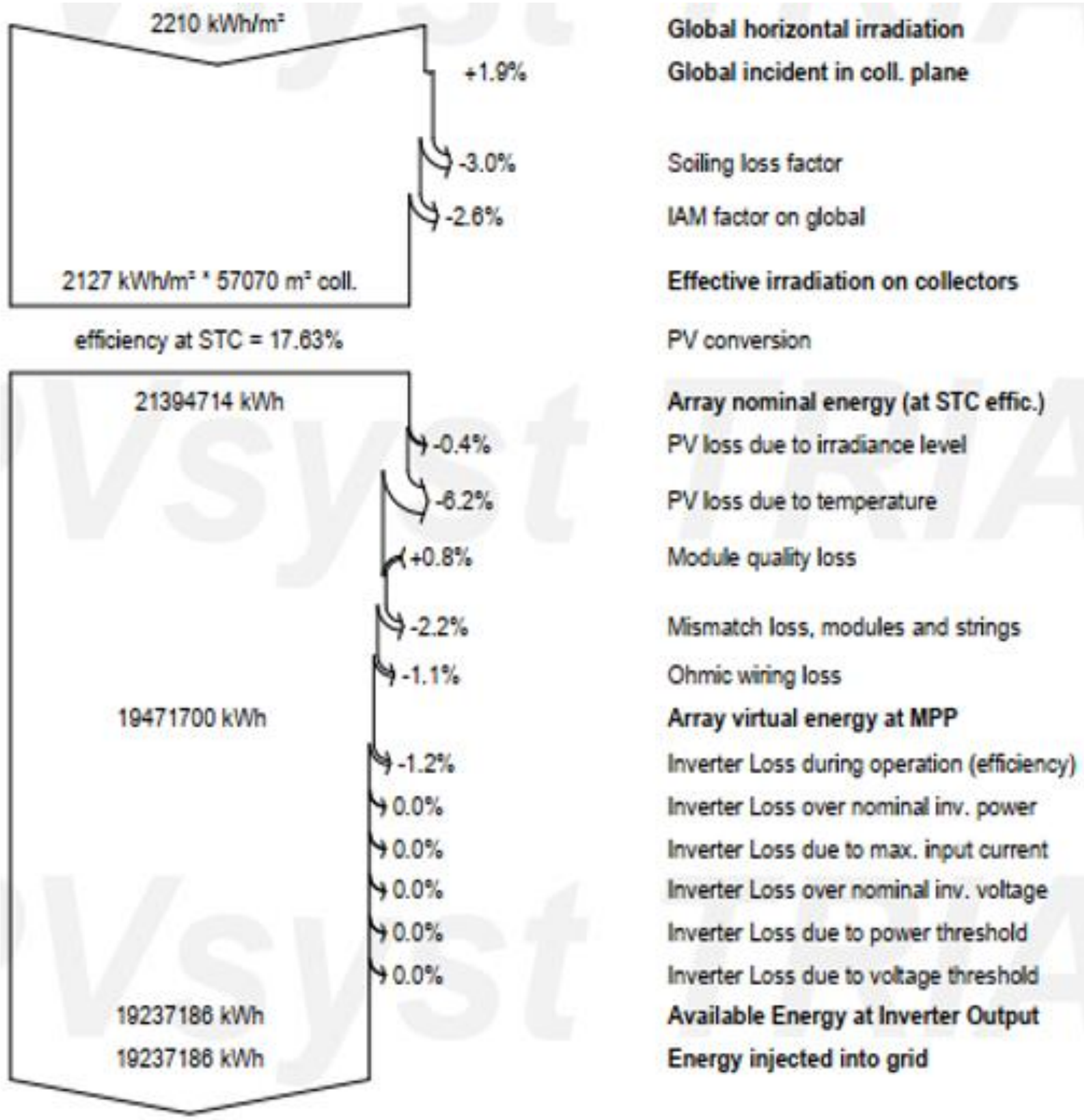

Figure 4- 12 Annual Loss Diagram of 10 MW Plant Using Pvsyst

4.4 Design 15MW Wind System

A 15 MW wind farm was designed as ten 1.5MW units. Each unit has several wind turbines and transformers. The turbine is selected based on its size, wind resource, availability, reliability, warranty, and spare parts availability, proximity of operation and maintenance teams. Amongst others, the selection of the most suitable wind turbine size depends on several site-related criteria, such as:

- Available space on site.
- Wind conditions and, particularly, extreme wind conditions on site.
- The financing available for the project.
- The ability of the transmission or distribution grid to handle the additional energy from the project.

A wind turbine's power transfer is directly proportional to the air density, the cube of wind speed, and the area swept out by its rotors. The power P can be obtained by applying Equation (4.16): [51]

$$P = \frac{1}{2}\rho A V^3 P_{coff} \qquad \textit{(Eq. no. 4.16)}$$

Where, P =Turbine power coefficient

ρ =Air density (1.225Kg/m^3)

A =Area swept by the rotor (m^2)

V =Mean wind speed (m/s)

P_{coff} = The power coefficient typically has a maximum value of 40–45%; the theoretical peak value of Pcoff is 59%, known as Betz's limit, after its discovery by Albert Betz in 1919.[52]

$$P = \frac{1}{2} \times 1.225 \times 4736 \times 11.5^3 \times 0.40 = 1.6\text{MW}$$

4.4.1 Wind Turbine Selection

The main options in a wind turbine design and construction include:

- Number of blades (commonly two or three) and blade material.
- Hub height.
- Orientation through direct control (active yaw) or self-aligning action (free yaw).
- Squirrel cage or wound rotor Synchronous and asynchronous generators (DFIG).
- The speed of the rotor can be variable or constant.
- Both aerodynamic control (stall control) and variable-pitch blades (pitch control) can be used to control power.

4.4.2 Wind Speed of Various Hub Heights in the Study Area

Wind speed at 10 m and 50 m hub heights is shown in Table 4.7 based on Global Wind Atlas records. Similarly, above 50 m, hub heights determine the wind speed using the extrapolation method. Assuming a power law relationship between height and wind speed, that is, that wind speed increases with height, the wind power law model extrapolates wind speed. Forecasting wind speed at the height of wind turbine hubs is a common practice in the wind energy sector. The wind power law is as follows[53]

$$V_2 = V_1 \left(\frac{h_2}{h_1}\right)^{\beta} \qquad \text{(Eq. no. 4.17)}$$

Where, V_1 and V_2 are wind speeds respectively

h_1 and h_2, are the heights of the turbine, respectively

β = the wind shear coefficient.

In case wind speed could be determined at two heights, the wind shear coefficient could be determined using the following formula.

$$\beta = \frac{\log({}^{V_2}/_{V_1})}{\log({}^{h_2}/_{h_1})} \qquad \text{(Eq. no. 4.18)}$$

Table 4- 7 Wind Speed at 10m and 50m Hub Heights in the Study Area[54]

Hub height	Mean wind speed (m/s)
10m	5.41
50m	6.76

Table 4- 8 Mean Wind Speed of Various Hub Heights in the Study Areas

V@10m (m/s)	**V@50m (m/s)**	$\boldsymbol{\beta_{10m-50m} = \frac{\log({}^{V_2}/_{V_1})}{\log({}^{h_2}/_{h_1})}}$	$\boldsymbol{V_{@70m} = V_1 \left(\frac{h_2}{h_1}\right)^{\beta}}$ **(m/s)**	$\boldsymbol{\beta_{50m-70m} = \frac{\log({}^{V_2}/_{V_1})}{\log({}^{h_2}/_{h_1})}}$	$\boldsymbol{V_{@80m} = V_1 \left(\frac{h_2}{h_1}\right)^{\beta}}$ **(m/s)**
5.4099	6.76	0.138	7.08	0.1375	7.2

4.4.3 Hub Height

The most suitable sitting is the tower height of 70m amounting to a satisfactory mix of power output and the expenses on tower and base. Mean wind velocity at this altitude is 7.08m/s.

4.4.4 Selected Turbine Type

The wind turbine employed is the horizontal wind turbine with rated power of 1.5MW as Sany model (SE7715) whose rotor diameter is 77.7m. The model cut-in speed is 3m/s and the rated wind speed is 11.5m/s which has the benefit of producing power at a low wind speed.

4.4.5 Selected Generator Type

The generator selected is a doubly fed induction generator with variable speed control, which keeps the output voltages' frequency and amplitude constant regardless of the wind speed acting on the wind turbine rotor. As a result, DFIG can be directly linked to the distribution power network and maintain continuous synchronization with the AC power network. Further benefits consist of Wind turbines based on DFIG can be run in power factor control mode. The power factor is regulated by the DFIG when operating in the power factor control mode. Leading, lagging, and unity power factors are the three that are typically used in DFIG operations. When operating in leading PF mode, the DFIG can supply reactive power to the grid or power system. Under these operating conditions, the DFIG can be used to enhance the voltage profile and meet the system's reactive power requirements. On the other hand, in lagging PF operation, the DFIG absorbs reactive power from the grid. This reactive power is utilized for induction generator magnetization, along with the reactive power generated by the DFIG rotor. In the process of Unity PF operating, no reactive power is sent to the grid, or received. DFIG rotor provides all the power needed in magnetization in the form of reactive power.[55]

4.4.6 Selected Transformer

Transformers operate under one voltage of AC (alternating current) power to adjust the voltage to provide electricity on demand. A step-up transformer is used by wind power plants to increase the voltage, which decreases the necessary current and reduces power losses that occur when sending big currents over long distances via transmission lines. In designing a wind turbine generator power system, the step-up transformer is essential since it processes all of the energy produced. In this site, each layer of the wind turbine has a rated voltage of 0.69 kV, which is stepped up to 33 kV using a step-up transformer with a rating of 20 MVA. Figure 4.14 shows the ETAP model of the 15 MW wind system.

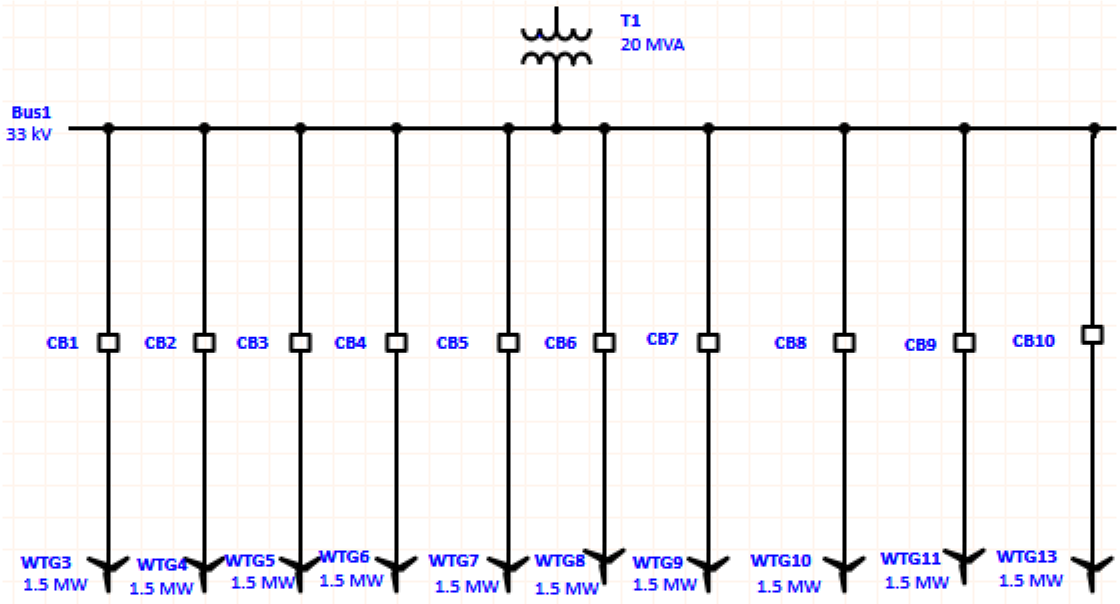

Figure 4- 13 Shows the ETAP Model of the 15 MW Wind System

4.4.7 Yearly Energy Production of the Wind System

Annual energy production is the total amount of energy generated by a wind energy system in a year. The total produced energy from wind farms per year is given by the following equation.[56]

$$E_{annu} = P_{rated} \times CF \quad \text{(Eq. no. 4.19)}$$

Where: E_{annu}=Total energy generated over a year (MWh)

P_{rated} =Wind turbine rated power (MW)

CF= capacity factor, which, for a large wind farm, can range from 20% to 42%.[57]

For this study, the capacity factor of a wind turbine can be taken as 0.21%. The wind power plant will produce the energy annually and this is acquired by Equation. (4.19).

$E_{annual} = 10turbines * 1.5MW * 0.21 * 8760$ =27,594MWh =27.6GWh

4.5 Optimization and Techno-Economic Analysis of the System

4.5.1 Economic Parameters

It is necessary to identify certain economic factors before assessing the study's economics. The discount rate in Ethiopia is 8 %.[58] The monitoring period average inflation rate of 1966-2023 GC was 10.2%.[59] This assessment extends to 2048, and the assumption here is that the grid connection will start functioning by the close of 2024 and the economic life of the grid connection will be 25 years. The total cost of a solar PV, including an inverter and all transportation, civil work, PV structures, and design, is 1855 USD/kW. [60]. According to recent information, the price of a wind turbine in Ethiopia per kW in 2024 is estimated to be around $2,950. [61] This also included details like operational and maintenance costs at 8% of the investment cost. The actual price per kWh of the EEU bill is 0.017 USD/kWh. A hybrid solar and wind system's grid sell-back price varies by location, energy provider, and government policy. In general, it falls between $0.01 and $0.15 per kilowatt-hour (kWh). The selection and system dimension creation have been done through the HOMER software. An input of one year of electrical load data has been given to perform the simulation. For the specified geographic location, HOMER has downloaded and entered the monthly average global radiation, monthly clearness index, and monthly average wind speeds.

Figure 4- 14 Load Profile of the Adama Industrial Park Under Analysis

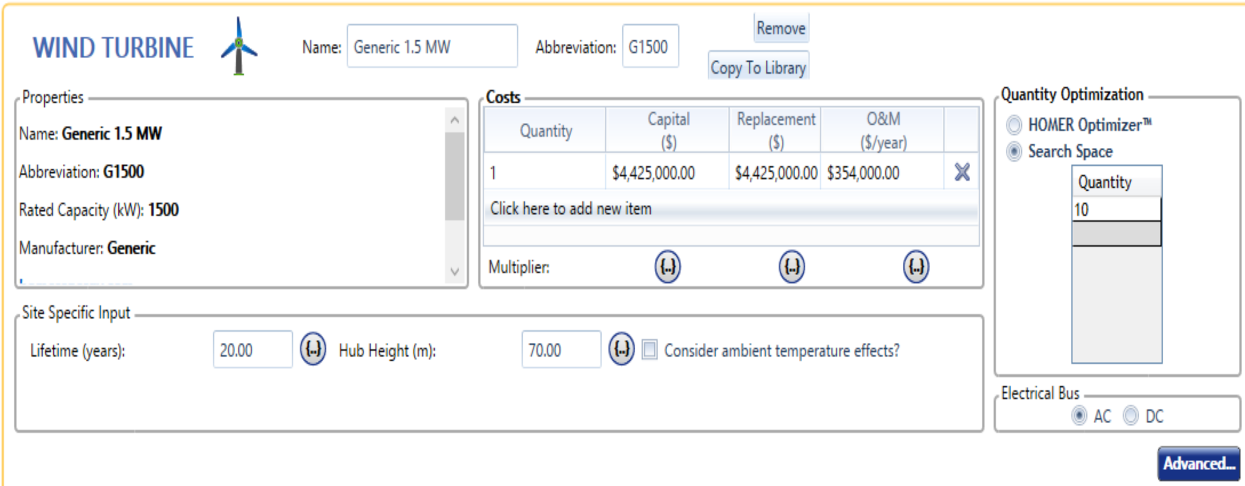

Figure 4- 15 Wind System Settings

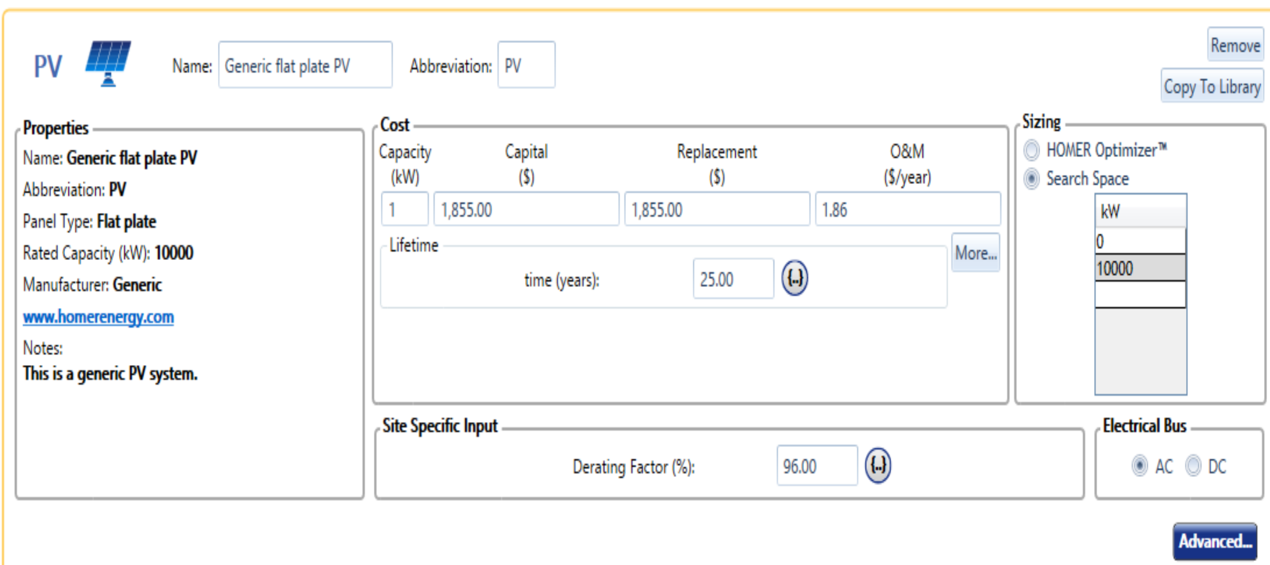

Figure 4- 16 PV Settings System

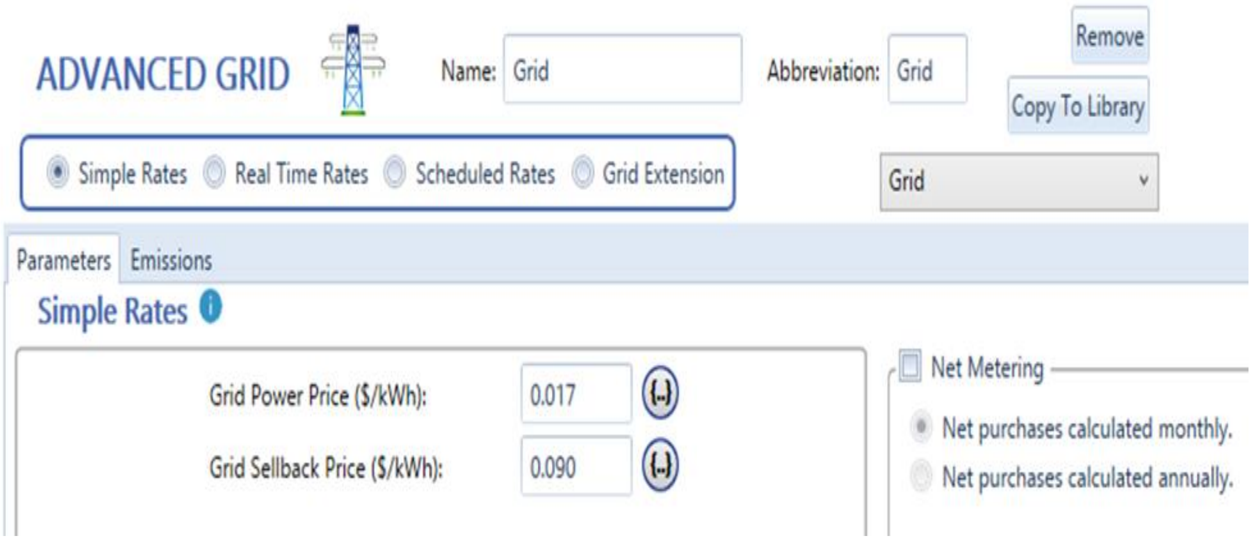

Figure 4- 17 Grid Setting of the System

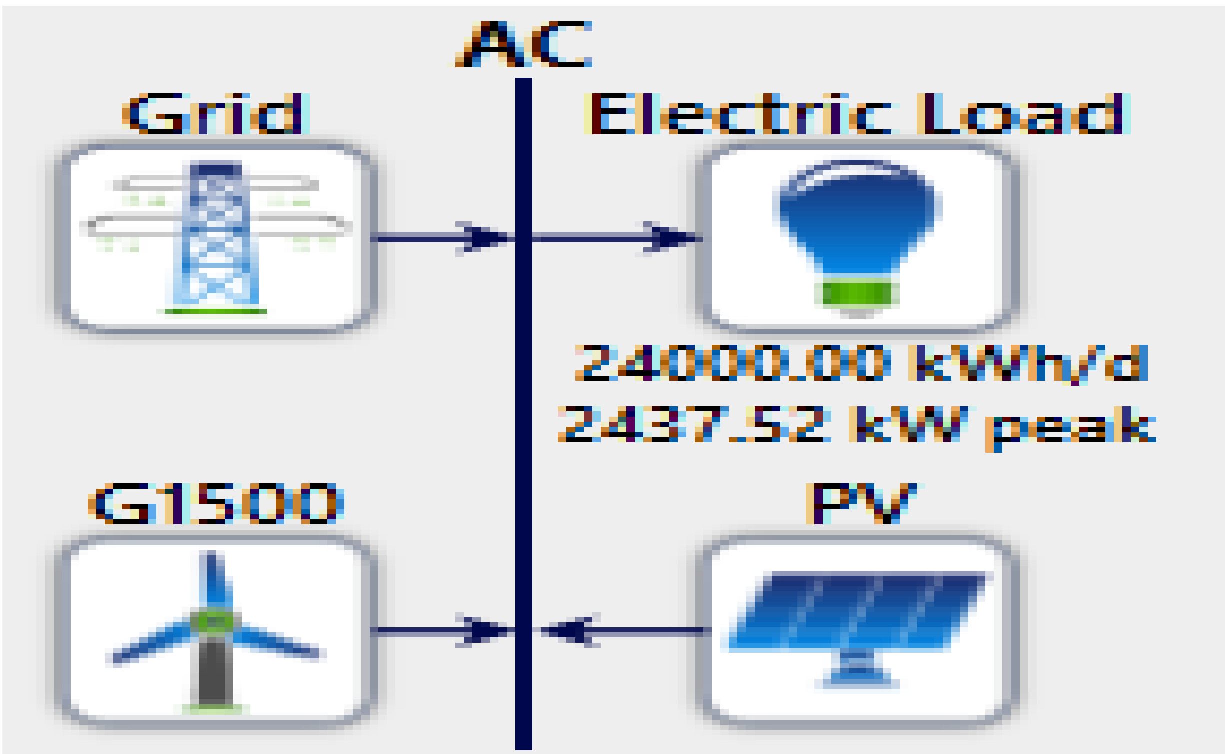

Figure 4- 18 Configuration of Grid Connected Hybrid Wind-Solar System in HOMER

4.5.2 Techno-Economic Grid-connected PV & Wind System Simulation

The system has been simulated and optimized to appraise its characteristics, electricity production, annual electricity load curve, renewable energy fraction, carbon emissions, etc. Load control following strategies have been used during the simulation; the addition of the central grid has been considered to ensure the product matches the required demand. The various simulations were ranked based on the customization of the different components based on the Levelized cost of energy and Net Present Cost. In Figure 4-19, the low-cost system layout can be viewed. HOMER has determined the optimal system to comprise a new photovoltaic array of 10,000kW and 10 wind turbines of 1500 kW each.

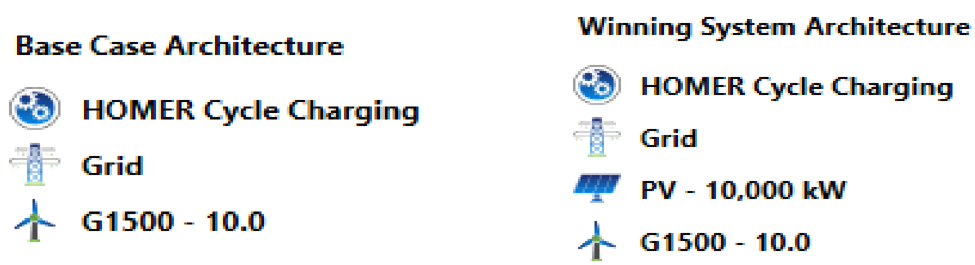

Figure 4- 19 Different Illustrations of System Architecture

Figures 4-20 show the optimization results for the hybrid power model with a grid-connected. For this grid-connected system, as shown in Fig., the cost of energy (COE) obtained the result of $0.0379, and the percentage of renewable energy contribution is 96.2%. In the suggested grid-connected architecture, an appropriate amount of renewable energy sources is turned on and provides power to the load. The net present cost (NPC) is $64.6 million.

Export...

Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

Architecture							Cost				System
PV	Wind	Grid	PV (kW)	G1500	Grid (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
PV	Wind	Grid	10,000	10	999,999	CC	$64.6M	$0.0379	$54,325	$62.8M	96.2
	Wind	Grid		10	999,999	CC	$107M	$0.103	$1.90M	$44.3M	90.4

Figure 4- 20 Optimization Results of Grid Connected

Production	kWh/yr	%
Generic flat plate PV	21,541,935	41.5
Generic 1.5 MW	28,385,359	54.7
Grid Purchases	1,957,913	3.77
Total	51,885,207	100

Consumption	kWh/yr	%
AC Primary Load	8,760,000	16.9
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	43,125,207	83.1
Total	51,885,207	100

Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	96.2	%
Max. Renew. Penetration	100	%

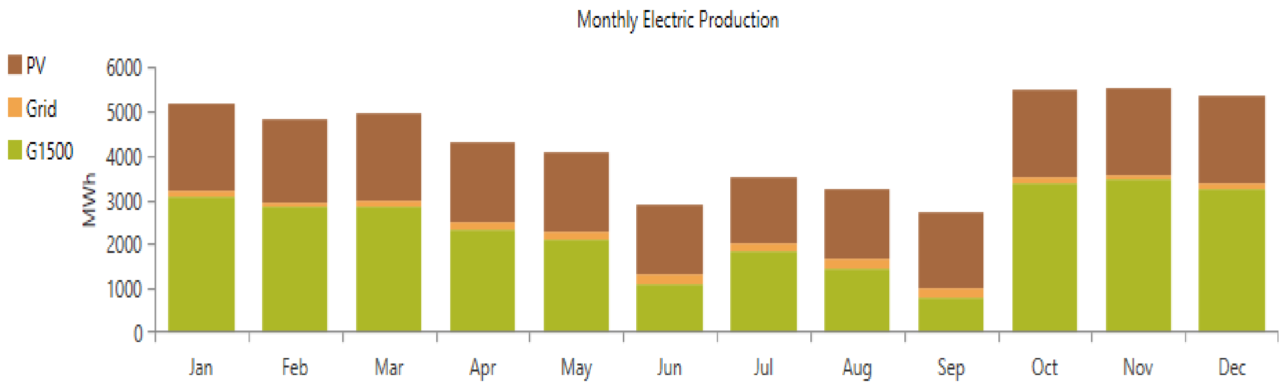

Figure 4- 21 Monthly Average Power Production of the Wind-Solar Hybrid System

Annual PV Output Variation and Wind Turbine Variation are shown in Figures 4-22 and 4-23, respectively.

Table 4- 9 Annual Generation Details of the Proposed PV System from Homer Pro

Quantity	Values	Units
Rated capacity	10,000	kW
Mean output	2,459	kW
Mean output	59,019	kWh/d
Maximum output	11,524	kW
Capacity factor	24.6	%
Hours of operation	4,423	hrs/yr
Total production	21,541,935	kWh/y

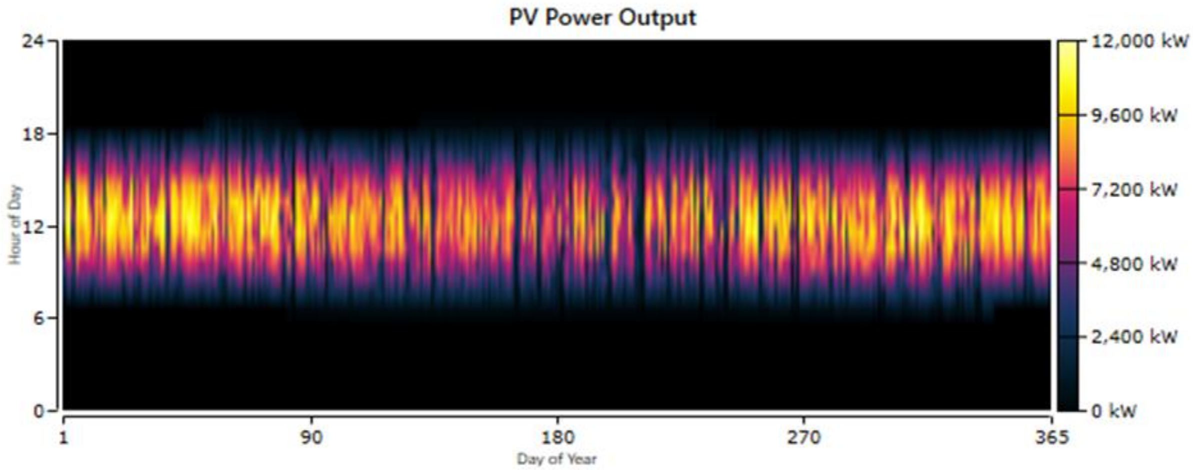

Figure 4- 22 Annual PV Output Variation

Table 4- 10 Annual Generation Details of the Proposed Wind Turbine from Homer Pro

Quantity	Values	Units
Total rated capacity	15,000	kW
Mean output	3,240	kW
Maximum output	15,000	kW
Capacity factor	21.6	%
Hours of operation	5,766	hrs/yr
Total production	28,385,359	kWh/yr

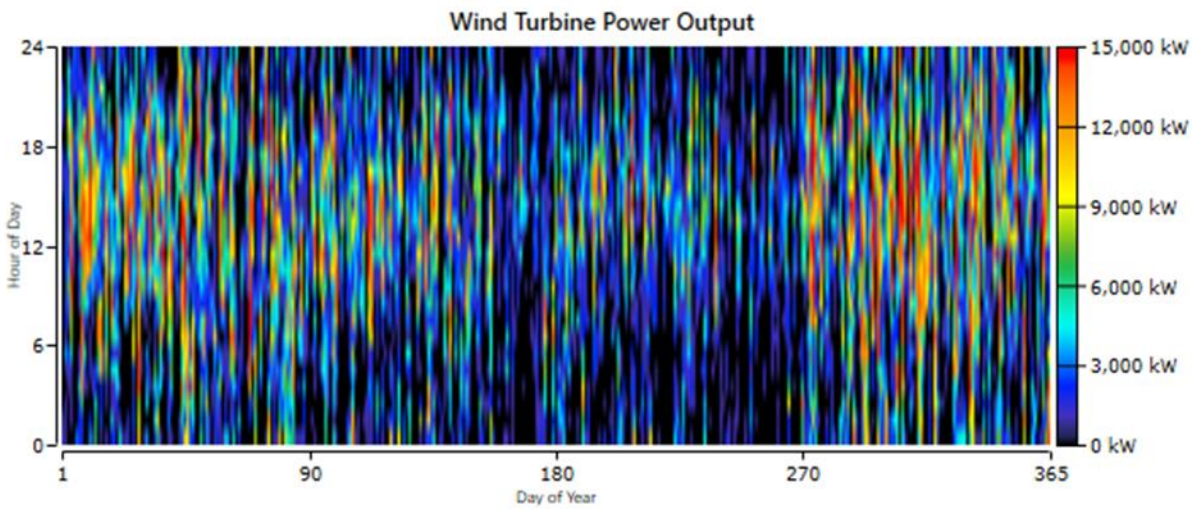

Figure 4- 23 Annual Wind Turbine Output Variation

4.5.3 Economic Analysis

The economic analysis summary shows that the project's Internal Rate of Return (IRR) is 8.7 %, with a Return on Investment (ROI) of 5.9%. The simple payback period is 10 years, and the discounted payback period is 9 years.

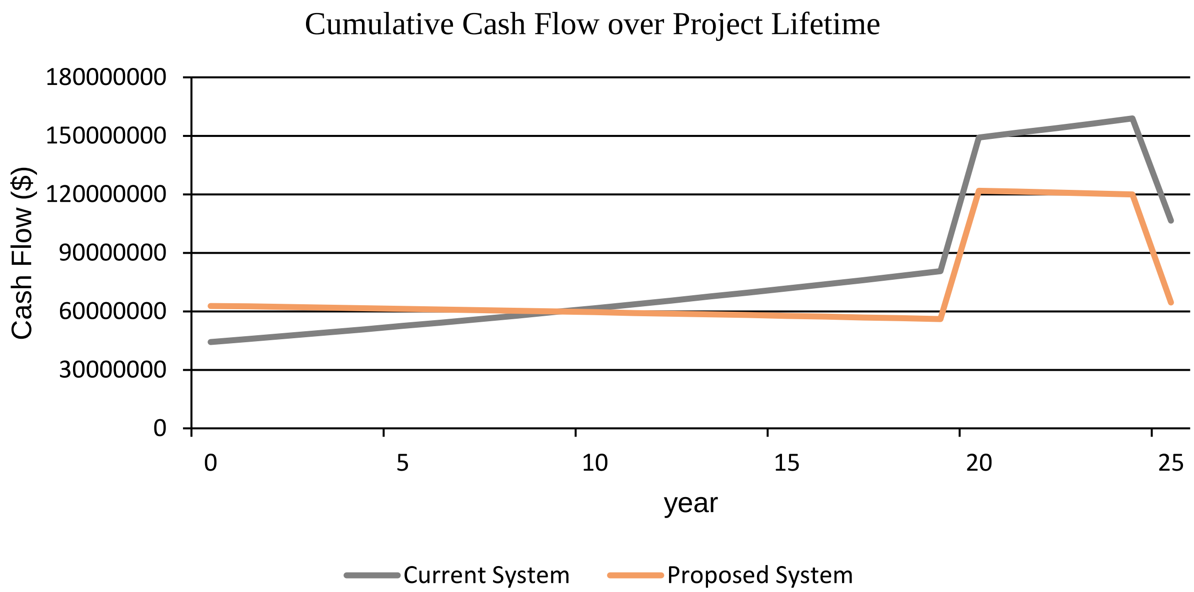

Figure 4- 25 The Forecasted Cash Flow of the Scenario and the Lowest-Cost System

Table 4- 11 Proposed Solar & Wind Grid Connected System Economic summary from Homer Pro

Component	Capital ($)	Replacement ($)	O&M ($)	Salvage ($)	Total ($)
Generic 1.5MW	44,250,000	66,232,333.38	116,245,801	54,944,030.45	-54,944,030.45
Generic flat plate PV	133,565,565	0	609,141.13	0	19,159,141.13
Grid	0	0	-126,359,319	0	-126,359,319.6
System	**62,800,000**	**66,232,333.38**	**-9,504,377.0**	**-54,944,030.45**	**$64,583,925.9**

Table 4- 12 Proposed system NPC and LCOE from Homer Pro

Indices	Base System ($)	Proposed System ($)
Net Present Cost	107M	64.6M
Initial Capital	44.3M	62.8M

LCOE (per kWh)	0.103/kWh	0.0379

4.6 Improvement and Analysis of Reliability using Power Factory

This section continues with a reliability simulation of the current AIP feeder, providing base case reliability (no DG) and the installation of the appropriate DG technology for a particular location and further simulation also presents an analysis of the results achieved. In order to improvement power reliability, this section also shows how distributed generation (DG) can be placed at a specific area.

During modifying of reliability analysis using power factory software the failure inputs given to each equipment is shown in table 4.14. However, the failure data are obtained from different researches because of EEP and EEU have no such data is available. Electrical and failure inputs are present in all equipment. The modified substation with DG below serves as an example of a line used in a distribution system. It receives its ratings, such as voltage and current ratings, and the failure inputs are the frequency and duration of interruptions.

Table 4- 13 Electrical Equipment and Failure Inputs[34]

Equipment name	Repair duration (Hr.)	Interruption Frequency(1/km*a)	Voltage level (kV)
External grid	0.12	0.675	132
Main Transformer	120	0.015	132
Distribution Transformers	200	0.015	15
Lines	0.8	18	15

The distribution system shown in Figure 4.25 receives 132 kV from the Awashe Melkasa substation and feeds a 31.5 MVA transformer. These transformers step down the voltage from 132 to 33 kV, and then industries will be supplied by their corresponding two feeders.

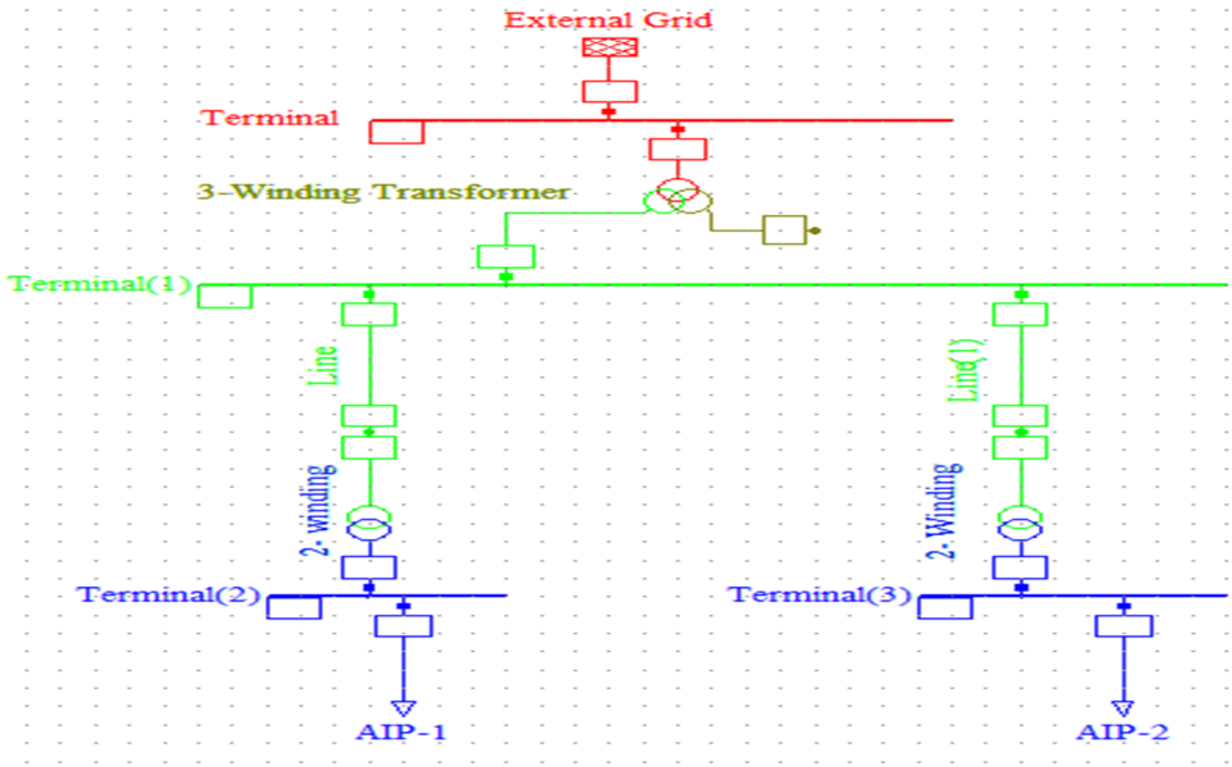

Figure 4- 26 One-line diagram from Awashe Melkasa substation to AIP

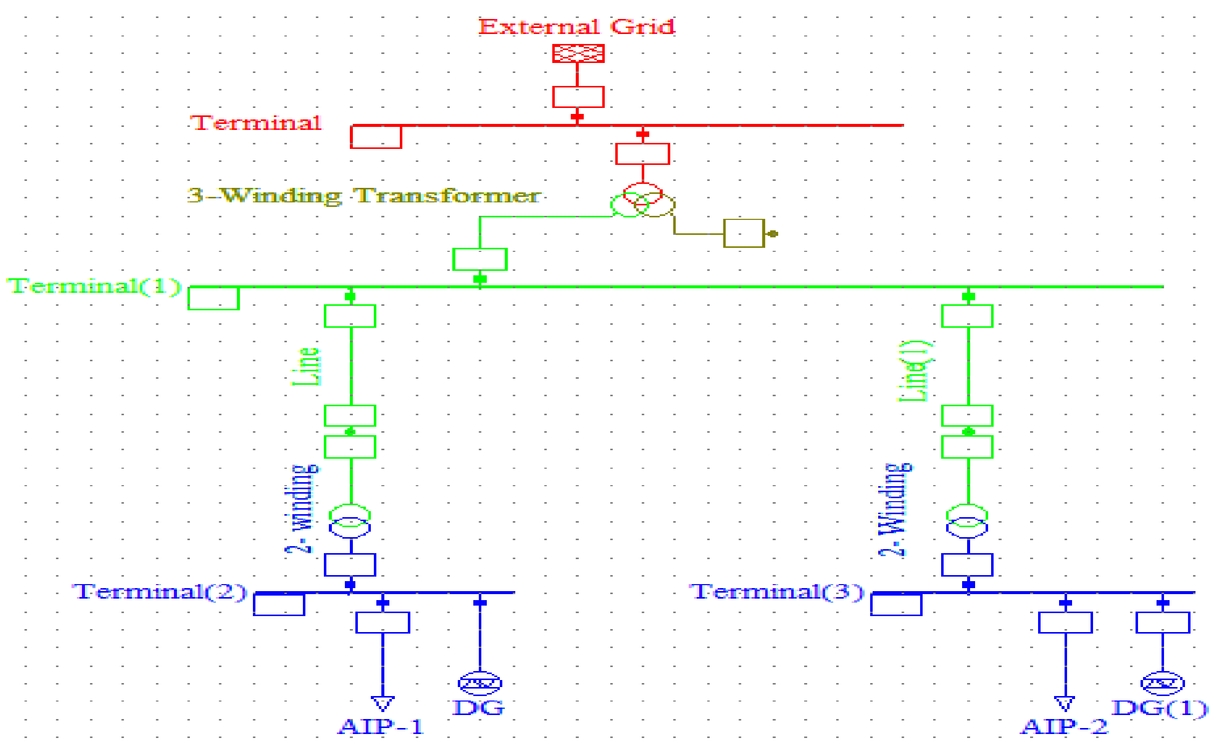

Figure 4- 27 Modified One-line diagram from Awashe Melkasa substation to AIP

4.6.1 Base Case Reliability Indices (with no DG)

In this case, the reliability indices are the same as calculated values when it is simulated in the DigSilent software shown below.

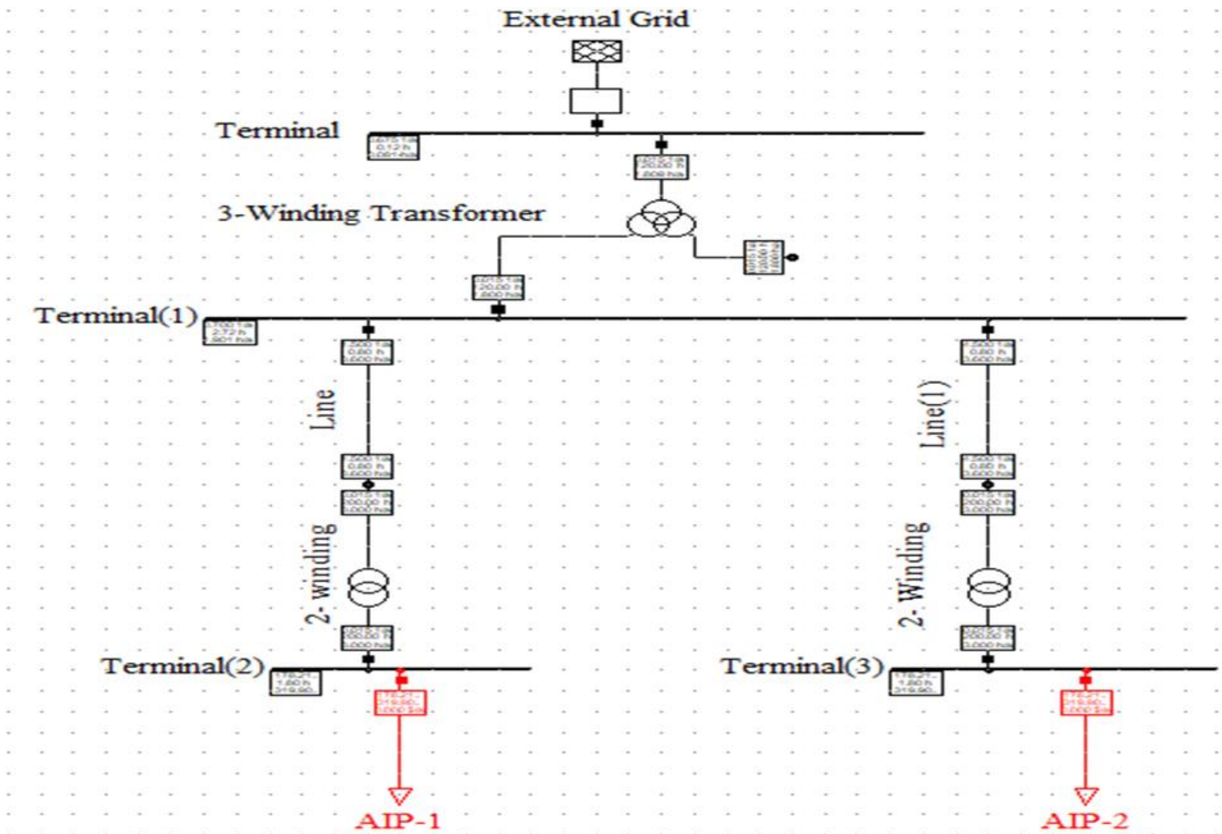

Figure 4- 28 Modeling base case reliability indices

Table 4- 14 Base case reliability indices

Study Case: Study Case					Annex:
System Summary					
System Average Interruption Frequency Index	:	SAIFI	=	178.215000 1/Ca	
Customer Average Interruption Frequency Index	:	CAIFI	=	178.215000 1/Ca	
System Average Interruption Duration Index	:	SAIDI	=	319.901 h/Ca	
Customer Average Interruption Duration Index	:	CAIDI	=	1.795 h	
Average Service Availability Index	:	ASAI	=	0.9634816219	
Average Service Unavailability Index	:	ASUI	=	0.0365183781	

Study Case: Study Case					Annex:
System Summary					
Energy Not Supplied	:	ENS	=	5861.216 MWh/a	
Average Energy Not Supplied	:	AENS	=	2930.608 MWh/Ca	
Average Customer Curtailment Index	:	ACCI	=	1971.940 MWh/Ca	
Expected Interruption Cost	:	EIC	=	0.000 M$/a	
Interrupted Energy Assessment Rate	:	IEAR	=	0.000 $/kWh	
System energy shed	:	SES	=	0.000 MWh/a	
Average System Interruption Frequency Index	:	ASIFI	=	178.214681 1/a	
Average System Interruption Duration Index	:	ASIDI	=	319.900418 h/a	
Momentary Average Interruption Frequency Index	:	MAIFI	=	0.000000 1/Ca	

As the result shown above table 4.15 reliability indices are so much less as compared to EEAs. This implies that the feeder needs more improvement with DG for both the advantage of the utility and the customer.

Table 4- 15 Reliability Indices at Base Case Simulated Value and Analytical Value

Reliability Indices	DigSILENT simulation	Analytical Value
SAIFI	178.21 Inter. / customer /yr.	173.667 Inter. / customer /yr.
SAIDI	319.9 Hrs. / customer. /yr.	318.178 Hrs. / customer. /yr.
CAIDI	1.795 Hrs./customer interruption	1.843 Hrs./customer interruption
ASAI	96.34%	96.4%
ASUI	3.65%	3.6%
ENS	5861.2 MWh/yr	3063.57 MWh/yr

4.6.2 Integrating DG (Only PV System) at AIP-1

From the results in Table 4.15, the overall system has improved in SAIFI, SAIDI, and ENS by 48.53%, 48.7%, and 44.1%, respectively. In this case study, it is shown that the presence of DG at the feeder has a positive impact on the power system's reliability. That means that the indices were reduced by the integration of DG into the overall system.

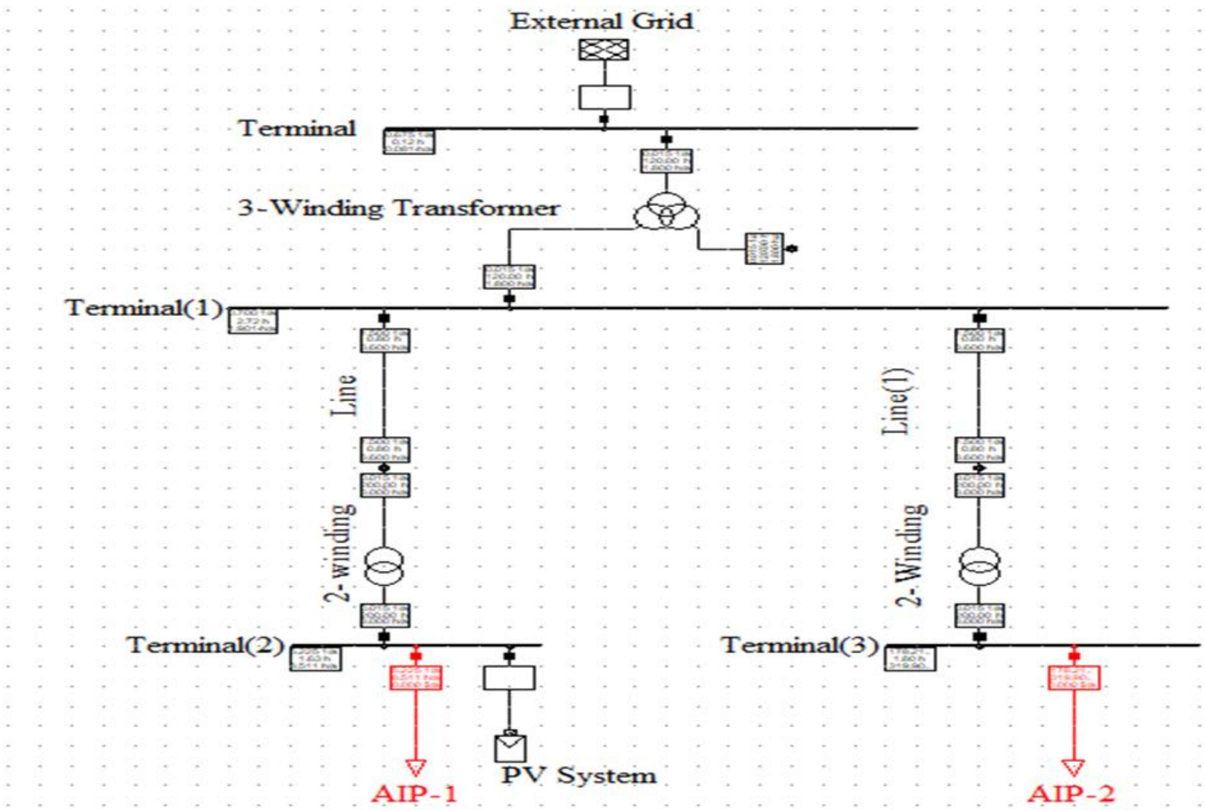

Table 4- 16 Reliability indices DG placed at AIP-1 feeder

Study Case: Study Case | Annex:

System Summary

System Average Interruption Frequency Index	SAIFI	= 91.720000	1/Ca
Customer Average Interruption Frequency Index	CAIFI	= 91.720000	1/Ca
System Average Interruption Duration Index	SAIDI	= 164.206	h/Ca
Customer Average Interruption Duration Index	CAIDI	= 1.790	h
Average Service Availability Index	ASAI	= 0.9812550233	
Average Service Unavailability Index	ASUI	= 0.0187449767	

Study Case: Study Case | Annex:

System Summary

Energy Not Supplied	ENS	= 3276.687	MWh/a
Average Energy Not Supplied	AENS	= 1638.343	MWh/Ca
Average Customer Curtailment Index	ACCI	= 1314.452	MWh/Ca
Expected Interruption Cost	EIC	= 0.000	M$/a
Interrupted Energy Assessment Rate	IEAR	= 0.000	$/kWh
System energy shed	SES	= 0.000	MWh/a
Average System Interruption Frequency Index	ASIFI	= 99.849186	1/a
Average System Interruption Duration Index	ASIDI	= 178.838907	h/a
Momentary Average Interruption Frequency Index	MAIFI	= 0.000000	1/Ca

4.6.3 Integrating DG in both feeders

As shown in Table 4.17, applying PV to AIP-1 and wind energy to AIP-2 improved SAIFI=97.1%, SAIDI=97.33%, and ENS=97.33% overall system reliability indices. This large improvement was achieved by combining two DGs of 10 MW PV systems with 15 MW wind energy, resulting in an improvement of almost 97%.

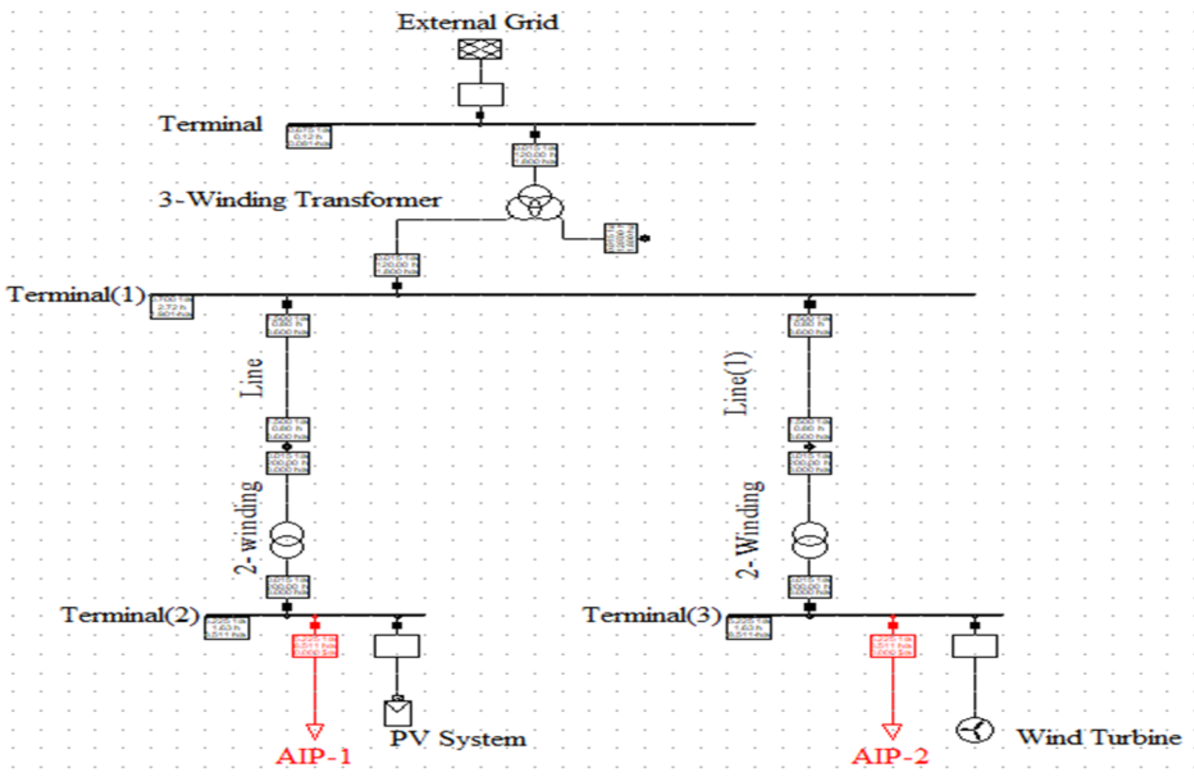

Table 4- 17 Reliability indices DG placed at both feeder

```
-----------------------------------------------------------------------------------------------------------
| Study Case: Study Case                                                                      | Annex:
-----------------------------------------------------------------------------------------------------------
| System Summary
-----------------------------------------------------------------------------------------------------------
| System Average Interruption Frequency Index          :  SAIFI  =     5.225000 1/Ca
| Customer Average Interruption Frequency Index        :  CAIFI  =     5.225000 1/Ca
| System Average Interruption Duration Index           :  SAIDI  =     8.511      h/Ca
| Customer Average Interruption Duration Index         :  CAIDI  =     1.629      h
| Average Service Availability Index                   :  ASAI   =     0.9990284246
| Average Service Unavailability Index                 :  ASUI   =     0.0009715754
-----------------------------------------------------------------------------------------------------------
□----------------------------------------------------------------------------------------------------------
| Study Case: Study Case                                                                      | Annex:
-----------------------------------------------------------------------------------------------------------
| System Summary
-----------------------------------------------------------------------------------------------------------
| Energy Not Supplied                                  :  ENS    =   155.938    MWh/a
| Average Energy Not Supplied                          :  AENS   =    77.969    MWh/Ca
| Average Customer Curtailment Index                   :  ACCI   =    77.453    MWh/Ca
| Expected Interruption Cost                           :  EIC    =     0.000    M$/a
| Interrupted Energy Assessment Rate                   :  IEAR   =     0.000    $/kWh
| System energy shed                                   :  SES    =     0.000    MWh/a
| Average System Interruption Frequency Index          :  ASIFI  =     5.224998 1/a
| Average System Interruption Duration Index           :  ASIDI  =     8.510997 h/a
| Momentary Average Interruption Frequency Index       :  MAIFI  =     0.000000 1/Ca
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CHAPTER FIVE

5. CONCLUSION, RECOMMENDATION, AND FUTURE WORK

This chapter deals with the conclusion mentioning all the necessary points from the result according to the objective of the study. It also remarks on the recommendation of this thesis for future works.

5.1 Conclusions

The main objective of this research is to improve the reliability of the Adama Industrial Park feeder through the use of renewable distributed generation or design available solar and wind energy. As a result, the analysis indicates that there is a serious reliability issue with the power distribution system in the Adama Industrial Park feeder. It has been accomplished by carefully gathering and analyzing data that was acquired from the distribution substation. The collected data are recorded data that include the type of faults, frequency, and duration of interruption in the 33 kV outgoing feeders of the distribution substation. The Adama Industrial Park was also found to be the major cause of interruptions. The most common major faults at Adama Industrial Park are 36% overcurrent, 3% short circuits, 52% earth faults, and the remaining 9% maintenance interruptions per year.

Additionally, the reliability of the indices (SAIDI, SAIFI, CAIDI, and EENS) for the three years was consecutively determined, evaluated, and the results were given in this study. The calculated results for the essential indices SAIDI and SAIFI have been compared with standard benchmarks of the most developed countries. The overall base case for AIP feeder SAIFI = 178 interruptions/customer/year, SAIDI = 319 hours/customer/year, CAIDI = 1.8Hrs./customer interruption, ASAI = 96.34%, ASUI = 3.66%, and ENS = 5861.2 MWh/year. Due to this, the system is not reliable by the standards of the Ethiopian Electric Agency (EEA).

After modeling the 10 MW polycrystalline grid-connected PV system, the findings demonstrate that 1634 strings with 18 modules in series must be installed for each field. 29412 modules will be required for this system, and they must be put in a minimum of 57070 m^2 of space. Additionally, A 15 MW wind farm was designed as ten 1.5MW units. The selection of a 70m hub height takes advantage of a proper mixing of the energy yield and the costs for the tower and foundation. The wind speed at an average of 7.08 m/s is experienced at this height.

HOMER has determined the optimal system to comprise a new photovoltaic array of 10000 kW and 10 wind turbines of 1500 kW each. The optimization results for the hybrid power model with a grid-connected. For this grid-connected system, the cost of energy (COE) obtained the result of $0.0379, and the percentage of renewable energy contribution is 96.2%. The net present cost (NPC) is $64.6M. According to the economic analysis summary, the IRR is 8.7%, while the ROI is 5.9%. The project will take 10 years to recover the investment using the simple payback method, while the discounted payback period is just 9 years.

After integrating DG into the AIP feeder, the simulation values of SAIFI, SAIDI, and ENS are 5.22 interruptions per customer per year, 8.55 hours per customer per year, and 155.9 MWh/year, respectively. In the presence of DG, the reliability indices SAIFI, SAIDI, and ENS are reduced by 97.1%, 97.33%, and 97.33%, respectively. The results show that DG integration effectively improves the reliability of the AIP feeder.

5.2 Recommendation and Future Work

According to this study, Ethiopia should have a separate source of renewable energy for industrial parks, giving a good understanding and inspiration for the development of such a project. As a result, the energy allocated for these parks can also benefit both rural and urban communities. The concept of perfection can be achieved by delivering energy with excellence through additional effort. The following can be taken as a recommendation.

- In Adama Industrial Parks, the company should continue to keep accurate records of interruptions.
- As a result of this thesis, and further development regarding solar PV assessment, wind assessment, and HOMER optimization, it is expected to be possible to predict a more detailed result structure going forward.
- Various governmental stakeholders must permit independent power producers to provide excess energy to the grid system and avoid energy waste.
- Different distributed generation options other than PV and wind technologies can be studied for this industrial park reliability improvement.
- To facilitate the on-grid connectivity of industrial parks and for efficient planning, various parties like the Ministry of Water, Irrigation, and Electricity (MOWIE) and/or Ethiopia Electric Authority (EEA) are taking part.

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Appendix A: Interruption Data for Adama Industrial Park Feeder

Table A-1 Interruption Data for AIP 33kV feeder for the Year 2021 G.C

Feeder Name	Interrupted		Reconnected		Duration time	Duration (hr.)	Fault type	Cause of interruption
AIP Feeder	Date	Time	Date	Time				
	5/1/2013	20:50	5/1/2013	21:15	0:25	0.416	Permanent	Tripped
	12/1/2013	15:33	12/1/2013	15:38	0:05	0.0833	Transient	Over Current
	13/01/13	8:05	13/01/13	8:59	0:54	0.9	Permanent	Earth fault
	15/01/13	8:10	15/01/13	8:16	0:06	0.1	Permanent	Over current &E/F
	17/01/13	13:05	17/01/13	15:43	2:38	2.6333	Permanent	Over current &E/F
	18/01/13	12:16	18/01/13	12:25	0:09	0.15	Permanent	Over current & E/F
	19/01/13	7:11	19/01/13	7:19	0:08	0.133	Permanent	Over current &E/F
	20/01/13	9:28	20/01/13	9:43	0:15	0.25	Permanent	Over Current
		9:49		13:00	3:11	3.1833	Permanent	Over Current
	21/01/13	13:06	21/01/13	13:14	0:08	0.1333	Permanent	Over Current
	24/01/13	16:08	24/01/13	16:15	0:07	0.1166	Permanent	Earth fault
	25/01/13	11:46	25/01/13	11:52	0:06	0.1	Permanent	Over Current
	26/01/13	0:07	26/01/13	6:42	0:35	0.5833	Permanent	Over Current
		16:50		16:54	0:04	0.0666	Transient	Over current & E/F
	27/01/13	16:12	27/01/13	18:17	2:15	2.25	Permanent	Over current & E/F
	28/01/13	16:41	28/01/13	16:49	0:08	0.133	Permanent	Over current & E/F
	5/3/2013	8:50	5/3/2013	18:13	9:23	9.3833	Permanent	Over current & E/F
		19:37		9:24	13:47	13.7833	Permanent	Over Current
	7/3/2013	10:14	7/3/2013	10:18	0:04	0.0666	Transient	Over Current
		12:48	7/3/2013	15:36	2:48	2.8	Permanent	Over Current
	14/03/13	8:15	14/03/13	10:15	2:00	2	Operation	By request
	17/03/13	15:41	17/03/13	15:55	0:14	0.233	Permanent	Over Current
	19/03/13	7:20	20/03/13	8:53	1:33	1.55	Permanent	Over Current
	20/03/13	11:23	20/03/13	11:27	0:04	0.066	Permanent	Over Current
	6/4/2013	16:51	6/4/2013	16:54	0:03	0.05	Transient	Over Current
	8/4/2013	7:32	8/4/2013	8:14	0:42	0.7	Permanent	Over Current
	10/4/2013	18:18	10/4/2013	19:10	0:52	0.8666	Permanent	Over Current
	11/4/2013	15:45	11/4/2013	15:50	0:05	0.0833	Permanent	Over current & E/F
	13/04/13	16:43	13/04/13	16:50	0:07	0.1166	Permanent	Over current & E/F

	15/04/13	7:30	15/04/13	8:36	1:06	1.1	Permanent	Over current & E/F
	5/5/2013	6:50	5/5/2013	8:54	2:04	2.066	Permanent	Over current & E/F
	7/5/2013	7:21	7/5/2021	7:25	0:04	0.066	Permanent	Over current & E/F
		7:25		8:14	0:49	0.8166	Permanent	Over current & E/F
	24/05/13	6:15	24/05/13	6:47	0:32	0.5333	Permanent	Earth fault
		8:14		8:29	0:15	0.25	Permanent	over current
	27/05/13	3:20	27/05/13	10:10	6:50	6.833	Permanent	o/c & E/F
	28/05/13	0:05	29/05/13	5:10	5:05	5.083	Permanent	Earth fault
	30/05/13	7:39	30/05/13	9:21	1:42	1.7	Permanent	Earth fault
		11:30		11:35	0:05	0.0833	Permanent	over current
		11:39		13:08	1:29	1.4833	Permanent	Over current & E/F
	1/6/2013	5:35	1/6/2013	9:20	3:45	3.75	Permanent	Over current & E/F
	2/6/2013	14:46	2/6/2013	15:02	0:16	0.2666	Permanent	Over current & E/F
		6:00		11:17	5:17	5.2833	Permanent	over current
	12/6/2013	1:10	12/6/2013	12:23	11:13	11.2166	Permanent	over current
	10/7/2013	6:37	10/7/2013	7:46	1:09	1.15	Permanent	over current
	30/07/13	7:46	30/07/13	9:29	1:43	1.7166	Permanent	over current
		10:07		11:10	1:03	1.05	Permanent	Over current & E/F
	2/8/2013	7:30	2/8/2013	9:02	1:32	1.5333	Permanent	Over current & E/F
	3/8/2013	10:45	3/8/2013	10:55	0:10	0.1666	Permanent	Over current & E/F
	6/8/2013	6:04	6/8/2013	6:35	0:31	0.5166	Permanent	over current
		6:35		10:19	3:44	3.7333	Permanent	over current
		10:57		14:05	3:08	3.1333	Permanent	Over current & E/F
	7/8/2013	15:38	7/8/2013	16:42	1:04	1.0666	Permanent	Over current & E/F
	8/8/2013	6:22	8/8/2013	6:25	0:03	0.05	Transient	Over current & E/F
		14:59		15:04	0:05	0.0833	Permanent	over current
		16:26		16:32	1:26	1.4333	Permanent	over current
		16:59		17:10	0:11	0.1833	Permanent	over current
	9/8/2013	7:15	9/8/2013	11:46	4:31	4.5166	Permanent	over current
	10/8/2013	19:11	10/8/2013	19:44	0:33	0.55	Permanent	over current
		22:33		8:30	9:27	9.45	Permanent	over current
	17/08/13	11:04	17/08/13	11:27	0:23	0.3833	Permanent	over current
	18/08/13	12:30	18/08/13	15:56	3:26	3.4333	Permanent	Earth fault
	19/08/13	11:05	19/08/13	13:40	2:35	2.5833	Permanent	over current
	21/08/13	13:19	21/08/13	13:29	0:20	0.3333	Permanent	over current&

								E/F
		13:41	22/08/13	19:29	5:48	5.8	Permanent	Over current & E/F
	11/9/2013	15:28	11/9/2013	16:08	0:48	0.8	Permanent	Over current & E/F
	30/09/13	22:21	30/09/13	22:27	0:06	0.1	Permanent	Over current & E/F
	1/10/2013	11:20	1/10/2013	12:10	0:50	0.8333	Permanent	Over current & E/F
		15:07		15:14	0:07	0.1166	Permanent	Over current & E/F
		17:42		17:58	0:16	0.2666	Permanent	Over current & E/F
	3/10/2013	18:16	3/10/2013	19:03	0:47	0.7833	Permanent	Over current & E/F
	5/10/2013	16:15	5/10/2013	17:15	1:00	1	Operation	By request
	7/10/2013	15:37	7/10/2013	17:25	1:48	1.8	Operation	By request
	10/10/2013	11:20	10/10/2013	11:23	0:03	0.05	Transient	Over current & E/F
	23/10/13	15:41	23/10/13	15:44	0:03	0.05	Transient	Over current & E/F
	30/10/13	4:40	30/10/13	7:32	2:52	2.8666	Blackout	Under frequency
	4/11/2013	8:03	4/11/2013	13:17	5:14	5.2333	Operation	By request
	11/11/2013	7:34	11/11/2013	10:25	2:51	2.85	Permanent	Over current & E/F
	12/11/2013	9:43	12/11/2013	10:23	0:40	0.6666	Operation	By request
	13/11/13	9:05	13/11/13	9:19	0:14	0.2333	Permanent	Over current
	15/11/13	15:08	15/11/13	15:16	0:08	0.1333	Permanent	Over current
	16/11/13	13:09	16/11/13	13:27	0:18	3	Permanent	Over current
	18/11/13	8:58	18/11/13	16:40	7:42	7.7	Operation	By request
	21/11//13	19:25	21/11//13	19:35	0:10	0.1666	Permanent	Over current
		21:30		21:50	0:20	0.3333	Operation	By request
	24/11/13	12:22	24/11/13	15:50	3:28	3.4666	Operation	By request
	25/11/13	9:54	25/11/13	12:58	3:04	3.0666	Operation	By request
	27/11/13	16:08	27/11/13	16:11	0:03	0.05	Transient	Over current & E/F
	28/11/13	18:30	28/11/13	18:45	0:15	0.25	Permanent	Over current
	29/11/13	8:18	29/11/13	10:28	2:10	2.1666	Permanent	Over current & E/F
	30/11/13	17:50	30/11/13	17:53	0:03	0.05	Transient	Over current & E/F
	7/12/2013	12:43	7/12/2013	12:47	0:04	0.0666	Permanent	Over current & E/F
	13/12/13	16:27	13/12/13	16:32	0:05	0.0833	Permanent	Over current & E/F
	15/12/13	0:07	15/12/13	13:50	13:43	13.7166	Permanent	Over current & E/F
	16/12/13	13:35	16/12/13	16:44	3:09	3.15	Operation	By request
		16:44		19:50	3:06	3.12	Permanent	Over current &

								E/F
	17/12/13	16:25	17/12/13	18:29	2:04	2.0666	Operation	By request
	18/12/13	10:56	18/12/13	11:17	0:21	0.35	Operation	By request
	19/12/13	1:15	19/12/13	7:14	5:59	5.9833	Permanent	Over current & E/F
	19/12/13	12:16	19/12/13	15:52	3:36	3.6	Operation	By request
	20/12/13	20:45	20/12/13	21:06	0:21	0.35	Permanent	Over current & E/F
	27/12/13	15:43	27/12/13	17:41	1:58	1.966	Permanent	Over current & E/F
	1/13/2013	10:37	1/12/2013	10:40	0:03	0.05	Transient	Over current & E/F
	4/13/2013	2:02	4/12/2013	9:08	7:06	7.1	Permanent	Over current & E/F

Table A-2 Interruption Data for AIP 33kV feeder for the Year 2022 G.C

Feeder Name	**Interrupted**		**Reconnected**		**Duration time**	**Duration (hr.)**	**Type of fault**	**Cause of interruption**
AIP feeder 1	Date	Time	Date	Time				
	1/1/2014	14:15	1/1/2014	14:20	0:05	0.0833	Permanent	Over current and E/F
	8/1/2014	16:25	8/1/2014	16:32	0:07	0.1167	Permanent	Over current and E/F
	16/01/14	9:10	16/01/14	9:13	0:03	0.05	Transient	Over current and E/F
	22//01/14	22:43	22/01/14	23:37	0:54	0.9	Permanent	Over current and E/F
	22/01/14	23:37	23/01/14	8:06	16:29	16.4833	Permanent	Over current and E/F
	23/01/14	8:42	23/01/14	9:04	0:22	0.367	Permanent	Over current and E/F
	24/01/14	7:38		7:52	0:14	0.2333	Permanent	Due to feeder CB
		12:37		12:48	0:11	0.1833	Permanent	Over current & E/F
		13:22		15:06	1:44	1.734	Permanent	Due to feeder CB
	25/01/14	16:44	25/01/14	17:42	0:58	0.967	Permanent	Due to feeder CB
	28/01/14	7:09	28/01/14	7:25	0:16	0.267	Permanent	Over current
	30/01/14	8:05	30/01/14	9:25	1:20	1.334	Operation	By request
	1/2/2014	0:45	1/2/2014	0:58	0:13	0.217	Permanent	Earth fault
	1/2/2014	0:58	1/2/2014	7:24	6:26	6.434	Permanent	Earth fault
	1/2/2014	10:53	1/2/2014	12:03	1:10	1.167	Permanent	Over current
	2/2/2014	11:03	2/2/2014	11:35	0:32	0.534	Permanent	Over current
	2/2/2014	13:21	2/2/2014	14:07	0:46	0.767	Permanent	Over current
	3/2/2014	9:24	3/2/2014	12:16	2:52	2.867	Operation	By request
	6/2/2014	9:18	6/2/2014	9:29	0:11	0.184	Permanent	Earth fault

	6/2/2014	13:10	6/2/2014	13:19	0:09	0.15	Permanent	Over current
	9/2/2014	10:09	9/2/2014	10:18	0:09	0.15	Permanent	Over current
	9/2/2014	13:24	9/2/2014	13:36	0:12	0.2	Permanent	Over current
	9/2/2014	13:49	9/2/2014	14:55	1:06	1.1	Permanent	Over current
	9/2/2014	15:34	9/2/2014	16:34	1:00	1	Permanent	Over current
	10/2/2014	13:06	10/2/2014	13:15	0:09	0.15	Permanent	Over current
	10/2/2014	13:39	10/2/2014	14:43	1:04	1.067	Permanent	Over current and earth fault
	11/2/2014	9:45		13:42	3:57	3.95	Permanent	Over current
	12/2/2014	5:45		7:19	1:34	1.567	Permanent	Over current and earth fault
		7:24		13:50	6:26	6.434	Permanent	Earth fault
		17:15		17:21	0:06	0.1	Permanent	Earth fault
	16/2/14	10:07		10:13	0:06	0.1	Permanent	Over current
		13:26		13:35	0:09	0.15	Permanent	Over current
	17/2/14	13:10		13:20	0:10	0.1667	Permanent	Over current
	19/2/14	8:17		8:23	0:06	0.1	Permanent	Over current
		14:55		15:03	0:08	0.1334	Permanent	Earth fault
	21/2/14	23:13	22/2/14	6:58	17:45	17.75	Permanent	Over current
	23/2/14	11:10		11:18	0:08	0.1334	Permanent	Over current and earth fault
	24/2/14	7:01		8:47	1:46	1.767	Permanent	Opened
	25/2/14	6:07		6:19	0:12	0.2	Permanent	Earth fault
	28/2/14	8:26		8:54	0:28	0.467	Operation	By request
	29/2/14	9:50		10:00	0:10	0.1667	Permanent	Over current
		14:03		14:17	0:14	0.2334	Permanent	Over current
		14:50		15:45	0:55	0.9167	Permanent	Over current
	30/2/14	8:05		8:11	0:06	0.1	Permanent	Over current
		9:03		9:09	0:06	0.1	Permanent	Over current
		9:26		9:30	0:04	0.067	Permanent	Over current
		10:23		13:11	2:48	2.8	Permanent	Over current
		14:17		15:20	1:03	1.05	Operation	By request
	1/3/2014	10:15		10:30	0:15	0.25	Permanent	Over current and earth fault
		10:50		14:53	4:03	4.05	Permanent	Over current
	2/3/2014	10:17		17:46	7:29	7.4834	Permanent	Feder opened
	3/3/2014	10:53		12:56	2:03	2.05	Permanent	Feder opened
	11/3/2014	12:35		12:40	0:05	0.0834	Permanent	Earth fault
	14/3/14	14:38		15:54	1:16	1.2667	Permanent	Short circuit
	18/3/14	10:57		11:57	1:00	1	Permanent	Opened
	20/3/14	15:15		15:30	0:15	0.25	Permanent	Over current
	28/3/14	14:14		14:25	0:09	0.15	Permanent	Over current

	30/3/14	10:03		10:13	0:10	0.1667	Permanent	Over current
	4/4/2014	7:35		8:32	0:57	0.95	Permanent	Earth fault
	6/4/2014	8:58		9:23	0:25	0.4167	Permanent	Over current
	7/4/2014	14:45		14:53	0:08	0.1334	Permanent	Over current
	10/4/2014	7:40		9:35	1:55	1.9167	Permanent	Opened
	13/4/14	6:44		6:53	0:09	0.15	Permanent	Earth fault
		16:06		16:10	0:04	0.0667	Permanent	Short circuit
		16:51		16:58	0:07	0.1167	Permanent	Short circuit
		18:18		18:59	0:41	0.6834	Permanent	Short circuit
		21:44	14/4/14	9:38	13:54	13.9	Permanent	Earth fault
	23/4/14	18:23		18:27	0:04	0.067	Permanent	Earth fault
	24/4/14	7:31		8:40	1:09	1.15	Permanent	Earth fault
	25/4/14	17:00		17:20	0:20	0.334	Permanent	Over current
	27/4/14	8:18		8:30	0:12	0.2	Permanent	Over current
		13:25		13:35	0:10	0.1667	Permanent	Over current
	3/5/2014	8:25		8:32	0:07	0.1167	Permanent	Over current
	5//5/14	10:06		10:20	0:14	0.2334	Permanent	Earth fault
		10:50		11:55	1:05	1.0833	Permanent	Earth fault
	6/5/2014	10:10		10:16	0:06	0.1	Permanent	Over current
		13:30		13:37	0:07	0.1167	Permanent	Over current
	7/5/2014	13:31		13:38	0:07	0.1167	Permanent	Over current
	9/5/2014	17:09		17:10	0.01	0.0167	Operation	By request
	10/5/2014	23:08		23:22	0:14	0.2334	Permanent	Earth fault
		2:35		7:23	4:48	4.8	Permanent	Earth fault
		7:23		11:15	3:52	3.8667	Operation	By request
		12:13		12:26	0:13	0.2167	Permanent	Earth fault
	11/5/2014	6:31		6:44	0:13	0.2167	Permanent	Over current
	19/5/14	9:02		9:27	0:25	0.4167	Permanent	Over current
		10:10		10:45	0:35	0.5834	Permanent	Over current
	26/5/14	7:06		7:10	0:04	0.067	Permanent	Short circuit
	28/5/14	14:10		14:14	0.04	0.067	Permanent	Over current
	1/6/2014	8:00		8:15	0:15	0.25	Operation	By request
	7/6/2014	14:03		14:09	0:06	0.1	Permanent	Over current
	8/6/2014	12:58		13:04	0:06	0.1	Permanent	Over current
		14:47		15:16	0:29	0.4834	Permanent	Over current
	9/6/2014	9:07		9:15	0:08	0.1334	Operation	By request
		14:38		14:46	0:08	0.1334	Permanent	Over current
	11/6/2014	17:50		18:08	0:18	0.3	Operation	By request
	15/6/14	21:05		21:30	0:25	0.4167	Permanent	Earth fault

	17/6/14	14:56		14:59	0:03	0.05	Transient	Earth fault
	22/6/14	6:56		7:11	0:15	0.25	Permanent	Feder trip
	23/6/14	6:53		7:03	0:10	0.1667	Permanent	Earth fault
	26/6/14	13:49		13:56	0:07	0.1167	Permanent	Earth fault
	28/6/14	13:50		13:55	0:05	0.0834	Operation	By request
	30/6/14	10:21		10:31	0:10	0.1667	Permanent	Over current
		13:50		13:54	0:04	0.0667	Operation	By request
	12/7/2014	9:43		9:52	0:09	0.15	Permanent	Earth fault
	13/7/14	8:43		8:50	0:07	0.1167	Permanent	Over current
	14/7/14	14:00		14:06	0:06	0.1	Permanent	Over current
	15/7/14	15:06		15:12	0:06	0.1	Permanent	Over current
	16/7/14	9:30		9:40	0:10	0.1667	Permanent	Over current
	17/7/14	8:13		8:25	0:12	0.2	Permanent	Opened
		12:59		13:02	0:03	0.05	Permanent	Over current
		13:42		14:21	0:39	0.65	Permanent	Over current
		16:10		16:59	0:49	0.8167	Permanent	Over current
	19/7/14	10:53		11:02	0:09	0.15	Permanent	Over current
		15:31		15:34	0:03	0.05	Permanent	Over current
	20/7/14	7:47		8:08	0:21	0.35	Permanent	Over current
	21/7/14	9:17		9:29	0:12	0.2	Permanent	Over current
		13:05		13:09	0:04	0.0667	Permanent	Over current
		14:05		14:59	0:54	0.9	Permanent	Over current
	22/7/14	14:35		14:41	0:06	0.1	Permanent	Short circuit
		14:54		16:15	1:21	1.35	Permanent	Over current
	23/7/14	15:57		16:05	0:08	0.1334	Permanent	Over current
		16:15		18:58	2:43	2.7167	Permanent	Opened
	27/7/14			11:55	8:57	8.95	Operation	By request
		13:33		15:15	1:42	1.7	Permanent	Earth fault
	28/7/14	8:00		8:08	0:08	0.1334	Permanent	Short circuit
		10:41		10:45	0:04	0.0667	Permanent	Earth fault
	2/8/2014	0:31		7:11	6:40	6.66	Permanent	Over current
	4/8/2014	17:08		17:17	0:09	0.15	Permanent	Opened
	13/8/14	8:34		10:45	2:11	2.1834	Permanent	Feder opened
	17/8/14	15:57		19:38	3:41	3.6834	Permanent	Feder tripped
	18/8/14	11:35		11:52	0:17	0.2834	Permanent	Feder opened
	20/8/14	3:36		8:32	4:57	4.95	Permanent	Feder opened
		6:15		6:38	0:23	0.3834	Permanent	Earth fault
	22/8/14	1:30		4:03	2:33	2.55	Permanent	Opened
	23/8/14	5:13		6:02	0:49	0.8167	Permanent	Earth fault

	24/8/14	16:14		16:17	0:03	0.05	Transient	Over current
	28/8/14	11:33		11:40	0:07	0.1167	Permanent	Earth fault
	29/8/14	6:15		13:18	7:03	7.05	Permanent	Opened
	3/9/2014	13:12		13:44	0:32	0.5334	Permanent	Earth fault
	4/9/2014	8:40		10:50	2:10	2.1667	Permanent	Opened
	5/9/2014	11:30		16:57	5:27	5.45	Permanent	Over current
	6/9/2014	6:50		6:59	0:09	0.15	Permanent	Earth fault
	7/9/2014	6:31		6:34	0:03	0.05	Transient	Earth fault
	8/9/2014	2:42		8:21	5:39	5.65	Permanent	Feeder tripped
	15/9/14	15:57		16:01	0.04	0.0667	Permanent	Feeder tripped
	20/9/14	6:07		6:14	0:07	0.1167	Permanent	Earth fault
	29/9/14	2:26		6:15	3:49	3.8167	Permanent	Earth fault
	7/10/2014	8:16		8:25	0:09	0.15	Permanent	Due to feeder tripped
	11/10/2014	17:15		17:38	0:23	0.3834	Permanent	Earth fault
		18:40		19:25	0:45	0.75	Permanent	Over current
		22:20	12/10/2014	9:43	13:23	13.3834	Operation	By request
	15/10/14	13:40		13:48	0:08	0.1334	Permanent	Earth fault
	16/10/14	14:47		15:29	0:42	0.7	Permanent	Feeder tripped
		22:00	17/10/14	8:34	14:34	14.5667	Operation	By request
	17/10/14	16:42		17:12	0:30	0.5	Permanent	Opened
		18:22		18:32	0:10	0.1667	Permanent	Short circuit
	19/10/14	6:45		6:51	0:06	0.1	Permanent	Earth fault
		8:54		11:54	3:00	3	Permanent	Opened
	20/10/14	16:25		16:30	0:05	0.0834	Operation	By request
	29/10/14	8:25		14:25	6:00	6	Operation	By request
	30/10/14	16:34		16:41	0:07	0.1167	Permanent	Earth fault
	1/11/2014	17:37		17:54	0:17	0.2834	Permanent	Earth fault
	3/11/2014	21:13		21:21	0:08	0.1334	Permanent	Earth fault
	6/11/2014	11:11		12:33	1:22	1.3667	Permanent	Opened
	9/11/2014	2:16		2:27	0:11	0.1834	Permanent	Earth fault
		15:13		15:21	0:08	0.1334	Permanent	Earth fault
		16:48		18:44	1:56	1.9334	Permanent	Opened
	10/11/2014	20:48		21:15	0:27	0.45	Permanent	Opened
	12/11/2014	11:43		12:31	0:48	0.8	Permanent	Opened
	14/11/14	13:27	13/11/14	13:07	23:40	23.667	Permanent	132/33 tripped
		1:26		11:17	9:51	9.85	Permanent	Feeder tripped
	20/11/14	12:50		14:02	1:12	1.2	Permanent	Short circuit
		7:58		8:46	0:48	0.8	Permanent	Earth fault
	21/11/14	22:34	21/11/14	9:04	14:30	14.5	Permanent	Feeder tripped

	26/11/14	11:20		11:33	0:13	0.2167	Permanent	Feeder opened
	27/11/14	15:55		16:02	0:07	0.1167	Permanent	Short circuit
		8:37	27/11/14	8:46	0:09	0.15	Permanent	Short circuit
	27/11/14	10:35		10:56	0:21	0.35	Permanent	Opened
	4/13/2014	10:20		10:26	0:06	0.1	Permanent	Short circuit
		6:31		6:42	0:11	0.1833	Permanent	Over Current
		7:52		7:58	0:06	0.1	Permanent	Over current

Table A-3 Interruption Data for AIP 33kV feeder for the Year 2022 G.C & 2023G.C

Feeder type	Interrupted		Reconnected		Duration time	Duration (hr.)	Fault type	Cause of interruption
AIP feeder2	Date	Time	Date	Time				
	1/7/2014	8:30		9:09	0:39	0.65	Permanent	Over current
		9:30		9:40	0:10	0.1667	Permanent	Earth fault
		13:14		13:20	0:06	0.1	Permanent	Short circuit
	2/7/2014	6:43		6:52	0:09	0.15	Permanent	Earth fault
		8:20		8:43	0:23	0.3834	Permanent	Over current
		13:26		13:58	0:32	0.5334	Permanent	Over current
		14:20		15:14	0:54	0.9	Permanent	Over current
	3/7/2014	14:46		14:56	0:10	0.1667	Permanent	Over current
	5/7/2014	13:44		13:51	0:07	0.1167	Permanent	Over current
	7/7/2014	8:32		8:49	0:17	0.2834	Permanent	Short circuit
	12/7/2014	13:20		15:50	2:30	2.5	Permanent	Over current
		19:40		19:50	0:10	0.1667	Permanent	Earth fault
	14/7/14	22:12	15/7/14	8:15	14:03	14.05	Permanent	Earth fault
	15/7/14	8:04		8:15	0:11	0.1834	Permanent	Earth fault
	16/7/14	12:02		13:39	1:35	1.5834	Permanent	Opened
	20/7/14	17:18		17:30	0:12	0.2	Permanent	Earth fault
	21/7/14	7:00		7:10	0:10	0.1667	Permanent	Earth fault
	22/7/14	14:35		14:41	0:06	0.1	Permanent	Short circuit
		14:41		14:44	0:03	0.05	Transient	Close
	23/7/14	16:15		18:58	2:43	2.7167	Permanent	Opened
		18:58	27/7/14	12:00	7:02	7.0334	Operation	By request
	28/7/14	10:41		10:46	0:05	0.0834	Transient	Earth fault
	4/8/2014	17:08		17:17	0:09	0.15	Permanent	Opened
		19:02		19:40	0:38	0.6334	Transient	Over current
	5/8/2014	23:32		23:39	0:07	0.1167	Permanent	Earth fault
	8/8/2014	20:35	9/8/2014	7:55	13:20	13.334	Operation	By request

	13/8/14	7:38		8:02	0:24	0.4	Permanent	Feeder opened
	16/8/14	9:15		9:27	0:12	0.2	Permanent	Earth fault
	17/8/14	2:10		8:23	6:13	6.2167	Permanent	Over Current
		19:38	18/8/14	9:55	10:17	10.2834	Operation	By request
	20/8/14	11:35		11:52	0:17	0.2834	Permanent	Feder opened
		3:36		8:33	4:57	4.95	Operation	By request
	22/8/14	1:30		4:03	2:33	2.55	Permanent	Opened
	23/8/14	5:13		6:03	0:50	0.8334	Permanent	Earth fault
	25/8/14	10:40		11:16	0:36	0.6	Permanent	Opened
	27/8/14	13:15		16:15	3:00	3	Permanent	Earth fault
	29/8/14	6:15		13:18	7:03	7.05	Permanent	Opened
	1/9/2014	8:52		8:55	0:03	0.05	Transient	Short circuit
	3/9/2014	13:12		13:44	0:32	0.5334	Permanent	Earth fault
	4/9/2014	8:40		10:50	2:10	2.1667	Permanent	Opened
	5/9/2014	11:30		16:57	5:27	5.45	Permanent	Over Current
	6/9/2014	22:51		8:23	15:32	15.5334	Permanent	Short circuit
		8:54		10:05	1:01	1.0167	Permanent	Earth fault
		10:44		11:15	0:31	0.5167	Permanent	Earth fault
	8/9/2014	2:42		11:06	8:24	8.4	Permanent	Earth fault
		11:43		12:35	0:52	0.8667	Permanent	Earth fault
	10/9/2014	0:43		8:50	7:07	7.1167	Permanent	Earth fault
		12:00		13:06	1:06	1.1	Permanent	Earth fault
	15/9/14	15:57		16:01	0.04	0.0667	Permanent	Due to feeder tripped
	16/9/14	7:35		7:47	0:12	0.2	Permanent	Earth fault
	24/9/14	14:05		15:35	1:30	1.5	Permanent	Earth fault
		15:53		16:10	0:17	0.2834	Permanent	Earth fault
	29/9/14	2:26		8:33	6:07	6.1167	Permanent	Earth fault
		14:51		15:20	0:29	0.4834	Permanent	Opened
	30/9/14	0:58		7:16	6:18	6.3	Operation	By request
		12:32		12:52	0:20	0.334	permanent	Opened
	1/10/2014	20:09		20:50	0:41	0.6834	Permanent	Over Current
		5:58		7:50	1:52	1.8667	Operation	By request
	3/10/2014	14:37		14:55	0:18	0.3	Permanent	Earth fault
	7/10/2014	8:16		8:25	0:09	0.15	Permanent	Due to feeder tripped
	11/10/2014	17:14		17:32	0:18	0.3	Permanent	Earth fault
		18:40		19:25	0:45	0.75	Permanent	Over Current
		22:20		9:43	13:23	13.3834	Permanent	Over Current
	12/10/2014	15:05		15:32	0:27	0.45	Permanent	Over Current

	14/10/14	12:46		12:51	0:05	0.0834	Transient	Earth fault
		15:23		15:35	0:12	0.2	Permanent	Short circuit
	16/10/14	14:47		15:29	0:42	0.7	Permanent	Feeder tripped
		15:41		16:06	0:25	0.4167	Operation	By request
	17/10/14	16:42		17:12	0:30	0.5	Permanent	Opened
		18:22		18:32	0.1	0.1667	Permanent	Short circuit
	19/10/14	6:45		6:51	0:06	0.1	Permanent	Earth fault
		7:25		11:54	4:29	4.4834	Permanent	Earth fault
		22:18	20/10/14	7:10	16:52	16.8667	Permanent	Earth fault
	20/10/14	8:07		8:25	0:18	0.3	Permanent	Earth fault
	25/10/14	7:22		7:51	0:29	0.4834	Operation	By request
		8:25		14:25	6:00	6	Operation	By request
	26/10/14	5:28		8:50	3:22	3.3667	Permanent	Earth fault
	28/10/14	7:43		8:16	0:33	0.55	Permanent	Earth fault
		17:02		17:25	0:23	0.3834	Permanent	Earth fault
	29/10/14	1:48		6:50	5:02	5.0334	Permanent	Over Current
		16:34		16:41	0:07	0.1167	Permanent	Earth fault
		18:48		18:54	0:06	0.1	Permanent	Earth fault
	30/10/14	6:22		7:35	1:13	1.2167	Permanent	Earth fault
		17:37		17:54	0:17	0.2834	Permanent	Earth fault
	2/11/2014	5:53		6:23	0:30	0.5	Permanent	Earth fault
		10:52		11:07	0:15	0.25	Permanent	Earth fault
		15:55		16:10	0:15	0.25	Permanent	Earth fault
	3/11/2014	11:11		12:33	1:22	1.3667	Permanent	Opened
		16:40		16:49	0:09	0.15	Operation	By request
	4/11/2014	7:34		7:40	0:06	0.1	Permanent	Earth fault
	5/11/2014	2:38		5:28	2:50	12.8334	Permanent	Earth fault
	8/11/2014	8:11		8:27	0:16	0.2627	Permanent	Over Current
	9/11/2014	16:57		21:15	4:18	4.3	Permanent	Opened
	10/11/2014	6:29		6:31	0:02	0.0334	Transient	Over Current
		11:16		12:31	1:15	1.25	Permanent	Opened
	12/11/2014	6:40		10:12	3:32	3.5334	Permanent	Earth fault
		10:50		10:54	0:04	0.0667	Transient	Opened
		13:27	13/11/14	13:07	22:40	22.667	Permanent	132/33 tripped
	13/11/14	23:13		23:20	0:07	0.1167	Permanent	Earth fault
	14/11/14	1:26		11:17	9:51	9.85	Permanent	Feeder tripped
		17:20		17:30	0:10	0.1667	Permanent	Earth fault
	16/11/14	23:57	17/11/14	0:03	0:06	0.1	Permanent	Earth fault
	17/11/14	0:42		6:20	5:38	5.6334	Permanent	Earth fault
	20/11/14	8:53		9:32	0:39	0.65	Permanent	Over Current

		22:34	21/11/14	11:36	11:02	11.0334	Permanent	Feeder tripped
	21/11/14	11:20		11:33	0:13	0.2167	Operation	By request
	22/11/14	5:02		7:22	2:10	2.1667	Operation	By request
	23/11/14	3:36		5:30	1:54	1.9	Permanent	Earth fault
		16:50		16:59	0:09	0.15	Permanent	Earth fault
	24/11/14	11:28		11:38	0:10	0.1667	Permanent	Earth fault
		12:11		13:47	1:36	1.6	Permanent	Earth fault
	25/11/14	2:00		2:12	0:12	0.2	Permanent	Earth fault
		2:14		9:38	7:24	7.4	Permanent	Earth fault
	30/11/14	3:04	30/11/14	5:57	2:53	2.8834	Permanent	Earth fault
		23:39		23:45	0:06	0.1	Permanent	Earth fault
		23:52	1/12/2014	6:36	18:44	18.7334	Permanent	Earth fault
	2/12/2014	18:25	2/12/2014	18:40	0:15	0.25	Permanent	Earth fault
	3/12/2014	18:50	3/12/2014	19:00	0:50	0.8334	Permanent	Earth fault
	2/13/2014	5:25	2/13/2014	6:06	0:41	0.6833	Permanent	Earth fault
		11:00		11:52	0:52	0.8667	Permanent	Earth fault
	4/13/2014	6:03	4/13/2014	6:09	0:06	0.1	Permanent	Earth fault
		6:31		6:42	0:11	0.1833	Permanent	Over Current
		15:26		15:53	0:27	0.45	Permanent	Opened
	5/13/2014	14:28	5/13/2014	14:42	0:14	0.2334	Permanent	Earth fault
		17:24		17:41	0:17	0.2834	Permanent	Earth fault
	2/1/2015	8:20	2/1/2015	8:39	0:19	0.3167	Permanent	Earth fault
	3/1/2015	18:50	3/1/2015	19:43	0:53	0.8834	Permanent	Earth fault
	4/1/2015	1:08	4/1/2015	5:28	4:20	4.3334	Permanent	Earth fault
	5/1/2015	17:09	5/1/2015	18:25	1:16	1.2667	Permanent	Earth fault
	6/1/2015	15:13	6/1/2015	15:20	0:07	0.1167	Permanent	Earth fault
	9/1/2015	2:45	9/1/2015	2:50	0:05	0.0834	Permanent	Earth fault
		19:00		19:05	0:05	0.0834	Permanent	Earth fault
	11/1/2015	5:35	11/1/2015	6:35	1:00	1	Permanent	Earth fault
	12/1/2015	22:43		22:50	0.07	0.1166	Permanent	Earth fault
	15/01/2015	17:26		18:19	0:53	0.8834	Permanent	Earth fault
		18:41		19:25	0:44	0.7334	Permanent	Earth fault
		23:15		23:20	0:05	0.0833	Permanent	Earth fault
	16/01/2015	8:04	16/01/2015	8:45	0:41	0.6834	Permanent	Earth fault
		14:25		17:25	3:00	3	Permanent	Earth fault
	17/01/2015	0:43		0:46	0:03	0.05	Transient	Earth fault
		4:50		5:22	0:32	0.5334	Permanent	Earth fault
	20/01/2015	0:05	20/01/2015	0:12	0:07	0.1166	Permanent	Earth fault
		1:37		6:10	4:33	4.55	Permanent	Earth fault
	21/01/2015	23:47		0:23	0:36	0.6	Permanent	Earth fault
	23/01/2015	4:17	23/01/2015	5:36	1:19	1.3167	Permanent	Earth fault

	26/01/2015	15:16		15:23	0:07	0.1167	Permanent	Over current
		18:07		18:12	0.05	0.0833	Permanent	Earth fault
	26/01/2015	23:45	27/01/2015	0:16	0:31	0.5167	Permanent	Earth fault
	27/01/2015	1:42	27/01/2015	7:05	5:23	5.3833	Permanent	Earth fault
		7:09		7:16	0:07	0.1166	Permanent	Earth fault
	3/2/2015	12:58	3/2/2015	13:17	0:19	0.3167	Permanent	Over Current
		13:17		13:58	0:41	0.6833	Permanent	Earth fault
	5/2/2015	7:05		7:47	0:42	0.7	Permanent	Earth fault
	6/2/2015	8:22		12:56	4:34	4.5667	Operation	By request
	16/02/2015	7:12	16/02/2015	7:18	0:06	0.1	Permanent	Earth fault
		7:18		7:20	0:02	0.0334	Permanent	Earth fault
	17/02/2015	23:32		23:42	0:10	0.1667	Permanent	Earth fault
		23:42		6:18	18:36	18.6	Permanent	Earth fault
	22/02/2015	12:12		12:17	0:05	0.0834	Operation	By request
	1/3/2015	8:15		8:40	0:25	0.4167	Permanent	Due to the Arboye 33kv line fault
	1/3/2015	22:25		22:33	0:08	0.1334	Permanent	Earth fault
		22:33		23:47	1:14	1.233	Permanent	Earth fault
	2/3/2015	6:36		6:44	0:08	0.1334	Permanent	Earth fault
		7:28		9:12	1:44	1.7333	Operation	By request
		8:37		9:12	0:35	0.5833	Operation	By request
	13/03/2015	14:45		15:50	1:05	1.0833	Permanent	Earth fault
	17/03/2015	2:18		6:40	4:22	4.366	Permanent	Earth fault
	19/03/2015	3:35		6:27	2:52	2.8666	Permanent	Due to the Arboye line fault
	19/03/2015	6:29		6:31	0:02	0.0333	Permanent	Earth fault
	6/4/2015	8:42		8:50	0:08	0.1333	Permanent	Earth fault
	14/04/2015	9:05		9:14	0:09	0.15	Permanent	Over Current
	18/04/2015	8:45	18/04/2015	8:53	0:08	0.1333	Permanent	Earth fault
		13:58		14:14	0:16	0.2666	Permanent	Earth fault
		1:31		1:41	0:10	0.1666	Permanent	Earth fault
		3:02	19/04/2015	7:39	4:37	4.6166	Permanent	Earth fault
	19/04/2015	15:28		15:44	0:16	0.266	Permanent	Earth fault
		6:34		6:46	0:12	0.2	Permanent	Earth fault
		6:46	20/04/2015	10:33	3:47	3.7833	Permanent	Earth fault
	21/04/2015	6:00		16:12	10:12	10.2	Permanent	Earth fault
	22/04/2015	15:30		15:35	0:05	0.08333	Permanent	Earth fault
	24/04/2015	4:18	24/04/2015	5:57	1:39	1.65	Permanent	Earth fault
		16:15		7:21	8:54	8.9	Permanent	Earth fault
		7:21		8:38	1:17	1.2833	Permanent	Earth fault
		9:10		9:28	0:18	0.3	Permanent	Earth fault

	28/04/2015	7:03		7:14	0:11	0.1833	Permanent	Earth fault
		9:25		9:37	0:12	0.2	Permanent	Earth fault
	30/04/2015	6:47	30/04/2015	7:02	0:15	0.25	Permanent	Earth fault
	1/5/2015	7:58	1/5/2015	8:03	0:05	0.0833	Permanent	Earth fault
	3/5/2015	7:25	3/5/2015	7:40	0:15	0.25	Permanent	Earth fault
		21:47		21:53	0:06	0.1	Permanent	Short circuit
		21:55		21:57	0:02	0.033	Permanent	Earth fault
	4/5/2015	16:48	4/5/2015	19:01	2:13	2.216	Permanent	Earth fault
	5/5/2015	7:31	5/5/2015	7:45	0:14	0.233	Permanent	Earth fault
	6/5/2015	7:46	6/5/2015	7:52	0:06	0.1	Permanent	Earth fault
		17:23		17:36	0:13	0.2166	Permanent	Earth fault
	7/5/2015	16:39	7/5/2015	16:48	0:09	0.15	Permanent	Earth fault
	8/5/2015	7:56	8/5/2015	8:19	0:23	0.3833	Permanent	Earth fault
	9/5/2015	18:13	9/5/2015	18:18	0:05	0.0833	Permanent	Earth fault
	10/5/2015	12:16	10/5/2015	12:25	0:09	0.15	Permanent	Earth fault
	11/5/2015	6:44	11/5/2015	6:55	0:11	0.1833	Permanent	Earth fault
		17:27		17:40	0:13	0.2166	Permanent	Earth fault
	13/5/2015	17:50	13/5/2015	18:01	0:11	0.1833	Operation	By request
	15/5/2015	8:32	15/5/2015	8:35	0:03	0.05	Transient	Earth fault
		12:04		12:07	0:03	0.05	Transient	Earth fault
	16/5/2015	8:07		10:27	2:20	2.3333	Permanent	Earth fault
	17/5/2015	8:46	17/5/2015	8:54	0:08	0.1333	Permanent	Earth fault
	18/5/2015	15:30	18/5/2015	15:43	0:13	0.2166	Operation	By request
	19/5/2015	14:34	19/5/2015	14:40	0:06	0.1	Permanent	Earth fault
	20/5/2015	8:58	20/5/2015	9:06	0:08	0.1333	Permanent	Earth fault
	22/5/2015	6:58	22/5/2015	7:10	0:12	0.2	Permanent	Earth fault
		10:27		10:36	0:09	0.15	Permanent	Earth fault
	24/5/2015	7:43	24/5/2015	7:53	0:10	0.1666	Permanent	Earth fault
	29/5/2015	10:37	29/5/2015	10:44	0:07	0.1166	Permanent	Earth fault
	2/6/2015	15:07	2/6/2015	15:15	0:08	0.1333	Permanent	Earth fault
	7/6/2015	4:59		5:11	0:12	0.2	Permanent	Earth fault
		7:42		8:56	0:14	0.2333	Permanent	Earth fault
	8/6/2015	3:05	8/6/2015	6:30	3:25	3.4166	Permanent	Earth fault
		6:30		8:07	1:37	1.6166	Permanent	Earth fault
		8:25		9:20	0:55	0.9166	Permanent	Earth fault
		12:05		13:40	1:35	1.5833	Permanent	Earth fault
		14:18		14:29	0:11	0.1833	Permanent	Earth fault
	9/6/2015	0:47	9/6/2015	0:58	0.11	0.1833	Permanent	Earth fault
		0:58		7:15	6:17	6.2833	Permanent	Earth fault
	9/6/2015	15:54		15:58	0:04	0.0666	Permanent	Earth fault
		17:36		17:44	0:08	0.1333	Permanent	Earth fault

		17:46		17:56	0:10	0.1666	Permanent	Earth fault
	10/6/2015	16:42	10/6/2015	16:57	0:15	0.25	Permanent	Earth fault
	11/6/2015	10:56	11/6/2015	11:03	0:07	0.1166	Permanent	Earth fault
	14/062015	12:28	14/062015	12:33	0:05	0.0833	Permanent	Earth fault
	18/06/2015	9:35	18/06/2015	9:50	0:15	0.25	Operation	By request
	18/06/2015	15:40	18/06/2015	16:00	0:20	0.3333	Permanent	Earth fault
	20/06/2015	8:40		8:59	0:19	0.3166	Permanent	Earth fault
	22/06/2015	23:25	22/06/2015	23:31	0:06	0.1	Permanent	Earth fault

Appendix B: Solar Module Specification

www.jinkosolar.com

JinKO Solar
Building Your Trust in Solar

Eagle 72
320-340 Watt
POLYCRYSTALLINE MODULE

Positive power tolerance of 0~+3%

KEY FEATURES

1500V **High Voltage**
UL and IEC 1500V certified; lowers BOS costs and yields better LCOE

PID Free
Reinforced cell prevents potential induced degradation

Innovative Solar Cells
Five busbar polycrystalline cell technology improves module efficiency

Better Low-Light Performance
Excellent performance in low-light environments

Strength and Durability
Certified for high snow (5400Pa) and wind (2400Pa) loads

Weather Resistance
Certified for salt mist and ammonia resistance

- ISO9001:2008 Quality Standards
- ISO14001:2004 Environmental Standards
- OHSAS18001 Occupational Health & Safety Standards

Nomenclature:

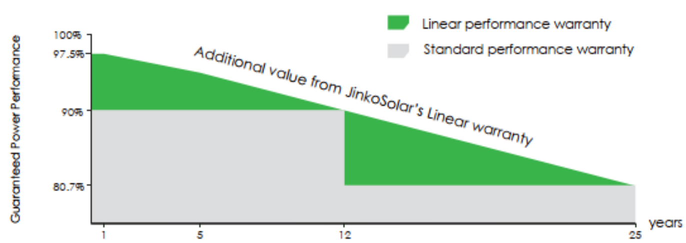
JKM340PP - 72 -V

Code	Certification
null	1000V
V	1500V

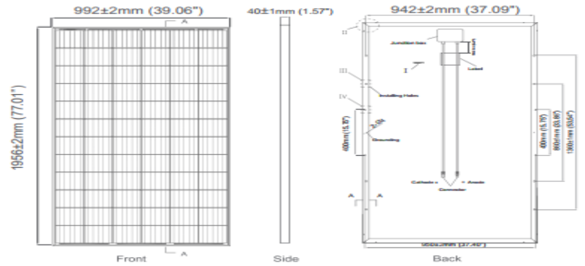
c UL us LISTED · IEC · TÜVRheinland CERTIFIED · CE

LINEAR PERFORMANCE WARRANTY

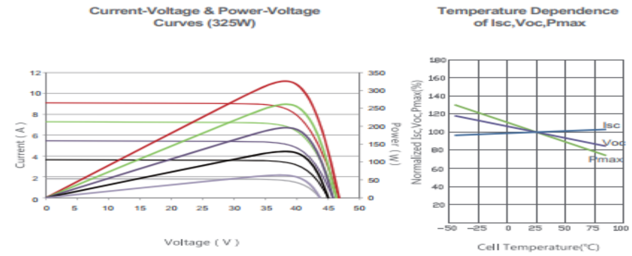
12 Year Product Warranty • 25 Year Linear Power Warranty



Engineering Drawings

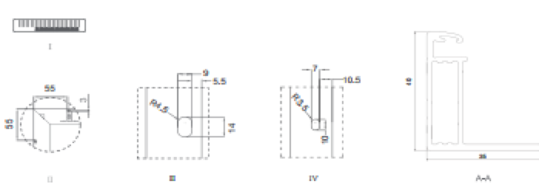


Electrical Performance & Temperature Dependence



SPECIFICATIONS

Module Type	JKM320PP-72-V		JKM325PP-72-V		JKM330PP-72-V		JKM335PP-72-V		JKM340PP-72-V	
	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax)	320Wp	237Wp	325Wp	241Wp	330Wp	245Wp	335Wp	249Wp	340Wp	253Wp
Maximum Power Voltage (Vmp)	37.4V	34.7V	37.6V	35.0V	37.8V	35.3V	38.0V	35.6V	38.2V	35.9V
Maximum Power Current (Imp)	8.56A	6.83A	8.66A	6.89A	8.74A	6.94A	8.82A	6.99A	8.91A	7.05A
Open-circuit Voltage (Voc)	46.4V	43.0V	46.7V	43.3V	46.9V	43.6V	47.2V	43.8V	47.5V	44.0V
Short-circuit Current (Isc)	9.05A	7.35A	9.10A	7.40A	9.14A	7.45A	9.18A	7.52A	9.22A	7.98A
Module Efficiency STC (%)	16.49%		16.75%		17.01%		17.26%		17.52%	
Operating Temperature (°C)	-40°C~+85°C									
Maximum System Voltage	1500VDC (UL and IEC)									
Maximum Series Fuse Rating	20A									
Power Tolerance	0~+3%									
Temperature Coefficients of Pmax	-0.38%/°C									
Temperature Coefficients of Voc	-0.31%/°C									
Temperature Coefficients of Isc	0.06%/°C									
Nominal Operating Cell Temperature (NOCT)	45±2°C									



Packaging Configuration

(Two pallets=One stack)

27pcs/pallet , 54pcs/stack, 648pcs/40'HQ Container

Mechanical Characteristics

Cell Type	Polycrystalline 157×157mm (6 inch)
No. of Cells	72 (6×12)
Dimensions	1956x992x40mm (77.01x39.06x1.57 inch)
Weight	22.5 kg (49.6 lbs.)
Front Glass	3.2mm, Anti-Reflection Coating, High Transmission, Low Iron, Tempered Glass
Frame	Anodized Aluminium Alloy
Junction Box	IP67 Rated
Output Cables	12 AWG, Length: 1200mm (47.24 inch)
Fire Type	Type 1

*STC: Irradiance 1000W/m² Cell Temperature 25°C AM=1.5

NOCT: Irradiance 800W/m² Ambient Temperature 20°C AM=1.5 Wind Speed 1m/s

* Power measurement tolerance: ± 3%

CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.

JKM320-340PP-72-V-A2-US

Appendix C: String Inverter Specification

Input(DC)	SG1000	SG1250
Max.PV input voltage	1000V	
Min.PV input voltage/Startup input voltage	460V/500V	520V/540V
MPP voltage range for nominal power	460-850V	520-850V
No.of independent MPP inputs	1 or 2	
Max.No.of DC inputs	8 - 16	
Max.PV input current	2244A	2712A
Max.DC short-circuit current	2920A	3390A

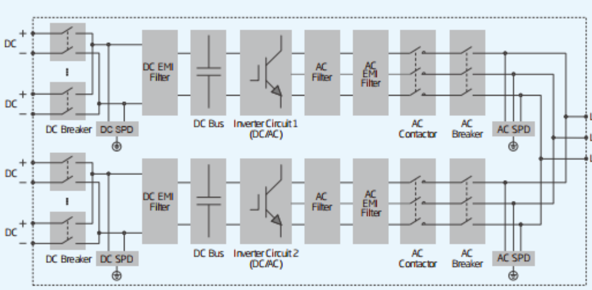
Output(AC)		
Nominal AC power(at 50°C)	1000KW	1260KW
Max.AC output power at PF=1(at 45°C)	1100KW	1386KW
Max.AC apparent power(at 45°C)	1100KVA	1386KVA
Max.AC output current	2016A	2222A
AC voltage range	252-362V	288-414V
Nominal grid frequency/Grid frequency range	50Hz/45-55Hz,60Hz/55-65Hz	
THD	<3%(at nominal power)	
DC current injection	<0.5%In	

Efficiency	
Max. efficiency/Euro. efficiency	99.0%/98.7%

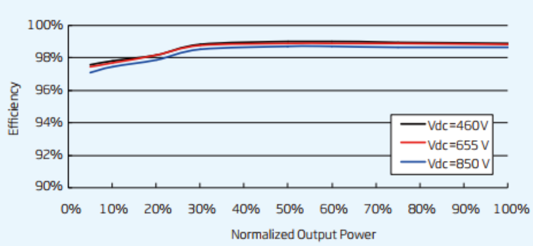
Protection	
DC input protection	Circuit breaker
AC output protection	Circuit breaker
Overvoltage protection	DC Type II/AC Type II
Grid monitorting/Ground fault monitoring	Yes/Yes
Insulation monitoring	Yes
Overheat monitoring	Yes
Anti-PID function	Optional

General Data	
Dimensions(W*H*D)	2991*2591*2438mm
Weight	4.3T
Isolation method	Transformerless
Degree of protection	IP54
Auxiliaey power supply	220Vac,2Vac， 5/Optional:380Vac,up to 15KVA
Operating ambient temoerature range	-35 to 60°C(>50°C derating)
Allowable relative humidity range(non-condensing)	0-95%
Cooling method	Temperature controlled forced air cooling
Max.operating altiude	5000m(>3000m derating)
Display	Touch screen
Connection	Standard:RS485,Ethernet;Optional:optical fiber
Compliance	CEA,IEC 62109,IEC 61727,IEC 62116, IEC 60068,IEC616883,CE
Grid Support	LVRT,HVRT,active & reactive power control and power ramp rate control
Type designation	SG1250HV-10

Circuit Diagram



Efficiency Curve



Appendix D: Wind Turbine Specification

1.5 MW WTGS

Product features

– Optimal Cp Operation Technology
Breaking through the limitations of traditional doubly-fed technology and greatly increasing the turbine's speed regulating range, make turbine run with the optimal Cp before it reaches the rated power, so as to significantly improve the power curve, power generation capacity and reduce the cut-in speed and rated wind speed.

– Intelligent Optimization Technology
WTG can automatically adjust the relationship between power and rotate speed by improving the control algorithm, in order to adapt itself to environmental changes (such as air density, temperature and humidity) and other factors resulting in error, and perfectly match turbine's operation parameters with actual environmental condition, aerodynamic and mechanical characteristics, etc.

– Intelligent Load Avoiding Technology
Based on the load condition of every part of turbine, control turbine's operating state, intelligently avoid limit condition, and substantially reduce turbine's limit load, so as to protect turbine's safety.

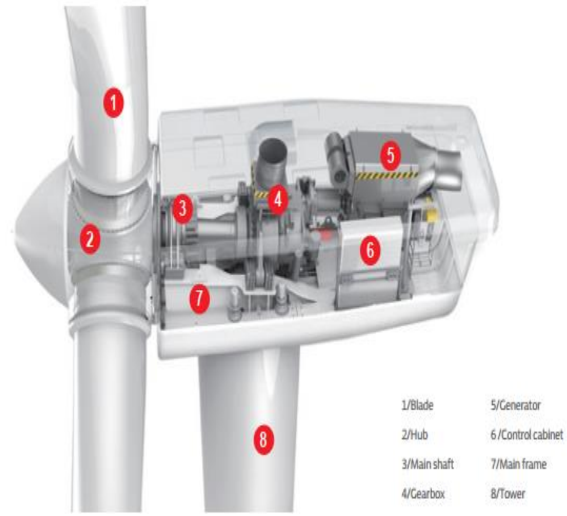
– High Reliability Design
The utilization of reliability design methodologies, such as redundancy design, margin design, environmental adaptability design, simulation modeling method with dynamics knowledge and analysis software such as CAE, which is scheduled for calculation, simulation and verification of the design.

– Good Grid Adaptability
Make the stator side of doubly-fed wind power generator output the same voltage and current with the frequency and phase of power grid voltage by magnetizing the rotor side of doubly-fed wind power generator, and carry out the independent active and reactive decoupling control according to requirement.

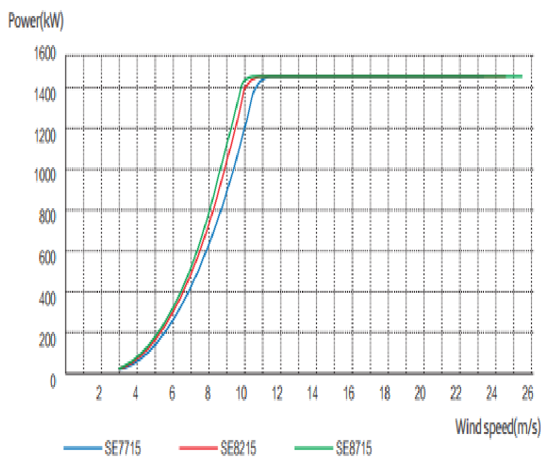
– The Low voltage Ride through Capability
The low voltage ride through test and evaluation of every model is accomplished, thus it can respond rapidly during the reduction of voltage, generate the dynamic reactive power, support the recovery of grid voltage, and the active power is recovered rapidly after the clearing the fault. It has good adaptability to all kinds of grid, a wider range of reactive power adjustment ability and capability of supporting the grid voltage.

– Excellent Adaptability in Plateau
High-efficient radiator with increased safety margin, to ensure that device works in a safe temperature range under full power situation. The air cooling system of the generator adopts a double centrifugal fan cooling scheme, the convertor is specifically designed for high temperature and high altitude.

Turbine Structure & Equipment Layout



Power curve



Technical Specifications

Model	SE7715	SE8215	SE8715
Wind class	IEC Ⅱ	IEC Ⅲ	IEC S
Rated power	1500kW	1500kW	1500kW
Rotor diameter	77.7m	83.3m	88m
Swept area	4736m²	5447m²	5900m²
Rated speed	19rpm	17.3rpm	16.7rpm
Rated wind speed	11.5m/s	11m/s	10.5m/s
Cut-in wind speed	3m/s	3m/s	3m/s
Cut-out wind speed	25m/s	25m/s	25m/s
Hub heights	65/70/80m	65/70/80m	70/80m
Rotor weight	33t	34t	36t
Nacelle weight	56t	56t	56t

Gearbox	Generator
Type: planetary / spur Stages: 3.0 Ratio: 1:95	Type: double-fed induction Number:1 Speed, max1800U/min Voltage:690.0 V Grid connection: IGBT Grid frequency:50 Hz

Appendix E: Hourly Power Consumption of AIP

1-Oct-22	Kingdom	Antex	Juton	Sunshine	Ykk	Shed #18, garment trim	Zld	Common buliding	Total power consumption MWhr
time hrs	*Power consu, MWhr*	*Power consu, MWhr*	*Power consu, MWhr*	*Power consu, MWhr*	*Power consu, MWhr*	*Power consu, MWhr*	*Power consu, MWhr*	*Power consu, MWhr*	
12:00	2.631697452	1.56726063	0.1398431	2.646594	0.02292451	0.09967177	1.6508864	0.0425756	8.8014535
1:00	2.685881052	1.32283841	0.1804981	2.711695	0.030404	0.13219130	0.4040602	0.0520368	7.5196049
2:00	2.390038596	1.333052019	0.3848612	2.432298	0.05231144	0.22744105	0.4050297	0.01008	7.2351120
3:00	2.466979308	1.554527484	0.49060732	2.518008	0.07983525	0.34710979	0.2928449	0.1236479	7.8735600
4:00	1.922975964	1.454710456	0.5560237	1.974928	0.09459623	0.411.2879	0.3626561	0.1173607	6.4832512
5:00	1.632551868	1.191668042	0.560021	1.654318	0.09981657	0.43398508	0.7530936	0.1236479	6.4491021
6:00	1.245139128	0.8804835	0.33888923	1.258555	0.08829581	0.38389482	3.8816205	0.1205043	8.1973823
7:00	1.3004064	1.4087736	0.2588502	1.326707	0.0105666	0.04594174	1.2007729	0.1205043	5.6725228
08;00	2.2215276	1.4087736	0.3828647	2.207117	0.0110284	0.04827321	0.6398310	0.0890684	7.0084840
9:00	3.4135668	1.760967	0.5323345	3.367299	0.01550348	0.06740643	0.3762808	0.0995470	9.6329051
10:00	3.6303012	1.645095371	0.5500654	3.570531	0.01763895	0.07669107	0.9097235	0.1162081	10.516254
11:00	3.3593832	1.173860602	0.5869432	3.241852	0.01721344	0.07484102	0.7928566	0.1144267	9.3613768
12:00	3.521934	1.202388268	0.32001892	3.412536	0.00959694	0.04172583	0.6317008	0.0350898	9.1749905
13:00	3.9824946	1.204501428	0.14877234	3.847179	0.1391492	0.06049963	0.3425165	0.0233932	9.748506
14:00	4.899281112	1.241833928	0.1538765	4.81582	0.01510299	0.06566519	0.2939946	0.0350898	11.520664
15:00	3.172991616	0.91570284	0.12105784	3.114881	0.01603005	0.06969589	0.6504634	0.0444470	8.1052697
16:00	3.1968324	1.015021379	0.1256554	3.147208	0.01865823	0.08112273	0.6669924	0.0509971	8.3024877
17:00	1.653683472	0.645922696	0.1809876	1.660401	0.01741615	0.07572237	0.4650778	0.0538043	4.7530155
18:00	1.751755788	1.473577186	0.190861	1.751032	0.01283484	0.05580367	0.3852533	0.0552079	5.676325
19:00	1.77180372	1.39327709	0.1090922	1.790895	0.033981	0.05365135	0.2772760	0.0520264	5.4820029
20:00	3.2781078	1.56048768	0.11881181	3.257892	0.01343788	0.05842558	0.2420295	0.0493596	8.5785519
21:00	3.251016	1.449519667	0.1267773	3.249673	0.01567003	0.06813057	0.0780887	0.0463185	8.2851938
22:00	3.01260816	1.356323875	0.14808652	2.984583	0.0121418	0.05279043	0.3671882	0.0444470	7.9781690
23:00	2.5466292	1.031926662	0.09993211	2.553983	0.01882024	0.08182712	0.7458325	0.041172	7.1201229