Design and Implementation of Solar Power System in South Sakucia Union, Bhola, Bangladesh: A Software Based Analysis

by

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CERTIFICATE OF APPROVAL

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DECLARATION OF CANDIDATES

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for award of any degree or diploma.

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DEDICATION

We would like to dedicate this thesis to our family members and everyone who have given us unwearied support throughout the entirety of our existence and every situation of our life. They have always been a source of motivation for us. They pushed us ahead and showed us how to make the correct decisions. They never fail to inspire us to work hard and move forward to overcome life's difficulties. They have provided us with the protection, wisdom, and fortitude we need to face difficult situations.

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ABSTRACT

Renewable energy is expanding all over the world due to energy supply chain issues and increasing cost of electricity. In the perspective of Bangladesh, solar energy can be the optimum solution for meeting the demand of ever-increasing electricity of Bangladesh. In this study, performance of a 200 KWp installed capacity solar arrangements were evaluated in three different setting: fixed tilt, seasonal tilt and with solar trackers (dual axis) using monofacial and bifacial PV modules. The selected local area is South Sakucia Union, Monpura Upazilla, Bhola, Bangladesh. Three different software, PVSOL, PVsyst, SAM were used to perform the rigorous simulation and to evaluate the results. The fixed monofacial module generated 124,419 kWh, while the fixed bifacial module yielded a slightly higher output of 126,522.3 kWh. The seaspnal tilt PV panel exhibited an increased energy production of 130,536 kWh, likely due to its optimized tilt angle for seasonal variations. In comparison, the PV panel equipped with a solar tracker demonstrated the highest energy output of 149,070.3 kWh. These findings highlight the importance of considering panel type and additional features when aiming to optimize energy production in solar installations.

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CHAPTER 1

INTRODUCTION

1.1 Overview

Since 2021, global energy demand has experienced a significant upsurge of 5.4% [1]. The depletion of fossil fuels and the escalating demand for energy has instigated a drive towards economically feasible, sustainable, and eco-friendly renewable energy schemes [2]. Furthermore, the addition of Solar PV net capacity is projected to reach almost 200GW in 2023 [3]. By the end of 2021, the renewable share of electricity generation had reached 28.3%, marking an increase of approximately 8% over the past decade.

Solar energy is one of the most popular types of renewable energy and offers a lot of advantages over other types of energy. Solar energy keeps carbon dioxide and other harmful emissions from being released into the air [4]. Annual solar PV additions was 126 GW/year in recent years and it is expected to be 444 GW/year by 2050. Between 2010 to 2020, the global weighted-average levelized cost of electricity from newly commissioned utility-scale solar PV installations plummeted 85%. So, electricity from renewable sources is now the cheapest in most regions [5]. Thus, solar energy allows us to significantly reduce overall grid use and save a substantial amount of money on power bills.

Solar panels can be categorized into two types: monofacial and bifacial panels. Monofacial solar panels possess photovoltaic cells on one side, while bifacial solar panels have photovoltaic cells on both sides [6]. Optimizing solar modules' tilt and azimuth angle depends on the energy requirements. Fixed-tilt solar panels are positioned at a specific angle and remain unchanged throughout the year. In contrast, seasonal tilt solar panels are installed on tracking systems that enable adjustments to their angle over time. Solar trackers come in two forms: single-axis and dual-axis. Single-axis solar trackers facilitate movement around a single axis, typically the azimuth axis, while dual-axis solar trackers enable movement around both the azimuth and elevation axes [7]. It is noteworthy that from 2021, global energy demand has witnessed a 5.4% increase. This surge led to the most significant annual rise in global CO^2 emissions from the energy sector ever recorded in 2021, resulting in a total of 36.6 Gt of CO^2 emissions from the energy sector. The objective of this research paper is to provide a comprehensive examination of the design and implementation of solar power systems on remote islands, with a particular focus on various orientations and technologies employed. The paper will explore different types of solar power systems, including monofacial and bifacial PV panels. Additionally, it will investigate factors that must be considered during the design and implementation of a solar power system, such as fixed and seasonal tilt, as well as single-axis and dual-axis trackers. Moreover, the paper will offer an overview of the current state of solar power technology, highlighting recent advancements and identifying areas for future research in Bangladesh. Through this thorough analysis of solar power systems design and implementation, the paper aims to provide valuable insights for engineers, policymakers, and individuals interested in the field of renewable energy.

1.2 Renewable Energy

Renewable energy comes from natural resources that can be renewed within a human lifetime. It offers an alternative to standard energy sources like fossil fuels, which are limited and hurt the environment. Renewable energy methods use the power of natural processes like sunlight, wind, water, geothermal heat, and biofuels to make electricity, heat, and power. Sustainability is one of the biggest benefits of sustainable energy. Unlike fossil fuels, which take millions of years to form and run out as they are used, green energy sources can always be replaced. Because of this, renewable energy is an important part of fighting climate change and lowering greenhouse gas pollution. The most popular renewable energy sources are: Solar energy, Wind energy, Hydro energy, Tidal energy, Biomass energy etc.

Hydropower, which comes from water that is flowing or falling, is another important green energy source. In hydroelectric power plants, it uses the force of water's gravity to turn turbines and make energy. Geothermal energy uses the heat stored in the Earth's crust to make electricity or heat buildings. It does this by using geothermal power plants or geothermal heat pumps. Bioenergy is another renewable energy source that includes turning organic matter, like crops, agricultural waste, or wood, into biofuels, biogas, or heat. These kinds of energy can be used for transportation, heating, and making power.

Renewable energy methods have become more popular in recent years because they have a lot of benefits. First of all, green energy sources are cleaner than fossil fuels. This means they reduce air pollution and lessen the negative effects of climate change. By using renewable energy, we can lower greenhouse gas emissions, fight global warming, and improve air quality, all of which are good for public health. Also, renewable energy has the ability to make us energy-independent and secure. Countries can reduce their reliance on fossil fuel imports and broaden their energy portfolios by using more renewable resources. This can make the energy system more stable and less vulnerable to price changes or geopolitical issues, which are problems that come with being dependent on fossil fuels.

In addition, the growth of renewable energy industries provides new jobs, which helps the economy grow and encourages new ideas. In the renewable energy sector, which includes research and development, manufacturing, installation, and upkeep of renewable energy systems, a skilled workforce is needed. Renewable energy technologies have the ability to change the world's energy landscape as they continue to improve and become more affordable. By using renewable energy, we can move toward a more sustainable, low-carbon future, fight climate change, and give future generations a cleaner, healthier world.

1.3 Solar Energy

Solar energy is a great type of green energy that uses the power of sunlight to make electricity or heat. It has many benefits that help make the future of energy more safe and cleaner. One of the best things about solar energy is that it can be used again and again. The sun gives off a lot of energy, and as long as it keeps shining, there will be solar energy. Solar energy is a sustainable way to meet our energy needs because it is a steady and reliable source of power, unlike fossil fuels, which run out as they are used. Solar energy is also great for the earth. During usage, solar power doesn't release any greenhouse gases or air pollutants. By switching from fossil fuels to solar energy to make power, we can cut down on carbon emissions and make climate change less bad. Solar energy also helps improve air quality by reducing the amount of toxic pollutants that get into the air and cause health problems for people and the environment. Energy freedom is another big benefit of solar energy. People, companies, and communities can make their own electricity by putting up solar panels. This makes people less reliant on centralized power sources and makes it less likely that the power will go out or be interrupted. People have more control over their energy supply when they use solar energy, and they can even sell any extra power back to the grid. This promotes self-sufficiency and resilience. Solar energy solutions save money in the long run. Even though the initial cost of installing solar panels can be high, the costs to keep them running are usually cheap. Once the system is set up, the fuel source, which is the sun, is free. Over time, this leads to lower electricity bills, which helps people and companies save money. Some areas also offer incentives, like tax credits or feed-in tariffs, to help pay for the upfront costs of putting solar systems. Another benefit is that solar energy can be used in many ways. Photovoltaic (PV) panels can be put on roofs or built into buildings. This makes it possible to generate energy in a decentralized way. Using solar thermal methods, you can heat water for your home or your business. Solar energy can also be used to power remote or off-grid places where connecting to a regular power grid may not be possible or cost-effective.

Even with these benefits, there are a few things to keep in mind. The sun doesn't always shine because of the weather, and it doesn't shine at night, which makes it hard to make constant power. But improvements in energy storage devices, like batteries, are helping to solve this problem and allow extra energy to be saved for later use. Installing solar panels can be hard for some people or businesses because of how much they cost up front. But the prices of solar panels have gone down a lot over the years, making solar energy cheaper and easier to use. Also, there are ways to pay for solar systems that cost little or nothing up front, such as solar loans or power purchase agreements. Space needs are another thing to think about, especially for large-scale solar systems. Solar farms or solar power plants need a lot of land or roof room to fit a large number of solar panels. In places with a lot of people, it can be hard to find good spots for large-scale solar projects. But putting solar panels on roofs, parking lots, and other places that aren't being used can help make the most of the land that's available. For making solar cells and getting rid of them afterward, certain materials and chemicals are used. Even though the environmental effect of making solar panels has gone down over time, proper recycling and disposal methods are still needed to reduce waste and make sure that solar panels are handled in a responsible way when they are no longer useful.

Even with these problems, solar energy is a good choice for a greener and more sustainable future because it is sustainable, has a low effect on the environment, can be used on its own, and saves money. Solar energy is growing because technology is getting better and governments are making it easier to use. This means that people, communities, and companies all over the world can get clean energy from the sun.

CHAPTER 2

OBJECTIVES AND OUTLINE

2.1 Thesis Objectives

The primary goal of this thesis is to implement monofacial & bifacial (fixed tilt), seasonal tilt (monofacial), solar tracker (dual axis) The following are some additional goals:

- ✓ To implement monofacial & bifacial (fixed tilt), seasonal tilt (monofacial), solar tracker (dual axis)
- ✓ To evaluate three different software to estimate generated energy.
- ✓ To Find suitable components for the location
- ✓ To Determine the reason for different results

2.2 Thesis Organization

The thesis is structured into multiple sections to provide a comprehensive exploration of the research topic.

- ✓ Chapter 3 serves as the background study, delving into previous research and studies conducted in a similar vein to the present research. This section establishes the foundation for the current study by reviewing existing knowledge and identifying research gaps.
- ✓ Chapter 4 focuses on the detailed view of the site and components involved in the research. This section provides a thorough examination of the specific location and the various components relevant to the study, offering a comprehensive understanding of the experimental setup.
- ✓ In Chapter 5, the results and data collected during the research are meticulously analyzed. This section presents a systematic evaluation and interpretation of the gathered data, enabling a comprehensive understanding of the outcomes and their implications.
- ✓ Chapter 6 is dedicated to the exploration of performance parameters. This section involves an in-depth examination of various performance indicators and metrics relevant

to the research topic. It provides a quantitative analysis and discussion of the identified performance parameters, facilitating a comprehensive evaluation of the system's effectiveness.

- ✓ In Chapter 7, the thesis encompasses a comprehensive discussion of the conclusions drawn from the research findings. This section provides an in-depth analysis of the results and their implications, allowing for a comprehensive understanding of the outcomes within the context of the research objectives. Additionally, the limitations encountered during the study are critically examined and discussed, providing insights into the boundaries and constraints of the research.

CHAPTER 3

LITERATURE REVIEW

3.1 Design and Investigation of Grid-Associated PV Framework Using PVSYST Software

In [8], grid-connected photovoltaic (PV) systems are utilized as they have received a lot of interest as a sustainable and renewable energy alternative. This review of the literature looks at a research study that focuses on the design and investigation of a grid-connected PV architecture. PVSYST software is used in the research to examine and optimize the performance of the PV system. PVSYST software, a widely used tool for PV system design and analysis, is employed in the study report. Solar irradiance, temperature, shading analyses, and system configurations are all included in the research. The program allows simulation and assessment of the system's performance by inputting essential data and taking into account the geographical location.

Considerations for design: Several elements must be carefully considered during the design process. The process includes selecting adequate PV modules, optimizing tilt and azimuth angles, sizing the inverter and other components, and determining shading impacts. The software calculates the proposed PV framework's energy yield, system losses, and economic feasibility. Simulation and analysis: The study article exhibits the grid-connected PV system's performance and energy generation potential using PVSYST software simulations. The analysis includes the evaluation of energy output, system losses, and financial indicators such as payback period and returns on investment. Sensitivity analyses may also be used to evaluate the influence of various factors on system performance.

A case study or validation of the proposed grid-associated PV framework may be included in the research paper. This may entail applying the software-based technique to a real-world installation. The research may offer actual data and compare it to software simulations, confirming the design process's correctness and dependability. The study report emphasizes the importance of using PVSYST software to design and analyze grid-connected PV frameworks. The program allows for an in-depth investigation of many parameters influencing the system's performance and economic viability. The study provides useful insights for system optimization and decision-making in grid-connected PV installations by modeling energy output, analyzing losses, and conducting sensitivity assessments.

3.2 Design, simulation and analysis of monofacial solar pv panel based energy system for university residence: a case study

In [9], PV (photovoltaic) systems are precisely estimated and designed. It is critical for maximizing energy output while remaining cost-effective. This literature study delves into a research report examining the precision of software tools for estimating and planning PV installations. The study's goal is to evaluate the dependability and accuracy of various software solutions.

A comparison method is employed in the research article to assess several software programs typically used for PV system estimate and planning. Solar irradiation, shading studies, system settings, and climatic data are all taken into account. The research evaluates the correctness of the software tools using real-world data and performance measures. The study article chooses a variety of common software packages for estimating and designing PV systems. PVsyst, PVSOL, SAM, and other comparable software packages are examples of extensively used choices. The software's capabilities, user-friendliness, feature availability, and compliance with industry standards may all be considered as selection factors.

Accuracy testing entails comparing the outputs of the chosen software tools to real-world data or validated reference models. The analysis might take into account performance indicators including expected energy generation, system losses, and financial metrics. To measure and analyze the differences between software forecasts and actual system performance, statistical analysis techniques are used. Limitations and Potential Causes of Error: The study article covers the software tools' limitations and potential causes of error. Data input accuracy, assumptions made by software algorithms, and limits in modeling certain phenomena are all taken into account. The study's goal is to discover places where software tools may deviate from actual system performance.

The study report includes a discussion of the strengths and shortcomings of the examined software tools based on the accuracy analysis. It delves into the elements that lead to disparities and makes suggestions for enhancing the accuracy of PV system assessment and planning. These suggestions might include improving input data, improving modeling methods, or inventing new validation approaches. The study continues by underlining the significance of precise software tools for PV system estimate and design. It emphasizes the possible consequences of mistakes in these tools as well as the necessity for constant development in software algorithms. The findings help to clarify the dependability and precision of software solutions utilized in the solar sector.

In summary, this study article presents a thorough examination of the precision of software tools for estimating and designing solar systems. The study provides light on the strengths, limits, and recommendations for enhancing the accuracy of PV system modeling and prediction by assessing several software solutions and taking into account real-world data.

3.3 Assessment of solar radiation resources in Saudi Arabia

[10] focuses on the assessment of Saudi Arabia's solar radiation resources, with the goal of providing significant insights into the country's solar energy potential. Saudi Arabia's enormous solar resources make it a suitable site for solar power development, with a growing worldwide emphasis on renewable energy.

The study analyzes the solar resource potential across different locations in Saudi Arabia using various solar radiation assessment methodologies and data sources. These approaches include ground-based observations, satellite data analysis, and numerical modeling. The study integrates historical solar radiation data with meteorological characteristics to determine the country's solar resource availability and fluctuation.

The study article collects and analyzes a large quantity of meteorological and solar radiation data from various sources in order to evaluate solar radiation resources. Long-term ground-based observations, satellite-derived data, and atmospheric modeling outputs are all included. The data is processed, verified, and standardized to guarantee accuracy and dependability. It creates solar resource maps for Saudi Arabia, displaying the geographical distributions of solar radiation characteristics throughout the nation. These maps give significant information on the quantity of solar energy accessible in various locations, enabling site-specific solar energy project planning and decision-making. Solar irradiance, direct normal irradiance (DNI), diffuse horizontal irradiance (DHI), and other associated characteristics are taken into account.

The research conducts validation and uncertainty analysis to assure the dependability of the solar resource evaluation. This entails comparing predicted or satellite-derived solar radiation statistics with ground-based observations for specified places or times. Statistical techniques are utilized in the evaluation to estimate uncertainties and confirm the correctness of the solar radiation data used in the study.

This paper's conclusions are critical for regulators, energy planners, and investors in Saudi Arabia's solar energy sector. The assessment of solar radiation resources aids in the identification of places with high solar potential, making it easier to pick ideal sites for solar power installations. The study also emphasizes the importance of ongoing monitoring and data collecting in order to increase the accuracy of solar resource evaluations. According to the research article, Saudi Arabia has enormous solar radiation resources, making it ideal for solar energy growth. The evaluation of solar radiation resources utilizing multiple data sources and modeling approaches helps to improve understanding of the country's solar energy potential. This information can help guide decisions and pave the path for the spread of solar power in Saudi Arabia.

3.4 The Influence of Spectral Albedo on Bifacial Solar Cells: A Theoretical and Experimental Study

[11] studies the effect of spectral albedo on bifacial solar cell performance using theoretical models and actual data. Bifacial solar cells can catch sunlight from both the front and back sides, making use of reflected and dispersed light from surrounding surfaces. The research looks at how spectral albedo, the ratio of reflected light to incident light at different wavelengths, affects the energy output of bifacial solar cells.

The study employs theoretical modeling and experimental analysis to assess the impact of spectral albedo on bifacial solar cells. The theoretical models take into account optical features such as light scattering, transmission, and absorption in the context of various spectral albedo conditions. The research investigates how changes in spectral albedo affect the performance of bifacial solar cells. It investigates the effect of various albedo spectra, such as differences in surface reflectance across wavelengths. The study looks at how these differences impact the total energy generation, electrical properties, and efficiency of bifacial solar cells.

The study gives theoretical and practical results on the effect of spectral albedo on bifacial solar cells. It reveals that variances in albedo spectra can result in considerable disparities in energy generation and performance of these cells. The research reveals the best spectral albedo settings for maximizing energy production and efficiency. The results of this study have significance for the design and optimization of bifacial solar systems. Understanding the impact of spectral albedo can help in the selection of optimal locations, surface materials, and configurations for bifacial solar cells to maximize energy production. The study's findings may be utilized in various scenarios, including rooftop installations, solar farms, and urban surroundings with varying albedo properties.

The study finds that spectral albedo is critical to the performance of bifacial solar cells. The research includes theoretical models as well as practical evidence to demonstrate the impact of albedo fluctuations on energy generation and efficiency. Taking spectral albedo into account in the design and evaluation of bifacial solar systems, optimum configurations can be achieved, improving their overall performance and contribution to renewable energy.

CHAPTER 4

METHODOLOGY

4.1 Site Selection

This research article presents a detailed assessment of the solar energy potential in Bhola, Bangladesh, with a focus on the South Sakucia Union located in the Monpura Upazilla. The study examines key parameters such as annual global irradiance, horizontal diffuse irradiance, average temperature, wind velocity, and humidity to evaluate the feasibility of solar energy utilization in this region.

Solar energy has emerged as a promising renewable energy source with the potential to meet the growing energy demands while reducing greenhouse gas emissions. Understanding the solar energy potential of a specific location is crucial for effective planning and implementation of solar power systems. In this context, the present study aims to assess the solar energy potential in Bhola, Bangladesh, specifically within the South Sakucia Union in the Monpura Upazilla. By examining key climatic and environmental factors, such as annual global irradiance, horizontal diffuse irradiance, average temperature, wind velocity, and humidity, this analysis will provide valuable insights for renewable energy stakeholders and policymakers in the region.

To assess the solar energy potential in Bhola, relevant climatic data for the South Sakucia Union was collected. The latitude and longitude of the site were determined to be 22.17850 N and 90.7101 E, respectively. Annual global irradiance, representing the total solar radiation received on a horizontal surface, was found to be 1793 kWh/m^2. This parameter provides an estimation of the total solar energy available throughout the year. The horizontal diffuse irradiance, which accounts for the scattered solar radiation, was measured to be 864 kWh/m2. The average temperature recorded in the area was 24.9 °C, indicating a favorable climate for solar energy utilization. Additionally, the wind velocity was determined to be 0.8 m/s, suggesting low wind speeds that may not significantly affect solar panel efficiency. The humidity level of 81% highlights the prevailing moisture conditions in the region.

Table 4.1: Meteorological data of the selected site

Location	South Sakucia Union, Monpura Upazilla, Bhola, Bangladesh.
Latitude & Longitude	22.17850N, 90.71010E
Annual global irradiance	1793 kWh/m^2
Average temperature	24.9 °C
Wind Velocity	0.8 m/s
Humidity	81%

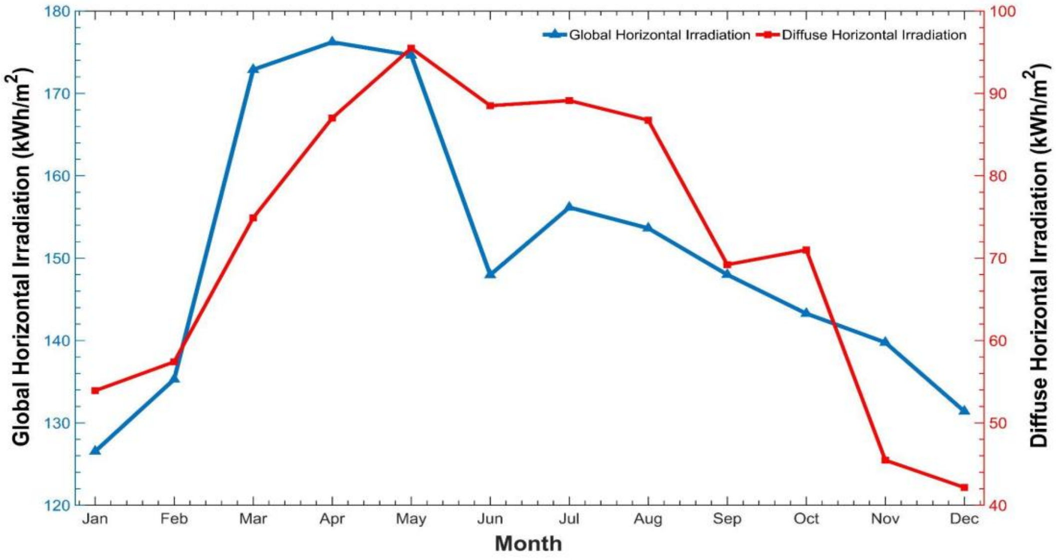


Figure 4.1: Monthly temperature data at the selected site

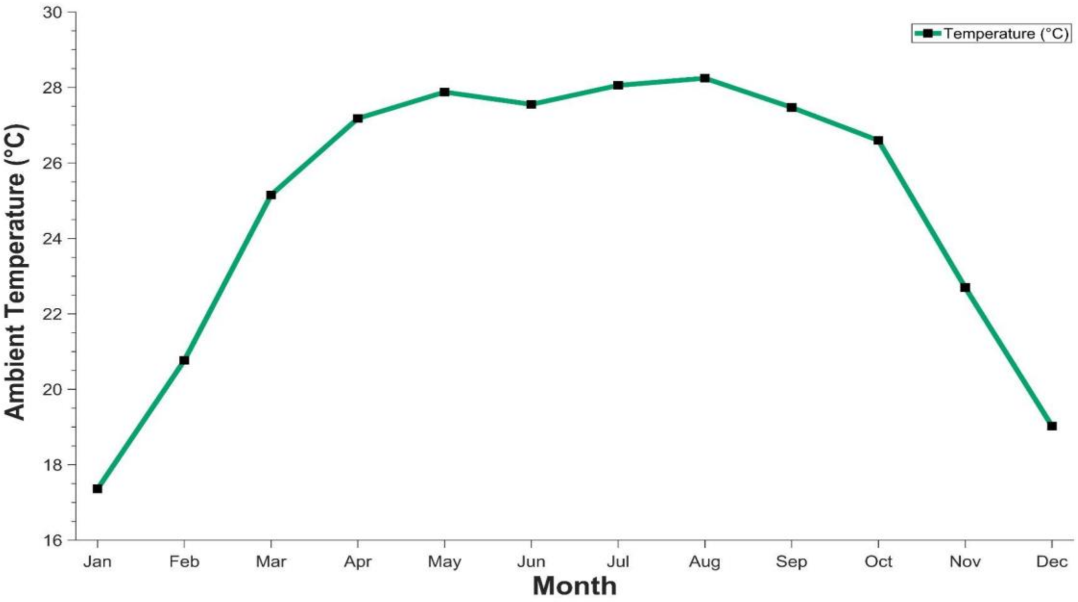


Figure 4.2: Monthly variation in direct and diffuse irradiation

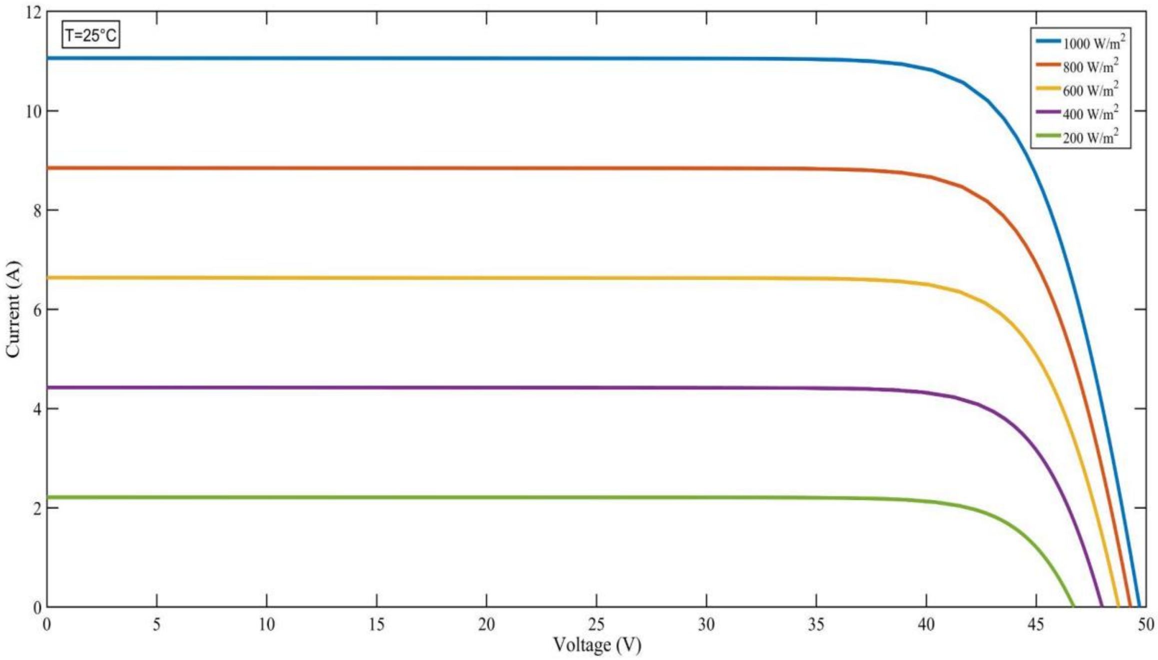
4.2 PV Module Selection

The monofacial module under consideration is the LG450N2W-E6, manufactured by LG Electronics. It is equipped with monocrystalline cells, which are known for their high efficiency and performance. The module consists of a total of 144 cells and has a power output of 450 W. With a module efficiency of 20.3%, it demonstrates an ability to convert a significant portion of the received solar energy into usable electricity. The rated voltage (Vmpp) of the module is measured at 41.1 V, while the rated current (Impp) is recorded at 10.96 A. These values indicate the optimal operating conditions for the module, where the maximum power output can be achieved. The open circuit voltage (Voc) of 49.0 V represents the voltage across the module when no load is connected, while the short circuit current (Isc) of 11.47 A denotes the maximum current that the module can deliver under short circuit conditions.

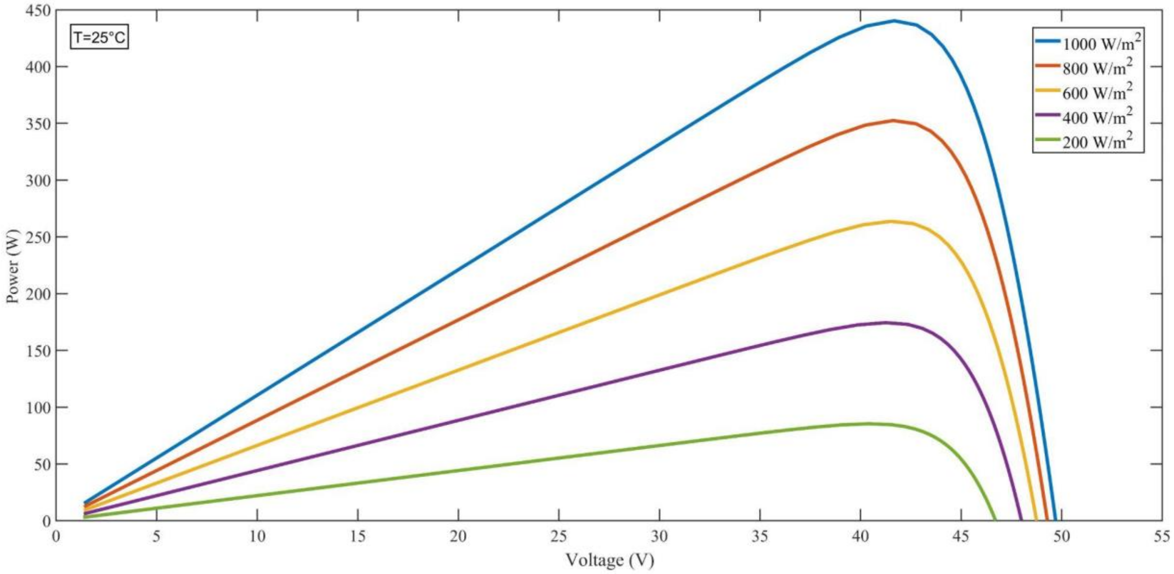
The bifacial module under consideration is the LG455N2W-E6, manufactured by LG Electronics. It features monocrystalline cells, known for their high efficiency and performance. The module consists of 144 cells and has a power output of 455 W. With a module efficiency of 20.7%, it showcases the ability to convert a significant amount of solar energy into usable electricity. The rated voltage (Vmpp) of the module is 42.1 V, indicating the voltage at which the module operates most efficiently. The rated current (Impp) is measured at 10.83 A, representing the optimal current output under normal operating conditions. The open circuit voltage (Voc) of 49.9 V signifies the voltage across the module when no load is connected, while the short circuit current (I_{sc}) of 11.39 A indicates the maximum current the module can deliver under short circuit conditions.

Table 4.2: Parameters of modules

	Monofacial Module	**Bifacial Module**
Manufacturer	LG Electronics	LG Electronics
Model	LG450N2W-E6	LG455N2W-E6
Cell Properties (Material)	Monocrystalline	Monocrystalline
Number of cell	144	144
Module Power [W]	450	455
Module Efficiency [%]	20.3	20.7
Rated Voltage (Vmpp) [V]	41.1	42.1
Rated Current (Impp) [A]	10.96	10.83
Open Circuit Voltage (Voc) [V]	49.0	49.9
Short Circuit Current (Isc) [A]	11.47	11.39



(a)



(b)

Figure 4.3: (a) I-V Curve and (b) P-V Curve, at different irradiance of the selected monofacial PV panel

4.3 Simulation of Monofacial Solar Panel

4.3.1 SAM

Table 4.3: Inverter details for monofacial in SAM

Inverter	CSI-60KTL-GS [480V]
Number of PPT inputs	1
European weighted efficiency	98.401%
Maximum AC power	60000 Wac
Maximum DC power	61015.7 Wdc
Power use during operation	92.9937 Wdc
Power use at night	1Wac
Nominal AC voltage	480Vac
Maximum dc voltage	720 Vdc
Maximum dc current	93.8702Adc
Minimum MPPT DC Voltage	580Vdc
Nominal DC voltage	650 Vdc

Maximum Mppt Dc voltage	720 Vdc

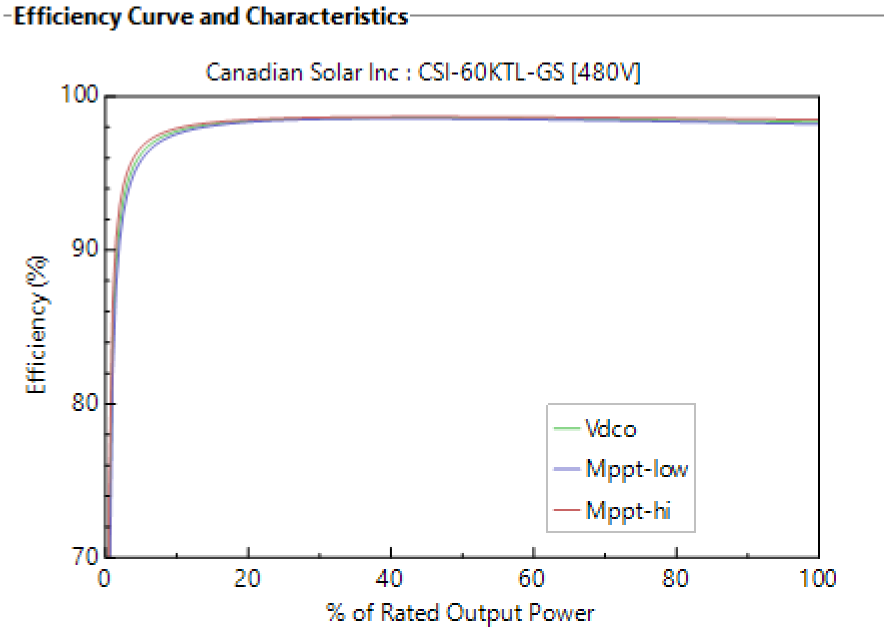


Figure 4.4: Efficiency curve of Inverter

Table 4.4 Simulation Parameters for monofacial in SAM

Number of Inverters	1
DC to AC ratio	1.5
Modules per string in subarray	20
Strings in parallel in subarray	10
Number of modules	200
Tilt	Fixed (22 degree)

Table 4.5: Loss for monofacial in SAM

Average annual soiling loss	1.5
DC Power Loss	1.495 %
AC wiring	1.2 %
Transformer no load loss	1.2 %
Transformer load loss	1.2 %
Transmission Loss	1.2 %
Annual Degradation rate	0.5 %

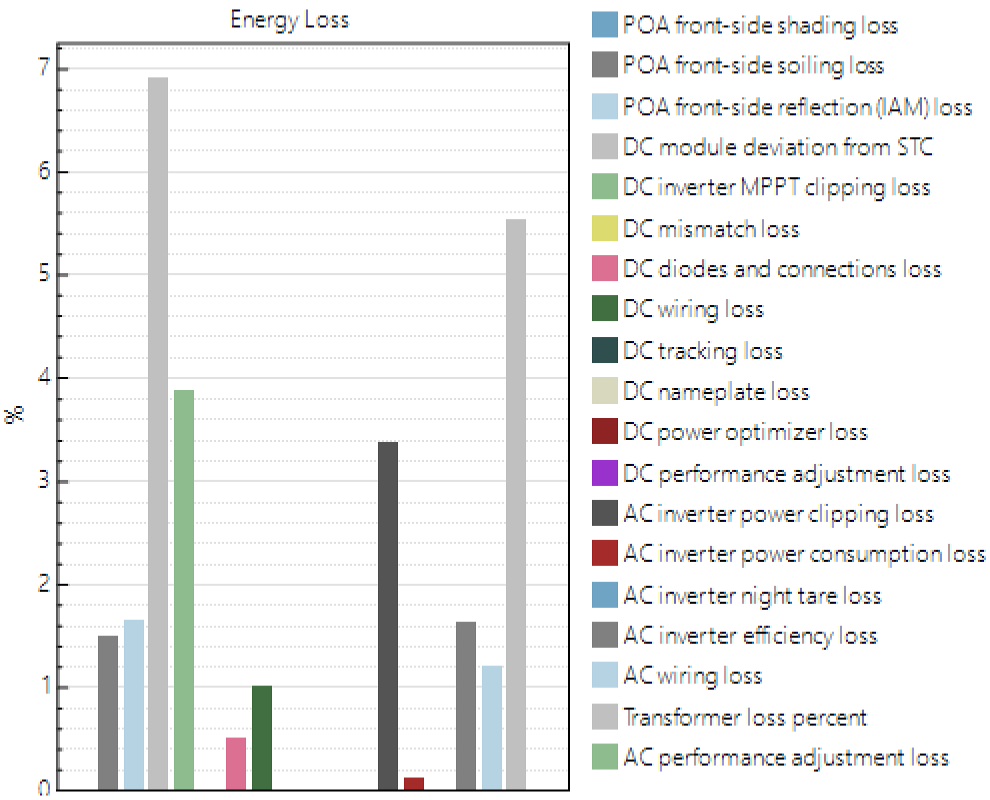


Figure 4.5: Energy Loss for monofacial in SAM

4.3.2 PVSOL

Table 4.6: Inverter details for monofacial in PVSOL

Inverter	Canadian: CSI-60KTL-GI-H
DC nominal output	60 KW
Maximum DC Power	80 KW
Nominal DC Voltage	720 V
Maximum Input Voltage	1100 V
Maximum Input Current	114 Amp
Number of Inlets	8

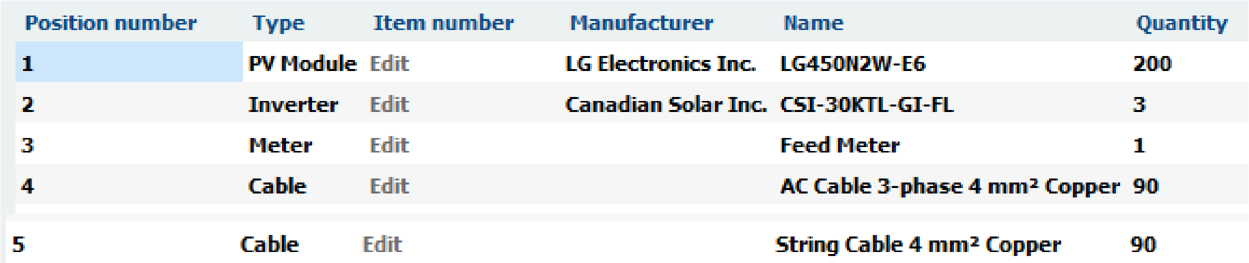
Table 4.7: Electrical data for monofacial in PVSOL

AC Power Rating	60 KW
Maximum AC Power	66 KVA
Number of phases	3

System Planning with 3D Visualization

Number of Covered Areas	1
Number of PV Modules	200
Number of Inverters	3
PV Generator Output	90 kWp

Figure 4.6: 3D Figure of simulation



Position number	Type	Item number	Manufacturer	Name	Quantity
1	PV Module	Edit	LG Electronics Inc.	LG450N2W-E6	200
2	Inverter	Edit	Canadian Solar Inc.	CSI-30KTL-GI-FL	3
3	Meter	Edit		Feed Meter	1
4	Cable	Edit		AC Cable 3-phase 4 mm² Copper	90
5	Cable	Edit		String Cable 4 mm² Copper	90

Figure 4.7: Simulation Parameters for monofacial in PVSOL

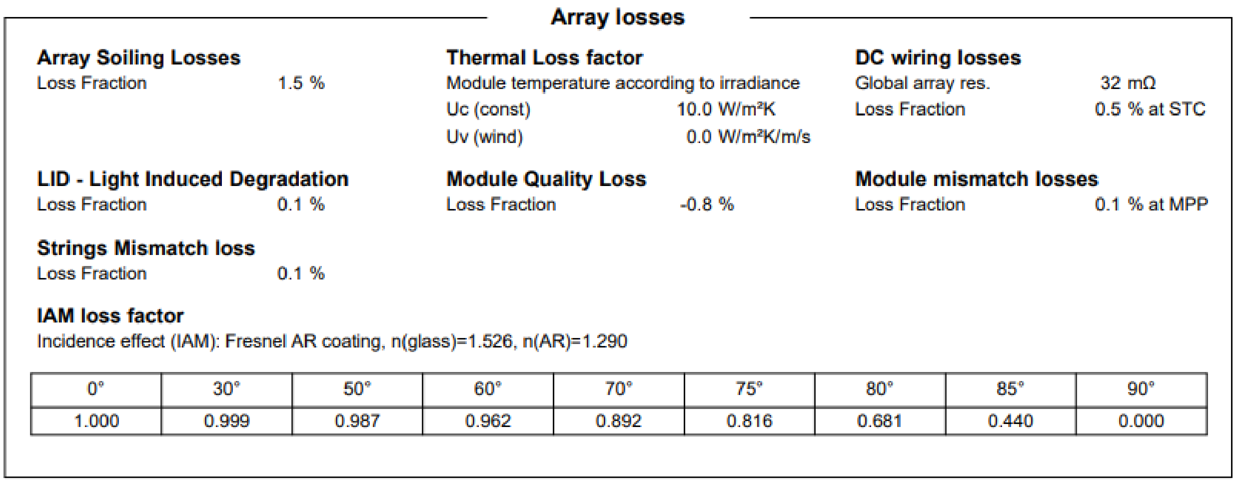
4.3.3 PVSYST

Table 4.8: Panel Parameters for monofacial in PVSYST

Number of modules	198
Pnom total	89.1 kWp
Tilt	22 degree
Azimuthal	0
Number of Inverters	1
Modules	11 Strings x 18 in series
Total nominal PV power (STC)	89 kWp
Module area	435 m^2
Cell area	388 m^2

Table 4.9: Inverter Parameters for monofacial in PVSYST

Inverter	CSI-60KTL-GI-H
Unit Nominal Power	60 KWac
Operation voltage	200-1000 V
Pnom ratio	1.49
Total power	60 KWac



Array losses

Array Soiling Losses
Loss Fraction 1.5 %

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 10.0 W/m^2K
Uv (wind) 0.0 $W/m^2K/m/s$

DC wiring losses
Global array res. 32 mΩ
Loss Fraction 0.5 % at STC

LID - Light Induced Degradation
Loss Fraction 0.1 %

Module Quality Loss
Loss Fraction -0.8 %

Module mismatch losses
Loss Fraction 0.1 % at MPP

Strings Mismatch loss
Loss Fraction 0.1 %

IAM loss factor
Incidence effect (IAM): Fresnel AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

Figure 4.8: Array losses for monofacial in PVSYST

4.4 Simulation of Bifacial Solar Panel

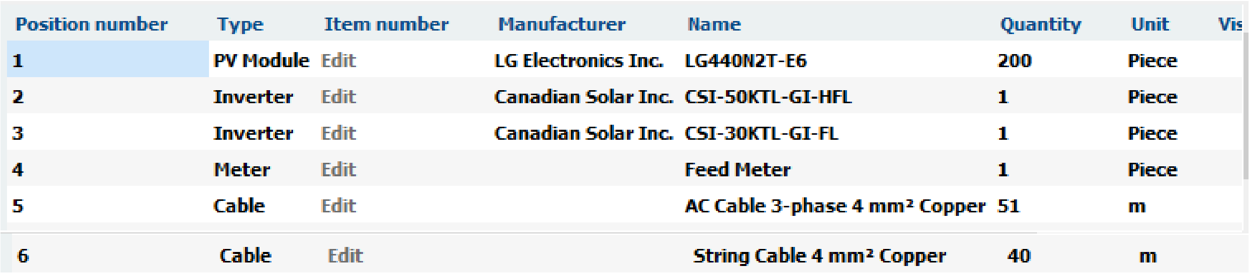
4.4.1 SAM

Same inverter was used here as monofacial solar panel.

4.4.2 PVSOL

Table 4.10: Panel parameters for bifacial in PVSOL

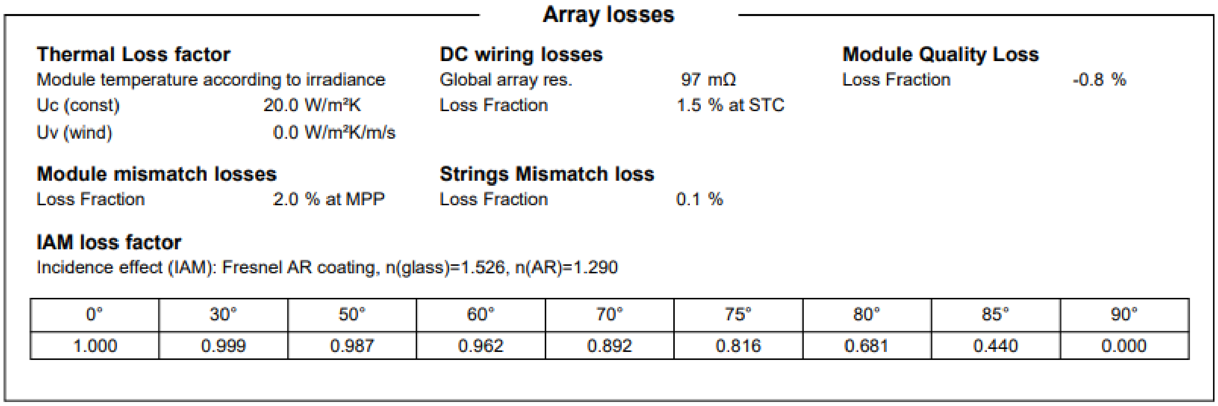
Width of Land	50 m
Length of Land	50 m
Total area	2500 m^2
Module spacing horizontal	0.005 m
Module spacing vertical	0.005 m
Mounting angle	22 degree
Depth of row	1.975 m
Mounting support clearance	1 m
Row spacing	2.975 m



Position number	Type	Item number	Manufacturer	Name	Quantity	Unit	Vis
1	PV Module	Edit	LG Electronics Inc.	LG440N2T-E6	200	Piece	
2	Inverter	Edit	Canadian Solar Inc.	CSI-50KTL-GI-HFL	1	Piece	
3	Inverter	Edit	Canadian Solar Inc.	CSI-30KTL-GI-FL	1	Piece	
4	Meter	Edit		Feed Meter	1	Piece	
5	Cable	Edit		AC Cable 3-phase 4 mm² Copper	51	m	
6	Cable	Edit		String Cable 4 mm² Copper	40	m	

Figure 4.9: Inverter and simulation parameters bifacial in PVSOL

4.4.3 PVSYST



Array losses

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 20.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

DC wiring losses
Global array res. 97 mΩ
Loss Fraction 1.5 % at STC

Module Quality Loss
Loss Fraction -0.8 %

Module mismatch losses
Loss Fraction 2.0 % at MPP

Strings Mismatch loss
Loss Fraction 0.1 %

IAM loss factor
Incidence effect (IAM): Fresnel AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

Figure 4.10: Array losses for bifacial in PVSYST

4.5 Software Details

We have used 3 different software packages: PVSOL, PVsyst and SAM.

PVSOL is a software that is used to design, simulate, and improve photovoltaic (PV) systems. The German company Valentin Software GmbH makes the software. PVSOL lets users make detailed models of PV systems that take into account things like the system's location, how much shade it gets, and how it is set up. The software also has a complete database of PV modules, inverters, and batteries that can be used to choose the best parts for a project. One of the best things about PVSOL is that it can simulate how a PV system will work over time. This lets users predict how much energy a system will produce in different weather conditions and improve the design of the system to make it as efficient as possible. PVSOL also has tools for doing financial analysis, like figuring out the levelized cost of energy (LCOE) and the payback period for a PV system. These tools can be used to figure out if a PV project is financially feasible and to compare the designs of different systems. Also, PVSOL has a 3D visualization tool that lets users make realistic models of PV systems and see them from different angles. This can help when showing designs to clients or other important people. [12]

The software known as PVsyst is utilized frequently in the process of planning and testing photovoltaic (PV) solar energy installations. PVsyst SA, a Swiss business that was created in 1992, was the entity responsible for its development and distribution. By taking into consideration factors such as solar radiation, temperature, shade, and electrical parameters, it provides customers with the ability to determine how to get the most out of their photovoltaic (PV) systems. PVsyst makes use of a comprehensive system model to make an accurate prediction of the amount of energy that will be produced by a PV system and to make an estimate as to whether or not the project will be profitable. Analyzing and optimizing photovoltaic (PV) systems for residential, commercial, and utility-scale projects is made possible with the help of PVsyst by engineers, designers, and researchers. System design, performance simulation, financial analysis, three-dimensional shading, and report generating are some of the capabilities it offers[13].

System Advisor Model, often known as SAM, is a robust piece of software that has quickly gained favor in the field of renewable energy research and development among engineers, designers, and academics. It contains a broad variety of capabilities, such as in-depth modeling of various renewable energy systems and analysis of the economic viability of these various systems. SAM is particularly useful for maximizing the efficiency of system design and reducing the total costs of projects that make use of renewable energy sources. Users of SAM are provided with a location in which they may enter data for various components of a renewable energy system, such as photovoltaic modules, wind turbines, batteries, and so on. Users are also given the ability to alter the financial aspects of the project, including the cost of capital, tax advantages, and financing choices. Because of these capabilities, it is an adaptable tool that can be used for modeling and assessing a wide variety of renewable energy systems, including those used in residential, commercial, and utility-scale projects. One of the most useful capabilities of SAM is its ability to mimic the operation of the system under a variety of climatic circumstances. The software makes use of sophisticated models to take into account a wide variety of parameters that affect energy output. Some examples of these factors are temperature, irradiance, and shade. Users are provided with an accurate and plausible representation of how the system should operate in a variety of contexts as a result of this. Both the research and development of novel renewable energy projects, as well as the planning and design of commercial renewable energy systems, have made extensive use of SAM in recent years. It is probable that SAM will continue to be an effective tool for the business even as demand for renewable energy sources increases [14].

CHAPTER 5

RESULT AND ANALYSIS

5.1. Fixed Tilt Monofacial Module

The data presented in the table showcases the monthly energy yield estimations obtained from the three modeling tools, along with the average energy yield production. Notably, the SAM, PVSOL, and PVsyst estimations demonstrate variations among themselves and when compared to the average energy yield.

Table 5.1: Fixed tilt monofacial simulation result

Month	**SAM (kWh)**	**PVSOL (kWh)**	**PVsyst (kWh)**	**Average (kWh)**
JAN	10514	10735	9850	10366
FEB	10865	10612	9750	10409
MAR	12757	12980	12100	12612
APR	11595	12571	11820	11995
MAY	11757	11469	11210	11478
JUNE	8189	9510	8800	8833
JULY	9729	8775	7840	8781
AUG	8891	9714	9400	9335
SEP	8810	10000	9130	9313
OCT	10297	10571	10090	10319
NOV	11054	10694	10010	10586
DEC	11486	10000	9680	10388
Total	**125944**	**127631**	**119680**	**124419**

These variations could be attributed to differences in the underlying algorithms, assumptions, and input parameters used by each tool. For instance, in March, the PVsyst estimation records the highest energy yield at 12,100 kWh, surpassing both SAM and PVSOL estimates. Conversely, in June, the PVsyst estimation drops to 8,800 kWh, indicating a substantial deviation from the average energy yield production of 8,833 kWh.

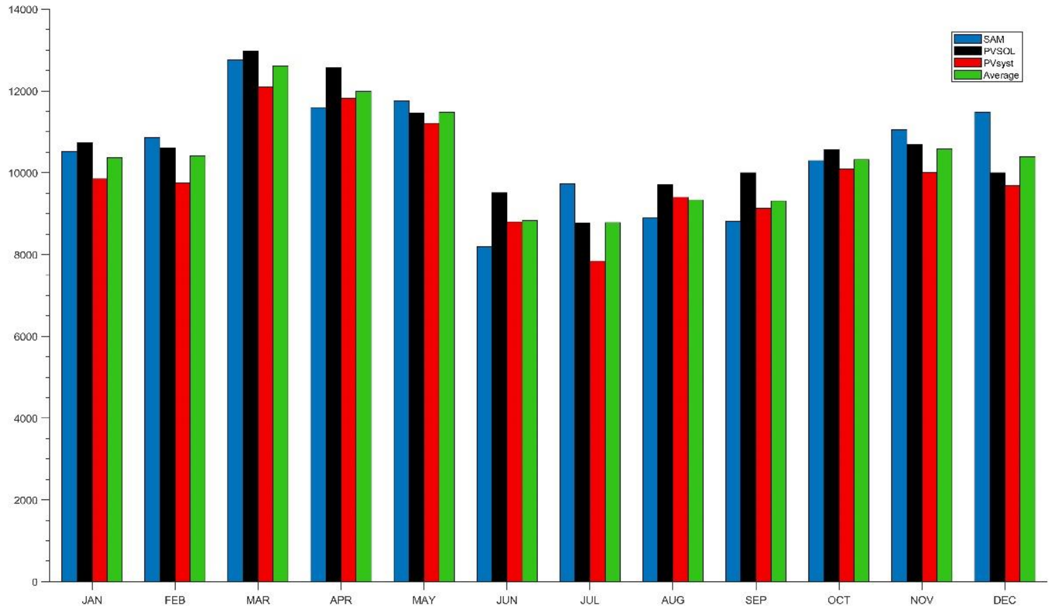


Figure 5.1: Fixed tilt results graphical analysis

Such deviations emphasize the importance of accurate modeling to ensure reliable energy yield predictions for optimal system design and resource planning. Moreover, the monthly energy yield estimations provided by SAM, PVSOL, and PVsyst exhibit varying trends throughout the year. SAM consistently tends to overestimate the energy yield compared to the other two tools, while PVSOL and PVsyst estimations often align more closely with each other. These differences underscore the need for careful consideration of modeling tool selection based on the specific project requirements and desired level of accuracy.

5.2 Fixed Tilt Bifacial Module

Analyzing the data, it is evident that the energy production varies throughout the year. In terms of SAM, PVSOL, and PVsyst, the highest energy production is observed in March, with values reaching 12,892 kWh, 12,645 kWh, and 12,990 kWh, respectively. The lowest values for these methods are recorded in July, with energy production falling to 8,110 kWh, 8,535 kWh, and 8,775 kWh, respectively.

Table 5.2: Fixed tilt bifacial simulation result

Month	SAM (kWh)	PVSOL (kWh)	PVsyst (kWh)	Average (kWh)
JAN	10622	10387	10380	10463
FEB	10946	10297	10390	10544
MAR	12892	12645	12990	12842
APR	11865	12329	12640	12278
MAY	12108	11200	11910	11739
JUNE	8621	9258	9190	9023
JULY	10135	8535	8110	8926
AUG	9297	9393	9890	9526
SEP	9027	9664	9690	9460
OCT	10459	10252	10760	10490
NOV	11189	10342	10680	10737
DEC	11675	9619	10180	10491
Total	**128836**	**123921**	**126810**	**126522.3**

Comparing the average energy production, it follows a similar trend. The maximum average energy produced is observed in November, with a value of 10,737 kWh, while the minimum average is seen in July, amounting to 8,926 kWh. Overall, the total energy production for the year sums up to approximately 126,522.3 kWh.

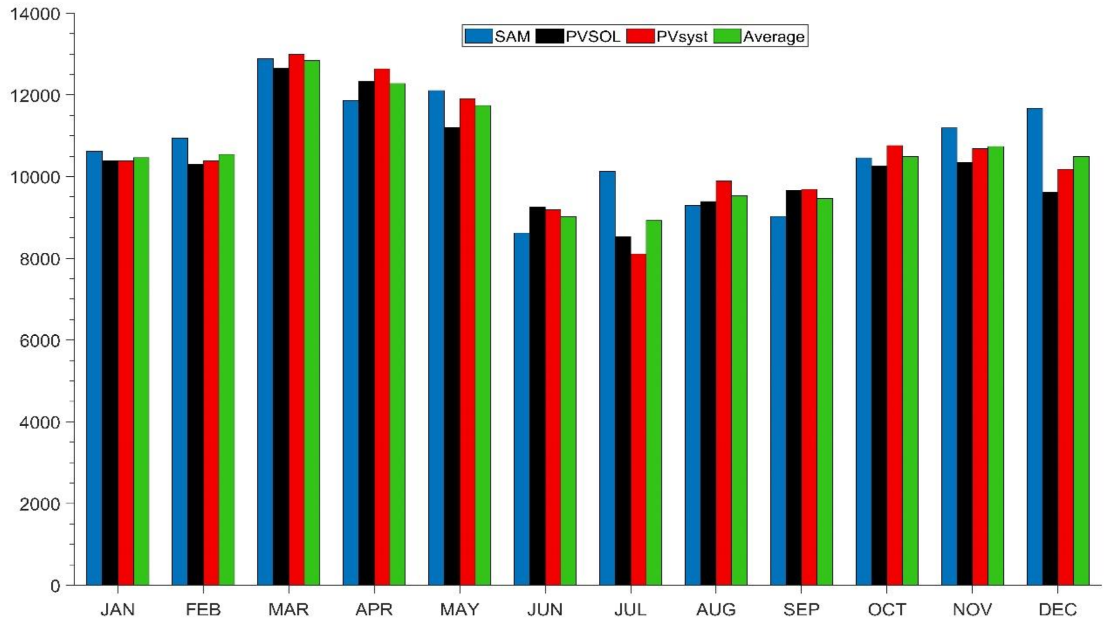


Figure 5.2: Fixed tilt bifacial result analysis

These energy production figures provide valuable insights into the seasonal variations and performance of the different methods used. Such data is essential for assessing the efficiency and effectiveness of renewable energy systems, aiding in the optimization and planning of future energy generation projects.

5.3 Dual Axis Solar Tracker

By observing at the individual systems, SAM, PVSOL, and PVsyst, we can observe some variations in their energy production throughout the year. For instance, PVSOL consistently records lower energy production values compared to SAM and PVsyst. This could be attributed to differences in the underlying models and algorithms used by each system to predict energy yield. PVsyst, on the other hand, consistently demonstrates higher energy production values, indicating its effectiveness in estimating and optimizing energy generation. When examining the monthly trends, we notice certain months where energy production tends to be higher or lower across all the systems. For example, March stands out as a month with significantly higher energy production values, with all three systems recording their peak performance. This could be due to favorable weather conditions, increased solar irradiance, or improved system efficiency during that period.

Table 5.3: Dual axis with solar tracker simulation result

Month	SAM (kWh)	PVSOL (kWh)	PVsyst (kWh)	Average (kWh)
JAN	12335	11632	12780	12249
FEB	12705	11272	12520	12165
MAR	15289	13897	15860	15015
APR	14037	13949	15950	14645
MAY	14671	12868	15300	14279
JUN	10511	10397	11230	10712
JUL	12335	9625	9540	10500
AUG	10556	10397	12180	11044
SEP	10627	10757	11840	11074
OCT	12417	11221	13200	12279
NOV	13314	11272	13410	12665
DEC	13585	10912	12820	12439
Total	**152382**	**138199**	**156630**	**149070.3**

Conversely, the summer months, including June, July, and August, exhibit lower energy production values across the board. This could be attributed to factors like increased cloud cover, higher ambient temperatures, or reduced sunlight hours during the summer season. These findings highlight the impact of seasonal variations on energy generation and emphasize the need for efficient energy management strategies during different times of the year.

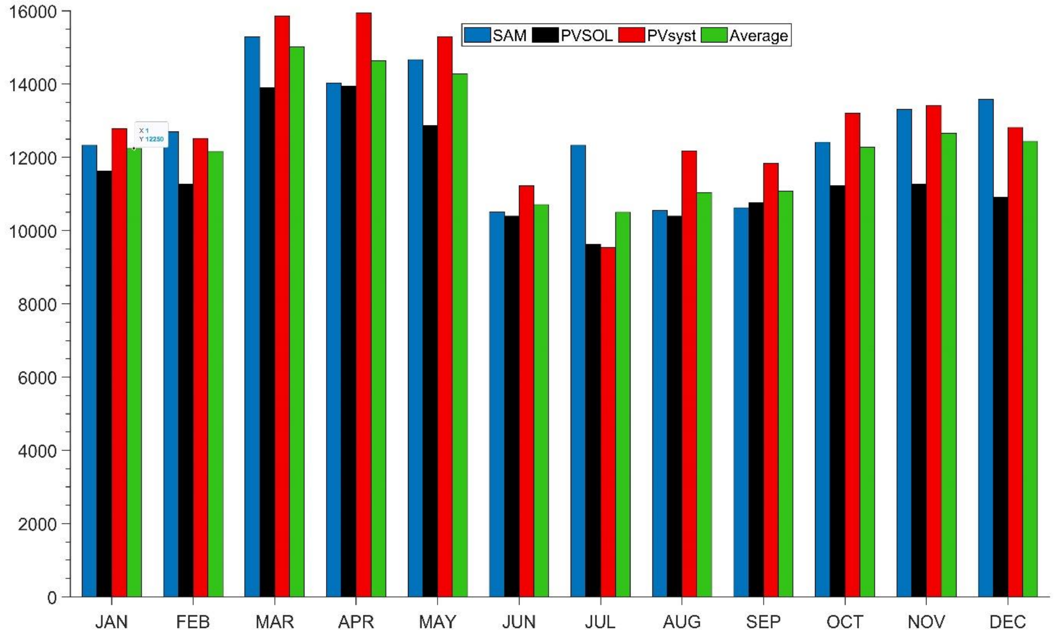


Figure 5.3: Dual axis results graphical representation

5.4 Seasonal Tilt PV system

The energy production data provided in the table reveals the monthly performance of a system. Analyzing the figures, we observe fluctuations in energy generation throughout the year.

The year commenced with January, during which the system produced 10,996 kWh according to the SAM model, 10,632 kWh according to PVSOL, and 11,230 kWh according to PVsyst. The average energy produced during this month was 10,952 kWh.Moving into February, the energy production remained consistent, with values of 10,991 kWh (SAM), 10,526 kWh (PVSOL), and 10,930 kWh (PVsyst). The average energy production for February amounted to 10,815 kWh.March witnessed a significant increase in energy production, with the system generating 12,737 kWh (SAM), 12,760 kWh (PVSOL), and 13,170 kWh (PVsyst). The average energy produced in March reached 12,889 kWh.As the months progressed, April maintained a relatively high level of energy production, reaching 11,677 kWh (SAM), 12,574 kWh (PVSOL), and 13,150 kWh (PVsyst). The average energy production for April was 12,467 kWh.

May showed a similar trend, with the system producing 12,394 kWh (SAM), 12,108 kWh (PVSOL), and 12,640 kWh (PVsyst). The average energy production in May amounted to 12,380 kWh.June marked a noticeable decrease in energy generation, as the system produced 8,862 kWh (SAM), 10,650 kWh (PVSOL), and 9,850 kWh (PVsyst). The average energy production for June was 9,787 kWh.Energy production in July continued to decline, with values of 10,219 kWh (SAM), 9,206 kWh (PVSOL), and 8,660 kWh (PVsyst). The average energy produced during this month was 9,361 kWh.August followed a similar pattern, generating 9,043 kWh (SAM), 9,782 kWh (PVSOL), and 10,410 kWh (PVsyst), resulting in an average energy production of 9,745 kWh.

In September, the system produced 8,792 kWh (SAM), 9,833 kWh (PVSOL), and 9,990 kWh (PVsyst), with an average energy production of 9,538 kWh.October exhibited an increase in energy production, reaching 10,316 kWh (SAM), 10,392 kWh (PVSOL), and 11,160 kWh (PVsyst). The average energy production for October amounted to 10,622 kWh.November's energy production was 11,589 kWh (SAM), 10,326 kWh (PVSOL), and 11,500 kWh (PVsyst), resulting in an average energy production of 11,138 kWh.

Table 5.4: Simulation tilt PV system simulation result

Month	**SAM (kWh)**	**PVSOL (kWh)**	**PVsyst (kWh)**	**Average (kWh)**
January	10996	10632	11230	10952
February	10991	10526	10930	10815
March	12737	12760	13170	12889
April	11677	12574	13150	12467
May	12394	12108	12640	12380
June	8862	10650	9850	9787
July	10219	9206	8660	9361
August	9043	9782	10410	9745
September	8792	9833	9990	9538
October	10316	10392	11160	10622
November	11589	10326	11500	11138
December	12168	9175	11170	10837
Total	**129784**	**127964**	**133860**	**130536**

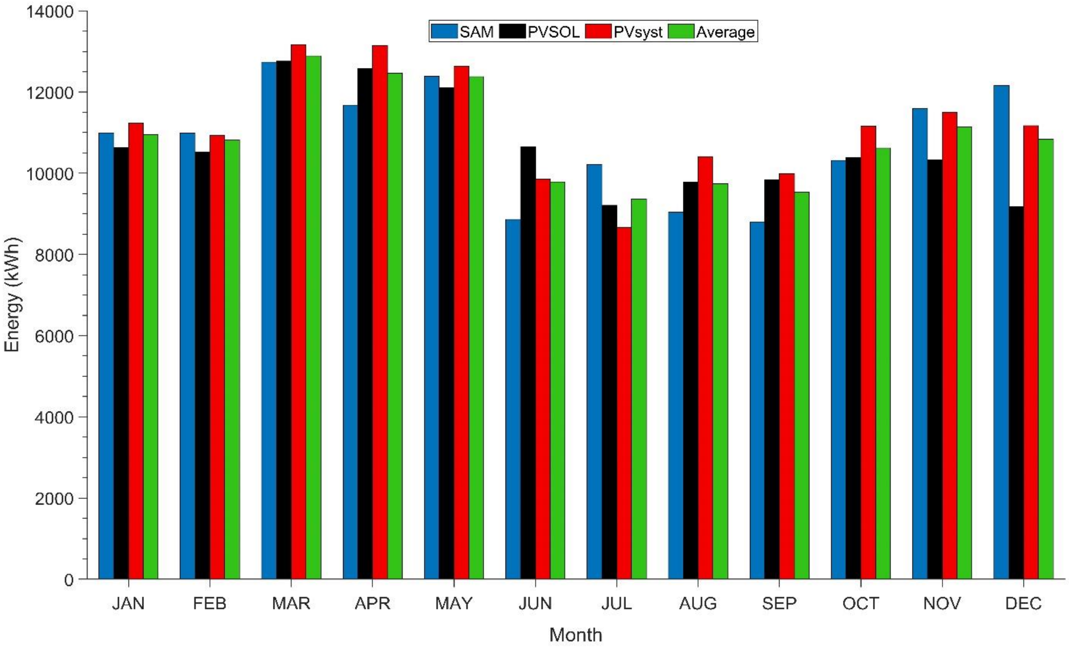


Figure 5.4: Seasonal tilt PV system graphical representation

In December, the system generated 12,168 kWh (SAM), 9,175 kWh (PVSOL), and 11,170 kWh (PVsyst), with an average energy production of 10,837 kWh. Considering the entire year, the system produced a total of 129,784 kWh (SAM), 127,964 kWh (PVSOL), and 133,860 kWh (PVsyst), resulting in an average energy production of 130,536 kWh.

These findings illustrate the fluctuating energy production levels throughout the year, providing insights into the system's performance and highlighting the months with the highest and lowest energy generation.

CHAPTER 6

PERFORMANCE PARAMETERS

6.1 Annual PV energy

The annual PV energy can be calculated from the output energy achieved from the PV modules. It is given by the formula:

$$E_a = I_{dc} \times V_{dc} \times t(kWh) \tag{1}$$

where Ea denotes the annual PV energy (kWh), I_{dc} denotes the DC current (A), Vdc denotes the DC voltage (V) and t denotes the time (h).

6.2 Reference yield

The reference yield, Y_r [15] is determined by dividing the total in-plane solar radiation H by the PV's reference irradiance G. It is the utmost amount of energy that can be produced under optimal conditions. Y_r represents the peak Sun hours or solar radiation in kWh/m^2 if G = 1 kW/m^2 and defines the solar-radiation resource for the PV system. It is determined by the location of the PV array, its alignment or azimuth, and the month-to-month and year-to-year variability of the weather profile. It has the unit h/d.

$$Y_r = \frac{\frac{kWh}{m^2}}{\frac{1kW}{m^2}}$$

$$Y_r = \frac{H_t}{G_0} \tag{2}$$

in which Y_r is the reference yield (h/d), Ht is the total horizontal irradiance on the array plane (Wh/m^2), and Go is the global irradiance under the standard test conditions (STC) (W/m^2).

6.3 Final Yield

The final yield, Y_f [15] is calculated by dividing the annual, monthly, or daily net AC energy output of the system by the peak power of the installed PV array under an STC of 1000 W/m^2 solar irradiance and 25°C cell temperature. The unit is kWh/d*kWp.

$$Y_f = E_{pv,AC}/P_{max\,G,STC} \tag{3}$$

where Y_f represents the final yield (kWh/d*kWp), $E_{pv,AC}$ represents the system's net AC energy output (kWh/d), and $P_{max\,G,\,STC}$ represents the maximal power of the PV array under STC (kWp).

6.4 Performance Ratio

The performance ratio (PR) is an internationally recognized indicator of the overall effect of losses on the rated output of a PV system due to array temperature, incomplete utilization of the irradiance, and system component inefficiencies or failures. The PR is the final yield divided by the reference yield. A PR is a comparison of the plant's output to the output that the plant could have achieved if irradiation, panel temperature, grid availability, aperture area, nominal power output, and temperature correction values were all considered [16].

$$PR = \frac{Y_f}{Y_r} \tag{4}$$

where PR represents the performance ratio, Y_f represents the final yield (kWh/d*kWp) and Y_r represents the reference yield (h/d).

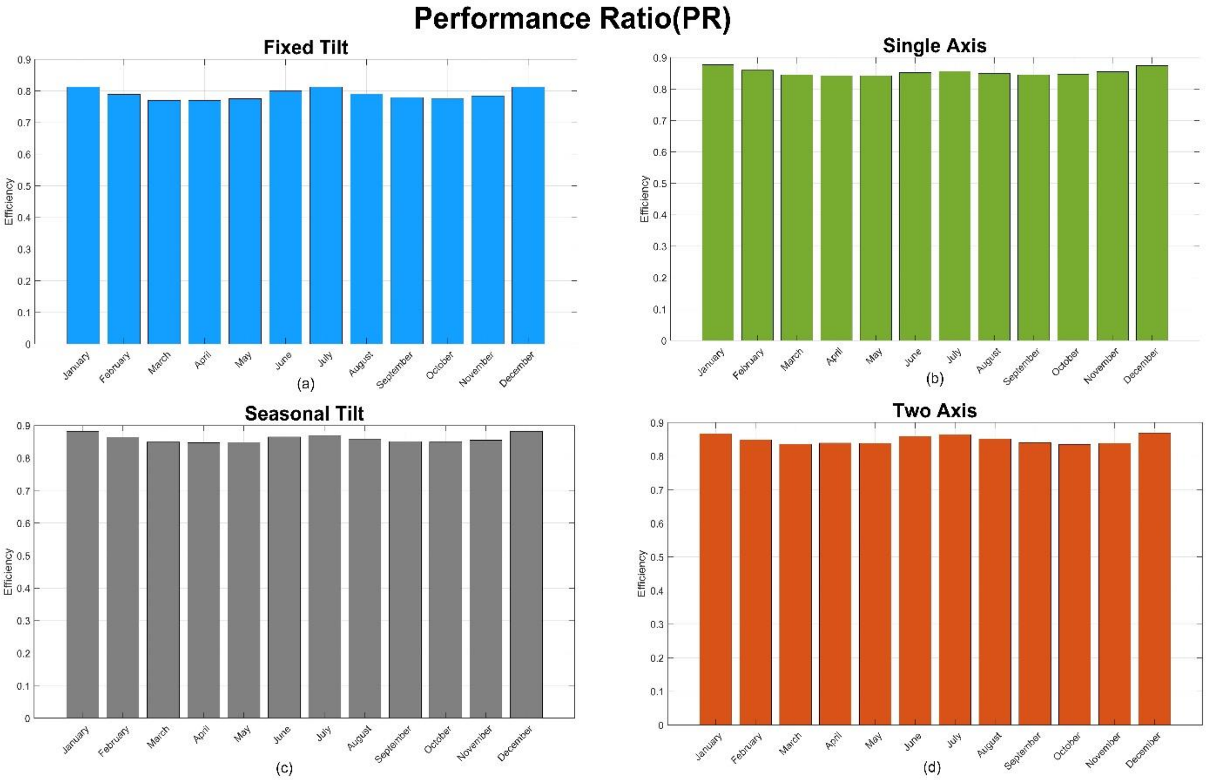


Figure 6.1: Monthly Variation of Performance analysis: (a) Fixed Tilt, (b) Single axis, (c) Seasonal Tilt, (d) Two axis

6.5 Specific Yield

The specified yield, Y_s, is defined by the quantity of energy (kWh) produced per module capacity (kWp) per year [17]. It has the unit kWh/kWp.

$$Y_s = \frac{E_{gen}}{Cap_{module}} \tag{5}$$

where Y_s is the specific yield (kWh/kWp), E_{gen} is the quantity of energy produced (kWh), and Cap_{module} is the module capacity (kWp) .

6.6 Carbon balance

The carbon-balance tool estimates the reduction in CO2 emissions that a PV installation will produce. This calculation is based on life cycle emissions (LCE), which represent the CO2 emissions associated with a particular component or energy quantity. These values include the total life cycle of an element or quantity of material, which includes, among other things, manufacturing, servicing, maintenance, and disposal. The unit is tonnes annually.

$$(E_{grid} \times project\ life\ time \times LCE_{grid}) - LCE_{system} \tag{7}$$

where LCE_{grid} represents the average quantity of CO2 emissions per energy unit for the grid's electricity production, given in gCO2 /kWh. According to the IEA, the value for Bangladesh is 584 g CO^2 per kilowatt-hour. Using the PVsyst carbon-balance instrument, LCEsystem was determined to be 79.8 tons of CO2; this includes production related to solar modules, inverters, wiring, and mounting systems [18]. E_{grid} represents the annual energy yield that is obtained. Here, we regard the project's lifespan to be twenty years.

CHAPTER 7

CONCLUSION AND FUTURE WORKS

7.1 Synopsis

This thesis focuses on design, simulation, and comparative analysis of a monofacial and bifacial solar panel-based energy harvesting system installed on a rural area electricity generation. In addition, they were compared with each other. The proposed configuration required a total of 144 modules. this study focused on several important aspects related to solar panels and PV systems. Firstly, the investigation explored the performance of both monofacial and bifacial solar panels under various test settings, providing valuable insights into their efficiency and suitability for different conditions.

The second part of this study entailed the building of a photovoltaic (PV) small grid in an isolated region. This mini grid was designed to meet the energy requirements of communities that are not connected to the primary power grid. This effort has the potential to significantly improve the quality of life in underserved areas by bringing power to those areas and bringing it to more people. In conclusion, the research highlighted how important it is to make an accurate estimation of the amount of energy that can be generated by PV systems before actually putting them into physical operation. This allows for improved resource management and planning. In general, the findings make a contribution to the development of technologies that use renewable energy sources and their use in the solving of energy problems in remote places.

7.2 Limitations

There are various limitations that need to be taken into mind before moving on. The findings that are generated by the various software tools, such as PVSol, PVsyst, and SAM, are not entirely consistent with one another. There is some degree of discrepancy. This is one of the constraints on the system. These tools make use of a variety of methodologies, and the same set of input variables could result in quite different predictions being given by them even though they employ the same techniques. The accuracy of these projections is also determined not just by the quality of the data but also by the assumptions that were made when the study was being carried out.

The fact that the software packages that were utilized in the accomplishment of this research do not come equipped with an in-built cost-benefit analysis is yet another disadvantage of this line of investigation. Despite the fact that they provide crucial insights into the energy generating capabilities, they do not instantly address the question of whether or not it is economically viable to create a solar system. This is despite the fact that they provide vital insights. The photovoltaic (PV) system that is scheduled to be installed will require additional research and consideration in order to investigate its financial consequences and determine whether or not it would be cost-effective.

The accuracy of the software's forecasts is also significantly influenced by the quality of the meteorological data that is utilized in the process. Inaccurate or insufficient data can bring errors into the process of estimating, which can result in discrepancies between the performance that was predicted for the solar system and the performance that was actually attained. These discrepancies can lead to a loss of energy production by the solar system. It is crucial to have an understanding that these calculations are merely estimates, and it is possible that they do not accurately portray the circumstances that are present in the real world or the complexities of the system. In light of these constraints, it is vitally required to conduct extra research and validation through on-site measurements and the gathering of data in order to ensure the dependability and precision of the performance estimations that are supplied by the software tools. These estimations may be found in the Software Tools section.

7.3 Future Works

Before moving on with the economic feasibility analysis of the project, there are a number of significant aspects that need to be analyzed. It is important to perform a computation that is known as the levelized cost of energy (often abbreviated as LCOE) in order to determine whether or not the PV system is cost-effective overall. In order to accomplish this, it will be necessary to take into consideration the costs of the initial investment, the expenditures associated with operation and maintenance, as well as the estimated energy output over the system's lifetime. Evaluation of the project's value elements (VF) is also required in order to gain an understanding of the implications the undertaking will have financially. In order to accomplish this, it is necessary to take a number of factors into consideration, including as the rates on the energy market, the integration of the grid, and the possibility of earning incentives or subsidies.

In addition, carrying out a comprehensive analysis of the payback period would be of great assistance in gaining useful insights into the practicability of the project from a monetary point of view. In this section of the study, we will compare the costs of the initial investment with the savings that are predicted to be achieved over time from the PV system. These savings will be in comparison to the expenses of the initial investment. The payback duration is an important indicator for all of the parties that are involved in the project because it indicates how long it will take for the project to earn a profit and repay the money that was initially invested in it. Consequently, the payback period is an important indicator for all of the parties that are engaged in the project.

It is important to develop and monitor a miniature test array in order to gather accurate and real-time data on the operation of the system. This is done in order to make an exact estimate of the energy yield that can be used in the system. In order to accomplish this goal, a photovoltaic (PV) array will need to be constructed on a smaller size and data will need to be gathered concerning the production of power under a variety of climatic and seasonal conditions. The accuracy of the energy yield projections and estimates for future projects can be improved thanks to the information that can be obtained from this test array.

An assessment of the effect that the action will have on the natural world is yet another vital component that needs to be given serious thought. It is strongly suggested that a comprehensive study be conducted in order to get an accurate assessment of the environmental footprint that the PV system would leave. This analysis ought to take a number of factors into consideration, including the exhaustion of resources, the emission of greenhouse gases, and the generation of waste. The parameterization of the environmental implications will help in the identification of prospective regions for enhancement and will make it possible to execute ecologically responsible practices throughout the lifecycle of the project. This will be beneficial to both the environment and the economy.

References

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