PV System Installation Design and Energy Production Analysis for Bangabandhu Bridge

by

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Declaration of Authorship

We, Ummay Habiba Wani (170021027), Shayla Sharmin Urmi (170021074), Tasneem Islam Promi (170021133), declare that this thesis titled, “PV System Installation Design and Energy Production Analysis for Bangabandhu Bridge” and the works presented in it are our own. We confirm that this work has been done for the partial fulfillment of the Bachelor of Science in Electrical and Electronic Engineering degree at this university. It has also been proclaimed that no part of this thesis has not been submitted anywhere else for obtaining any degree. Where we have consulted the published work of others, we have always clearly attributed the sources.

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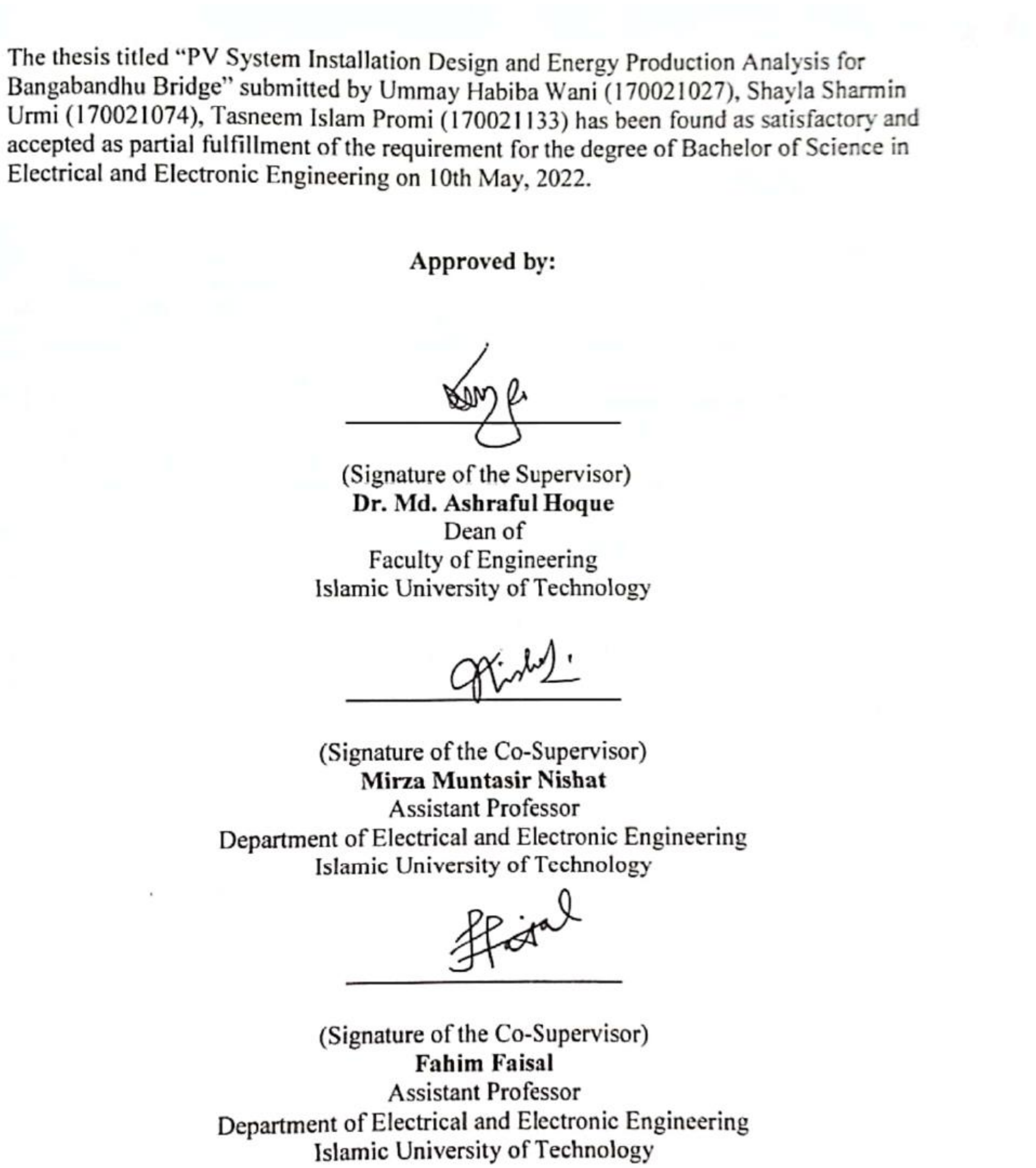

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Abstract

A potential strategy to minimize carbon footprint is to integrate solar panels into the power generating business and progressively move away from dangerous old energy production techniques. Given Bangladesh's dense population and high pollution levels, solar energy generation can assist the country fulfill two goals at once. This research intends to create a software-based green energy harvesting system that can assist nations like Bangladesh satisfy their energy needs while decreasing carbon emissions and avoiding the need of extra resources. For Bangladesh's longest bridge, we created and simulated a monofacial solar panel-based energy model. This facade-mounted energy model was examined for viability and application with the objective of satisfying demand while exceeding output in the neighboring rural and suburban regions. Design and simulation software includes PVSOL, PVsyst, and SAM. A thorough energy analysis was carried out in order to gain a better knowledge of the proposed system's practicality.

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Chapter 1

INTRODUCTION

1.1 Overview

With the depletion of convention non-renewable energy worldwide, such as fossil fuel, it has become difficult to cope with the rising demand of electricity.

According to the statistics below, the overall energy consumption of the globe in 1990 was 10,120TWh, of which Europe, CIS nations, North America, Latin America, Asia, Pacific, Africa, and the Middle East consumed 2515TWh, 1417TWh, 3154TWh, 507TWh, 1887TWh, 165TWh, 262TWh, and 213TWh, respectively. Since then, there has been a progressive climb in the graph has been observed worldwide with Asia currently having the the largest power consumption of energy at more than 10,000TWh, the highest energy consumption profile in the whole world. And the consensus shows that in the year 2020, global energy consumption was 23177TWh, and it is still increasing now.

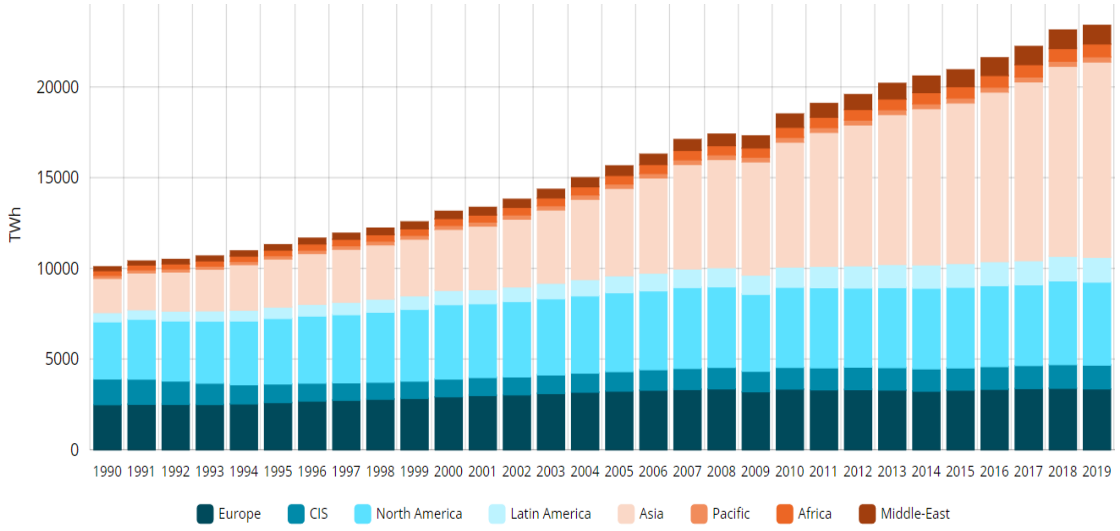

Figure 1.1: Global Energy Consumption from year 1990-2020 [1]

As a result, in order to fulfill the society’s current energy demand, we want an energy source that will never run out. That’s when men were compelled to harness nonrenewable energy sources for their endless beneficial purposes. Renewable energy is energy obtained from renewable resources such as sunlight, wind, rain, tides, waves, and geothermal heat that regenerate themselves spontaneously over time. Also, due to the threat of climate change from excessive carbon emissions grows, some countries are looking for alternative energy sources that are clean and sustainable to replace traditional fossil fuels. Among all the renewable resources, solar power is growing more popular as a result of its ease of access, which has resulted in cheaper installation and operating costs, with tiny and medium-sized panels becoming more practicable for both large sites and isolated areas. As a result, installing remote solar panels to generate power in a specific location or structure is becoming increasingly popular.

1.2 Current Energy Status of Bangladesh

Bangladesh's energy resources are extremely limited, with only a modest amount of oil, coal, and countable natural gas reserved. The country faces an internal energy crisis because around 93% of the country's thermal power plants are gas based, yet the industrial sector also needs gas. [2] Around 62.9% of the power produced in Bangladesh is from natural gas, whereas 10% is diesel, 5% is from coal, 3% is from heavy oil, and 3.3% from renewable sources. Currently, only roughly 52% of Bangladesh's population is connected to the main grid, with about 75% of the rural population still unconnected. The country's insufficient pricing policies are a second source of concern, as they block and complicate effective power sector investment, with inadequate space being another impediment. Given Bangladesh's current situation, a renewable energy source that is both less space consuming as well as environmentally benign and cost effective is required to satisfy the country's energy requirement.

1.3 Renewable Energy

1.3.1 Introduction to Renewable Energy

Renewable energy refers to capturing energy from renewed natural resources and is less detrimental to the environment since it does not create greenhouse gases such as carbon dioxide, carbon monoxide, and so on. Long-term usage of fossil fuels as a main source of energy has already degraded our ozone layer significantly. As a result, in order to avert more irreversible environmental harm, an increasing number of countries are transitioning toward renewable and 'clean' energy supplies. It is clear that renewable energy is seen as a viable alternative to energy shortage. The most popular renewable energy sources currently are: Solar energy, Wind energy, Hydro energy, Tidal energy, Geothermal energy and Biomass energy.

1.3.2 Solar Energy

One of our planet's most plentiful and readily available energy sources is sunlight. The quantity of solar energy that reaches the earth's surface in one hour is enough to meet the planet's whole annual energy needs. While every part of the world receives some sunshine year around, the quantity of solar radiation reaching any one spot on the planet's surface varies. This radiation is captured by solar technology and converted into energy. Photovoltaics (PV) and concentrated solar-thermal power are the two primary forms of solar energy technology (CSP). Although it appears to be an ideal renewable energy source, the quantity of solar energy we can utilize depends on the time of day, season of the year, and geographical location.

Advantages of Solar Energy

Solar energy is an unbiased, widely acknowledged, and feasible alternative energy source. Solar power is also clean energy because it is a renewable source that produces no greenhouse gas emissions. Solar panels are being installed to help combat climate change. People are eager to put their money into projects that will not harm the earth we live on. Installing solar panels will assist by producing clean energy that can be sold. The power generated from the PV cells can be stored and used at any time of need. Along with being energy independent PV system also ensures low maintenance cost. Solar energy not only ensures national security and independence, but it can also be installed on individual homes to supply electricity without the need for a larger electrical grid. Solar technology is growing more advanced with time passing by, and the cost price is becoming more affordable. Solar has a bright future; it is being used in every part of life.

Disadvantages of Solar Energy

With the cost of power growing by 3% to 5% every year, solar energy is being investigated as an alternate solution. However, before constructing a solar system, certain significant drawbacks must be considered. Energy can only be produced when sunlight strikes the panel's surface and is transformed. As a result, if there is no sun, no energy is produced. And despite solar power having the highest initial costs of any other renewable energy source, solar panels have low efficiency. In a prime location with the best and most expensive technology available around 22% conversion rate is achieved. On top of that, the initial outlay for installing solar panels is rather substantial. While solar energy is considered an everlasting renewable resource, the method we now harness it has various drawbacks ranging from unaffordability to inefficiency. Nevertheless, solar energy is still in its infancy, and many promising concepts are emerging.

1.3.3 Photovoltaic System

Photovoltaic system is an electric power system that uses photovoltaics to generate sustainable solar electricity. Solar cells, often known as photovoltaic (PV) cells, convert light energy into usable electrical power. These cells are made of materials that absorb light, which is alter converted into electric energy. A photovoltaic substance is a material used in the manufacture of solar cells that directly convert sunlight into energy. The primary objective of photovoltaic (PV) systems has been to minimize the reliance on power provided by fossil fuels. PV generated power is a reliable operational system that runs on low cost with minimum environmental contamination.

1.3.4 Solar Energy Status in Bangladesh

To avoid severe energy shortages, Bangladesh has resorted to renewable energy sources as alternatives. Even though solar power dominates Bangladesh's renewable energy mix, wind power is still at near-zero levels.

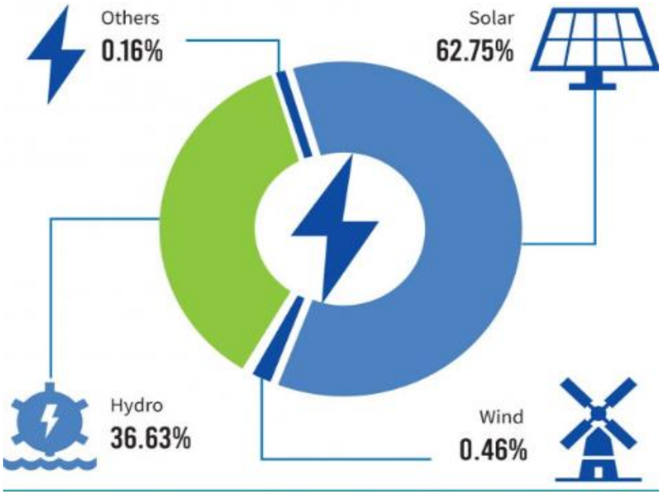

Figure 1.2: Share of total renewable sources.

Solar energy is the most common renewable energy source in this area. With an averaging 4-6.5 kWh/m2 of solar energy incident every day and an average of 10.5 hours of sun per day, 4-4.5 of which are peak hours of sunshine and 300 clear bright days per year, there are enormous solar energy potentials for the country. It is rather a difficult task to install the panels, especially in a country like Bangladesh who ranked 11th in the list of the most densely populated countries. [3] Hence, rooftops, highways, vacant places with ample sunlight can be utilized to that end. As a result, an initiative is being undertaken to develop a solar PV plant on the edge of the Bangabandhu Bridge in order to fulfill the rising power demand.

1.4 Overview of Bangabandhu Jamuna Bridge

Bangabandhu bridge, also known as the Jamuna multifunctional bridge, links Bhuapur in the east with Sirajganj in the west, with a length of 5.63 kilometers and a width of 18.5 meters, 47 spans each measuring 100 meters and two end spans of 65 meters. This bridge has acted as an important mode of communication, facilitating interregional trade while also benefiting the country's overall economy. In addition to managing railway traffic, the Jamuna bridge connects Bangladesh's electricity and gas networks, establishing a national grid.

Figure 1.3: Bangabandhu Jamuna Bridge Bangladesh

The goal is to capture electricity from solar panels that will be mounted on both sides of the bridge (north and south). This project not only saves space, but it is also a viable and long-term resolution for Bangladesh.

Chapter 2

LITERATURE REVIEW

When it comes to harvesting energy from solar panels, a lot of important research have been conducted in the three software- PVSOL, PVsyst, and SAM, as evidenced by study work by many scholars. Md. Sultan Mahmud addressed the concept of solar highway implementation, vertical installation of bifacial solar panels, solar panel efficiency, and other topics in their research paper, Solar Highway in Bangladesh Using Bifacial PV, published in 2018. [4]

In his research paper- Design, Simulation and Analysis of Monofacial Solar PV Panel Based Energy System for University Residence: A Case Study in 2021, Abdullah Al Mehadi designed and simulated a monofacial solar photovoltaic panel-based energy harvesting system for university residential. In this paper he showed monthly and yearly energy yield from simulated from PVsyst, PVSOL and SAM, and comparative analysis. [5]

Another research from the paper B shows a software-based technique to designing and simulating a bifacial solar panel-based energy model on the roof of the North Hall of Residence at Islamic University of Technology, Gazipur. This vertically mounted model looks at the feasibility and usefulness of such an energy model in a university dormitory that is prone to load shedding. Here also, the software PVSOL, PVsyst and SAM are used for model simulation.

Chapter 3

AIMS AND OBJECTIVES

3.1 Our Proposal

To produce electricity in order to meet the increasing electricity demand, we have proposed to build a solar PV plant on the edges of Bangabandhu Bridge. We have selected Bangabandhu Jamna bridge as it serves as an important link for Bangladesh power and gas station, forming a national grid. The placement of solar panels on the bridge is designed using a strict software-based technique. PV panels will be installed on both the north and south sides of the bridge. The software PVSOL, PVsyst, and SAM were used to design the PV system and compute energy production for various installations.

3.2 Motivation Behind Our proposal

One of the main reasons for our suggestion is that Bangladesh has to expand its power output in order to maintain its present GDP growth. If done using typical fossil fuel power plants, however, it will be a major drain on Bangladesh's limited fossil fuel supplies and damaging to the environment. The power generated and distributed in Bangladesh's sub-urban and rural areas is insufficient to meet the country's energy requirements. Furthermore, many individuals cannot afford a continuous source of electricity. Installing solar PVs on the edge of a bridge appears to be a viable option in the long term, given the economic and environmental conditions, and hence our research is based on it. Moreover, Bangladesh has plenty of sunny days and sunlight, making it perfect for establishing a solar project. As a result, we focused our study on solar energy as a renewable energy source.

3.3 Objectives of Our Research

The main objectives of our research are:

- To design a PV system and harvest energy from it
- To compile and compare results found in 3 software for different orientations (such as for north and south side, and for both sides combined)

- To meet energy demand of the locals
- To determine a way to expand the power sector of Bangladesh without causing harm to the environment through the implementation of renewable sources of power.
- To contribute to energy production in the country to meet increasing demand.

3.4 Thesis Outline

1. Our research begins with an overview and data on renewable and solar energy throughout the world, as well as in Bangladesh.
2. A literature review of some prior studies in this topic is included in the second chapter.
3. The third chapter discusses the research project's goals, objectives, and motivation.
4. The fourth chapter focuses on our project's methodology, process, and operational plans.
5. The fifth chapter contains a description of the technical components that are required for our design, as well as their specs and some other input factors.
6. The outcomes of our models' optimization are discussed in the sixth chapter.
7. The seventh and last chapter contains the conclusion and provides insight into the project's future potential.

Chapter 4

PHOTOVOLTAIC CELLS

Photovoltaic cells are composed of semiconductor material. To achieve larger voltages, currents, and power levels, PV cells are electrically coupled in series or parallel circuits. Photovoltaic modules are the primary building blocks of PV systems, consisting of PV cell circuits. PV panels are pre-wired, field-installable units that consist of one or more PV modules. Modules from various manufacturers can be intermixed as long as the rated voltage output is within 1.0 volt difference. The front surface of the module is protected by tempered glass (or another transparent material), while the back surface is protected by a protective and waterproof material. In a mountable device, the edges are sealed for weatherproofing, and there is generally an aluminum frame supporting everything together. A junction box is located on the back of the module that provides electrical connections.

4.1 Working principle

A solar cell is a semiconductor diode with a large surface area. It directly converts the energy from sunlight into electrical energy through the photovoltaic effect. Solar cells are made up of a p-n junction that is formed by adding impurities (doping) to the semiconductor crystal used in silicon solar cells. Only four electrons are required to fit phosphorus-atoms into the silicon crystal structure; the fifth electron is mobile and free. Because there are many (a majority) free negative charges in this region of the crystal, it is known as the n-region. For the p-region, the reverse is true: By doping the crystal with boron atoms, which only have three outer electrons, one electron is constantly absent for complete crystal structure binding. This electron can be borrowed from nearby atoms which cause shifting the location of the missing electron. This missing electron can also be viewed as a mobile and roaming "hole" with a positive charge. In the p-regions, there are much more free holes than free electrons, hence the electrons are known as minority charge carriers. Because of the concentration differences at the border between the two regions, electrons diffuse into the p-regions and "holes" into the n-regions, causing an increase in the electrical field in the once electrical neutral junction until further practical carrier diffusion is averted. Light striking the semiconductor generates electron-hole pairs, increasing the minority charge carrier concentration by several degrees of magnitude. As the charge carriers diffuse to the space charge zone they are divided by the electric field. A voltage can be detected between the contacts of two sides. When a load is applied current flows through it and thus we can get electric power. [6]

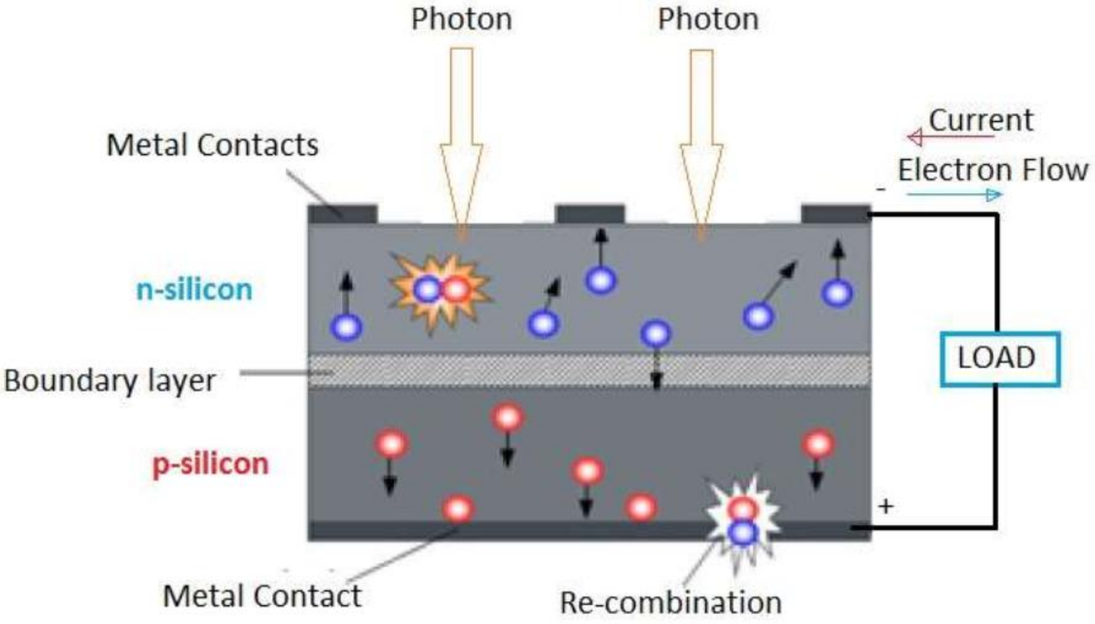

Figure 4.1: Working Principal of PV cell

4.2 Characteristics of a solar cell

The output current (I) and voltage (V) relationship defines the electrical characteristics of a solar array. The level of output current is determined by the amount and intensity of solar irradiance, while the operating temperature of the solar cells impacts the PV array's output voltage.

The superposition of the IV curve of the solar cell diode in the dark with the light-generated current gives the IV curve of a solar cell. 1 The light causes the IV curve to drop down towards the fourth quadrant, allowing power to be harvested from the diode. Illuminating a cell increases the dark saturation current(I_0) in the diode. It is an extremely important parameter which is a measure of the recombination in a device. A diode with a larger recombination will have a larger I_0. This phenomena changes the ideal diode equation to,

$$I = I_0[\exp(\frac{qV}{nkT}) - 1] - I_L$$

Where,

I = The net current flowing through the diode

I_0 = Dark saturation current

V = Applied voltage across the terminals of the diode

q = Absolute value of electron charge

k = Boltzmann's constant

T = absolute temperature (K)

I_L = light generated current

Now there a number of important parameters which can be used to characterize solar cells which are discussed in the following section.

4.2.1 Open circuit voltage

Under standard test conditions, the maximum output voltage that the modules provide at no load is the open circuit voltage of the module. The net current is zero at Voc point. It depends on the technology used to manufacture solar cells and the number of PV modules connected in series. Higher the Voc better the performance of the panel.

$$\mathrm{V_{oc}} = \frac{\mathrm{nkT}}{\mathrm{q}} \ln((\frac{\mathrm{I_L}}{\mathrm{I_0}} + 1)$$

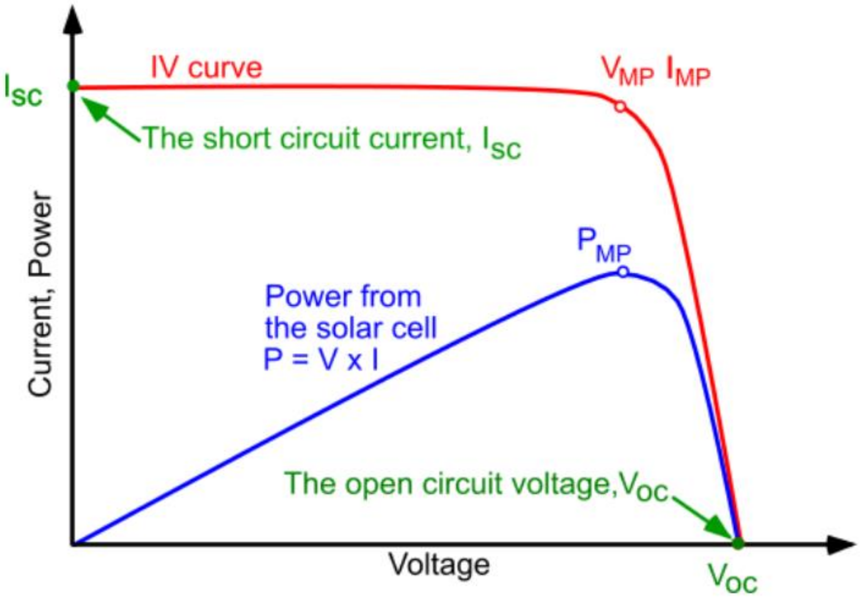

Figure 4.2: Current voltage (IV) cure of a solar cell

4.2.2 Short Circuit Current

Under standard test conditions when the output connectors of PV modules are shorted together, current delivered by the array is the short circuit current (Isc). Similarly to open circuit voltage, a higher short circuit current value also suggests that the module will provide better performance. This current depends upon a few factors such as the area of the solar cell, number of photons, spectrum of the incident light, optical properties (absorption and reflection) of the solar cell, collection probability. Generally short-circuit current density (Jsc) is used instead of the short-circuit current in order to remove the dependence on the solar cell area. For a cell with perfectly passivated surface and uniform generation, the short-circuit current can be estimated to be:

$$J_{sc} = qG(L_{n+}L_p)$$

Where,

G= generation rate

L_n= e- (electron) diffusion length

L_p= h+ (hole) diffusion length

4.2.3 Maximum Power Point

Any voltage and current combination up to Voc and Isc can be used to power a solar module. However, the output power is maximal for a specific current and voltage combination. That point is called the maximum power point. From the V-I characteristic curve, we can see that the output power increases nearly linearly with the current. But after a certain current power starts to drop as it approaches short circuit current. This happens because the voltage across the terminals of the module is considered to be theoretically zero. As a result, it is evident that a solar module's maximum output power does not occur at maximum current, but rather at a current that is less than short circuit current. Open circuit voltage also affects the curve in a similar manner. So we can see that the maximum power in a solar module occurs at a voltage lower than the open circuit voltage, just like it did in the previous case. MPP is the point where we get the maximum power from the solar module for a specific combination of voltage and current. In figure 4.3, we can see that the power curve has a point PMP which is the maximum power point. The voltage at this point is denoted as VMP and the current is denoted as IMP. The maximum power of a solar module is given as

$$P_m = V_m I_m \tag{1}$$

4.2.4 Fill Factor

Fill factor (FF) of a solar module is defined as the ratio of maximum power (Pm) to product of open circuit voltage (Voc) and short circuit current (Isc). It is a measure of how closely a solar cell is to an ideal source or its efficiency. Maximizing fill factor is essential for efficient operation of a PV system as it indicates the highest achievable power from the system. For silicon solar cells fill factor of a module is usually about 80%. [7]

$$FF = \frac{P_{max}}{V_{oc}\ I_{sc}}$$

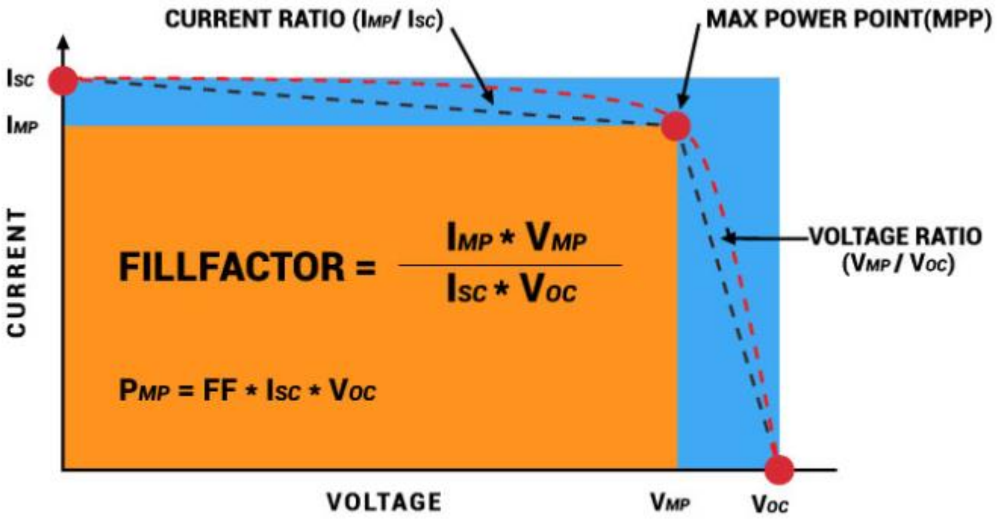

Figure 4.3: Fill factor from V-I characteristics curve

4.3 Solar cell efficiency

The efficiency is the most common metric used to compare the performance of different solar cells. Most solar panels today have an energy efficiency rating of 11 to 15 percent, which indicates how much solar energy is converted into usable power. While this may appear to be a small percentage, solar energy technology is always improving, and current panels can easily meet the energy needs of most business and residential applications. Using multi junction cells that are designed to collect different frequencies of light on the electromagnetic spectrum, scientists have now achieved a record of 40% efficiency. [8]

To get the efficiency of a solar cell the output electrical power at the maximum power point on the IV curve is divided by the incident light power - generally using a standard AM1.5G simulated solar spectrum. The fraction of incident power converted to electricity determines a solar cell's efficiency. It can be defined with the equation,

$$\eta = \frac{V_{oc}\, I_{sc} FF}{P_{inc}}$$

$$P_{max} = V_{oc}\, I_{sc} FF$$

Where,

η = Efficiency

Voc = Open-circuit voltage

Isc = Short-circuit current

FF = Fill factor

Pmax = Maximum power from the cell

4.4 Effect of Temperature on Solar Cells

Temperature variations have an impact on solar cells. As the temperature rises, the band gap of the semiconductor narrows, affecting most of the properties of the material. The energy of electrons in a material increases as the band gap of a semiconductor narrows with increasing temperature. As a result, less energy is required to break the connection.

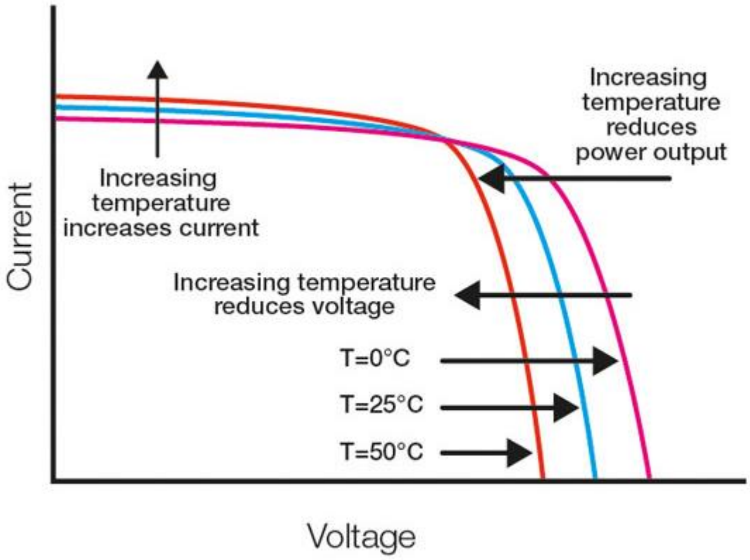

Figure 4.4: Effect of temperature on I-V curve

In a bond model of a semiconductor band gap, lowering the bond energy lowers the band gap. As a result, raising the temperature lowers the band gap. The open circuit voltage is the parameter in the solar cell that is most affected by temperature increases. Because I0 is temperature dependent, the open circuit voltage lowers as the temperature drops. The I0 equation from one side of a p-n junction is:

$$I_o = qA \frac{Dn_i^2}{LN_D}$$

Where,

q = Electronic charge

A = Area

D = Diffusivity of minority carrier provided for silicon as a function of doping

L = Minority carrier diffusion length

ND = Doping

ni = Intrinsic carrier concentration

Temperature has the most important effect on ni in the equation described above. It is determined by the energy of the band gap (smaller band gaps result in greater intrinsic carrier concentrations) and the energy of the carriers (higher temperatures result in higher intrinsic carrier concentrations).

$$n_i^2 = 4\left(\frac{2\pi kT}{h^2}\right)^3 (m_e^* m_h^*)^{3/2} \exp\left(-\frac{E_{G0}}{kT}\right) = BT^3 \exp\left(-\frac{E_{G0}}{kT}\right)$$

Where,

T= Temperature

h = Planck's constant

k = Boltzmann constant

me = Effective electrons mass

mh = Effective holes mass

EGO = Band gap linearly extrapolated to absolute zero B: constant independent of temperature

Substituting the equations into the equation for I0, assuming that the other parameters have minimal temperature dependence,

$$I_0 = qA\frac{D}{LN_D}BT^3\exp\left(-\frac{E_{G0}}{kT}\right) \approx B'T^{\gamma}\exp\left(-\frac{E_{G0}}{kT}\right)$$

Where,

B' = Temperature independent constant

γ = A constant used instead of the number 3 to incorporate possible dependencies of temperature of other material parameters.

The effect of I0 on open circuit voltage can be determined by the substitution of the equation of I0 into the Voc equation as below:

$$\begin{aligned} V_{OC} &= \frac{kT}{q}\ln\left(\frac{I_{SC}}{I_0}\right) = \frac{kT}{q}[\ln I_{SC} - \ln I_0] = \frac{kT}{q}\ln I_{SC} - \frac{kT}{q}\ln\left[B'T^{\gamma}\,exp\left(-\frac{qV_{G0}}{kT}\right)\right] \\ &= \frac{kT}{q}\left(\ln I_{SC} - \ln B' - \gamma\ln T + \frac{qV_{G0}}{kT}\right) \end{aligned}$$

EG0 = qVG0

Assuming dVoc/dT is independ on dIsc/dT, dVoc/dT can be determined as:

$$\frac{dV_{OC}}{dT} = \frac{V_{OC} - V_{G0}}{T} - \gamma\frac{k}{q}$$

So we can see that temperature sensitivity of a solar cell is proportional to its open circuit voltage. From the equation above we can observe that solar cells with higher voltage are less affected by temperature. [9]

4.5 Monocrystalline and Polycrystlline solar cell

The goal of both types of solar panels is to turn sunlight into power. Individual solar cells' crystalline silicon structure still has an impact on their performance and appearance. A monocrystalline solar panel is made up of monocrystalline solar cells, also referred to as "wafers." A single silicon crystal makes up each solar PV cell. Monocrystalline solar panels are distinguished by their rounded corners and black PV cells. Monocrystalline solar panels have the highest efficiency rates, which range from 15-20%. Because of their high efficiency, they produce more power per square foot and take up less space. These panels are expected to last the longest because they are monocrystalline and perform well in heat. The majority of them have a 25-year warranty but usually lasts more than that. In case of polycrystalline solar panels multiple silicon crystal fragments are melded together throughout the manufacturing process to create each PV cell. Polycrystalline cells are less efficient than monocrystalline cells. So to achieve the same power output more polycrystalline panels are required than it would for monocrystalline. However, because the production process for polycrystalline panels is simpler, they are less expensive. But the only con monocrystalline cells have is higher cost.

When the temperature of a solar panel rises, its efficiency drops temporarily, but monocrystalline solar cells are less affected than polycrystalline ones. The temperature coefficient shows how much temperature affects solar panels. To ensure a fair comparison, all solar panels are factory-tested under the same STC. Polycrystalline solar panels have greater temperature coefficients than monocrystalline solar panels, which is why they lose more productivity when they heat up.

Chapter 5

METHODOLOGY

5.1 Workflow Diagram

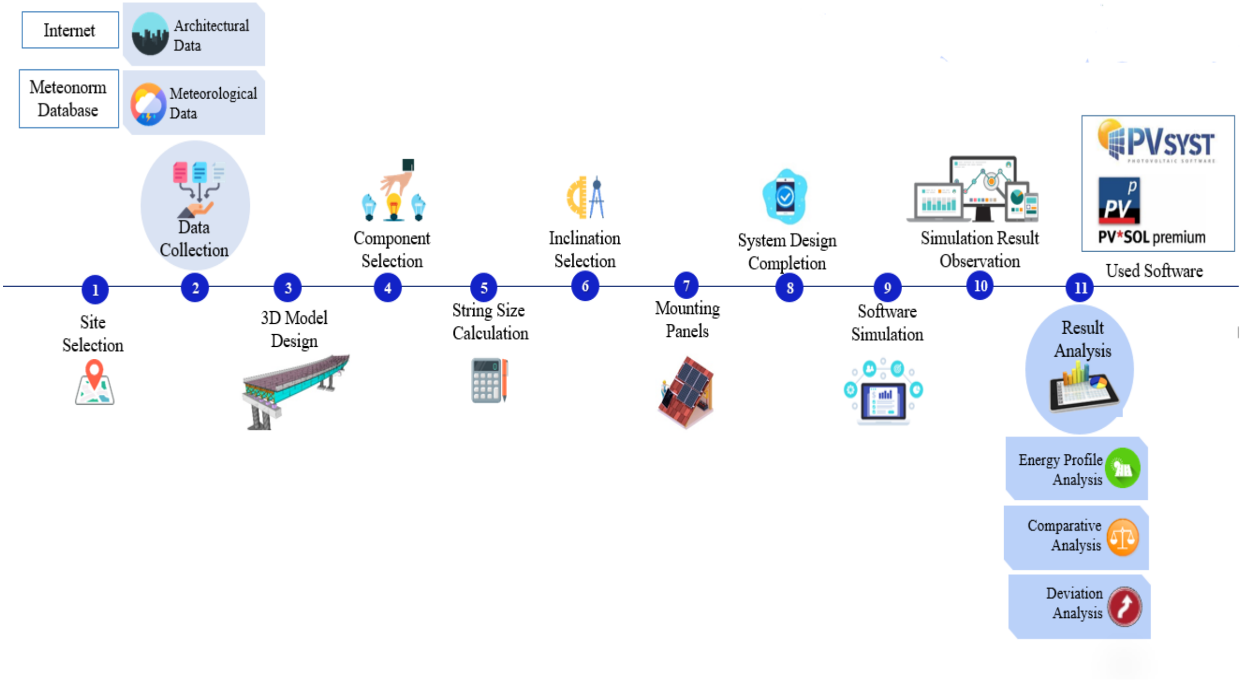

Figure 5.1: Basic workflow diagram

5.2 Site Selection

5.2.1 Site Information

Built in June 1998, the Bangabandhu Jamuna Multipurpose Bridge is the second longest bridge in Bangladesh and the sixth largest in South Asia. [10]

The bridge created a critical link between Bangladesh's eastern and western regions. It provides numerous benefits to the people and, in particular, encourages inter-regional trade in the country. It permitted the transmission of power and natural gas, as well as the integration of telecommunication networks, in addition to the efficient movement of products and passengers by road and rail. The bridge's superstructure is made up of pre-cast components. It is assembled using the balanced cantilever method. [11]

The main bridge is around 4.8 km in length, has a width of 18.5 m and height of 120 m. It has total 49 spans. 47 of which are main spans, each being 100 m long. Rest of the two spans are of 65 m long. The bridge is supported by 80-85 meter long, 2.5 meter and 3.15 meter diameter steel piles. These piles are driven by a powerful hydraulic hammer. This gives the bridge strength to endure possible storms and earthquakes.

5.2.2 Meteorological Data

Collecting meteorological data for the specific location where the PV system is to be designed, is the first step in the design process. The sun irradiance, ambient temperature, and wind speed are all important meteorological characteristics. A lot of meteorological databases are available on the internet. The database we used to access the data is Meteonorm 7.3 database through PVsyst 7.2.

Table 5.1: Site and Meteorological Data (Source: Meteonorm 7.2 database)

Site Name	**Bangabandhu Jamuna Multipurpose Bridge**
Coordinates	24.3996°N, 89.7686°E
Global horizontal irradiance	1788.2 kWh/m2
Diffused horizontal irradiance	899.2 kWh/m2
Direct normal irradiance	1370.9 kWh/m2
Wind velocity	0.8 m/s
Ambient temperature	24.94 °C

We collected monthly temperature data from the database and created a graph which is given in figure 5.2. From the figure we can see that, highest temperature of selected site is 35°C which occurs at May and the temperature stays relatively low during winter which is from November to February.

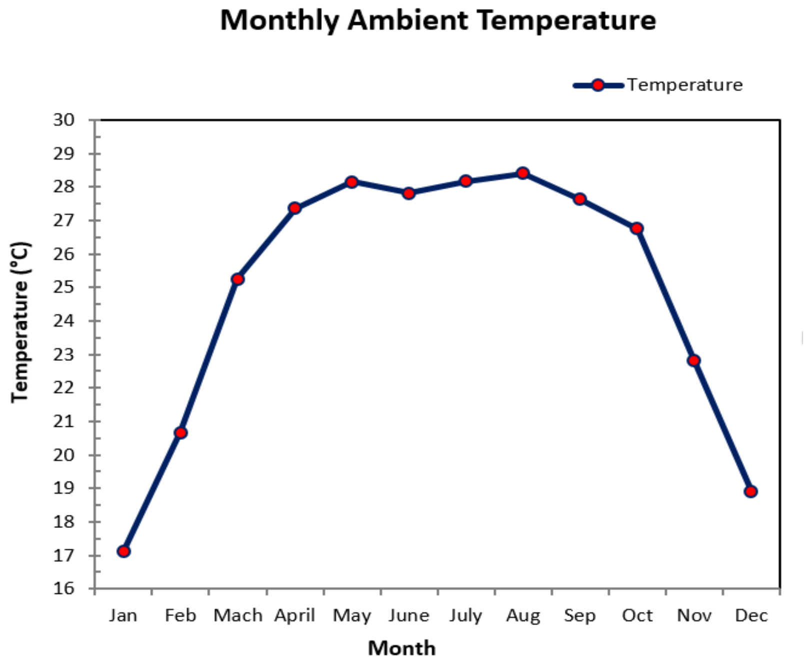

Figure 5.2: Monthly site temperature data (Source: Meteonorm 7.2 database)

Solar irradiance is the output of energy from the sun received at an area on the Earth. Different components of solar irradiance exists which is necessary to be considered while selecting a site for installing PV system. [12]

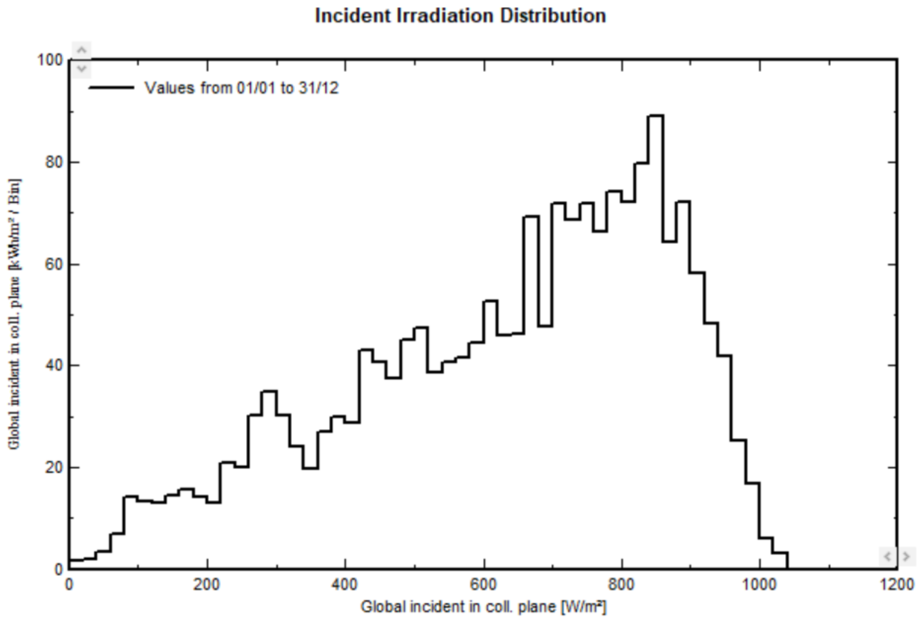

Figure 5.3: Monthly site temperature data

GHI is the most important parameter for calculation of PV electricity yield. It represents the total amount of shortwave radiation received from above by a surface which is horizontal (parallel) to the ground.

The total radiation received on a horizontal surface on the Earth. Global Horizontal Irradiance factors in both Direct Normal Irradiance and Diffuse Horizontal Irradiance, while also accounting for the angle of the sun. Direct normal irradiance represents the quantity of radiation received per unit area on a surface perpendicular (normal) to the sun.

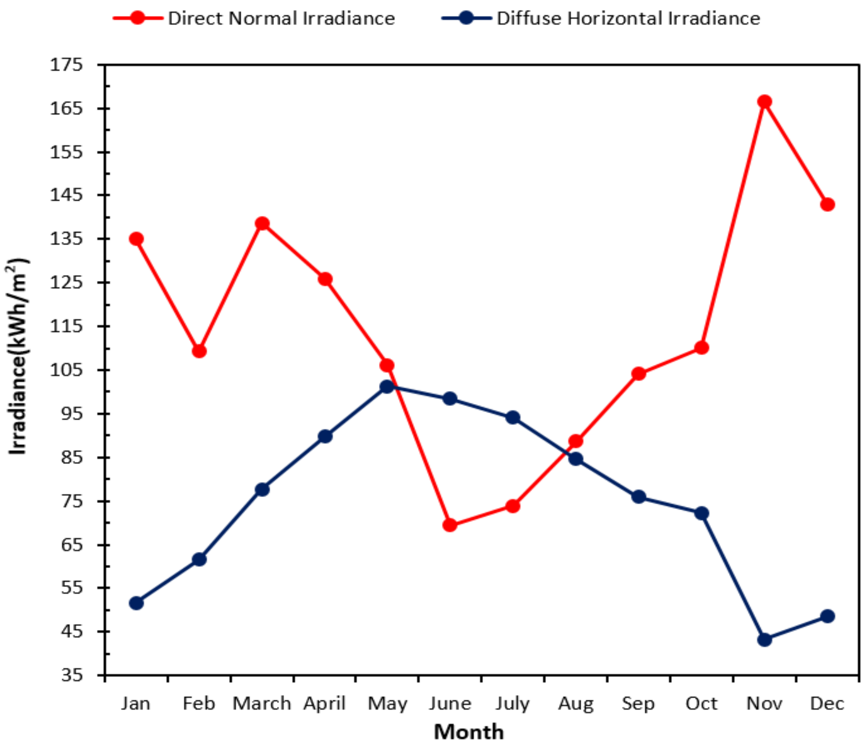

Figure 5.4: Monthly variation in direct and diffused irradiation (Source: Meteonorm 7.2 database)

5.3 Software details

5.3.1 PVSOL

PVSOL is a well-known, well-respected, and commonly used PV solar system design software. It's utilized in the design, visualization, and optimization of solar photovoltaic systems. The most thorough PV system architecture and shading analyses are provided by the industry's leading 3D solar software simulation tool. With PVSOL premium, users can accurately estimate the impact of shadows from nearby objects on solar efficiency by placing and sizing 3d objects. This program enables for the automatic determination of the optimal inverter design as well as human adjustments. The software can also determine the number of modules and show the module surface using a photo of the object. For any type of 2D roof top, automatic module mounting is also possible. The energy yield was calculated using this software, which was utilized to create a 3D model of the bridge. It can produce hourly simulations of grid-connected PV installations. This software may provide a complete economic prediction as well as the computation of AC losses, DC losses, and string losses. [13]

5.3.2 PVsyst

PVSYST was created with architects, engineers, and researchers in mind, but it's also a great educational tool. It's akin to the Swiss Army knife of photovoltaic software.

Main characteristics of this software are:

- Complete database of PV panels, inverters, and meteorological data
- Useful 3D application to simulate close shadings
- Full design of remote PV systems
- Full design of PV systems connected to the grid
- Data from PVGIS and NASA databases for radiation
- Data from PHOTON INTERNATIONAL for PV modules
- Cost-benefit analysis and payback
- Several tools to simulate the behavior of PV modules and cells in relation to radiation, temperature, and shadings [14]

5.3.3 SAM

The System Advisory Model (SAM) was created to aid in the techno-economic analysis of renewable energy projects. This software is used by energy researchers, project developers, policymakers, and financial analysts to make decisions and analyze data. This software can be used to create grid-connected power systems using technologies such as wind, photovoltaic, concentrating solar power, solar hot water, biopower, or geothermal electricity generation. The software's advanced simulation tools speed up parametric, sensitivity, and statistical analyses that require several simulation runs. The energy yield from the solar panels installed alongside the bridge façade was also calculated using this software. [15]

5.4 System Design

At first, we needed a 3D model of the bridge in order to use 3D modeling analysis in the PVSOL software. Now PVSOL does not allow importing structures that are more than 1000m in length. As the bridge is several kilometers long, we decided to consider designing for each span of 100 meters. This design will be applicable for all of the 47 spans. We built a 3d model using the Blender software with proper measurements of one span of the Jamuna bridge. But as we decided to put solar panels on 90 meters of each span, this is the length we chose. We then imported the block to PVSOL. We chose to mount panels on both the north and south side of the bridge. There are two ways to connect PV modules - series and parallel. We wanted to connect our modules in series so we can achieve maximum voltage. The reason it was our goal is due to higher voltage leading to lesser power loss and better efficiency. It is also less costly as longer strings have fewer combiners and wiring issues.

5.4.1 Module Selection

The PV module we selected for designing the system is LG 365 Q1C-A5 model from LG electronics. It is of 365W capacity. It has monocrystalline n-type solar cell. We have already explained previously how monocrystalline cells are the better option. N-type cells are in turn more efficient and are not affected by light-induced degradation (LID) whereas p-type cells suffer from it. N-type silicon wafers present a substantial possibility for commercial silicon solar cells with high efficiency. Under illumination, recombination and device characteristics have been shown to be stable. The great tolerance of n-type wafers to induced or inserted faults suggests that they are better suited for high-efficiency commercial silicon solar cells. [16] The important properties of the chosen solar panel are mentioned in table 5.2.

Table 5.2: Module Properties

Model Number	LG 365 Q1C-A5
Manufacturer	LG Electronics
Module Type	Monocrystalline / n-type
Maximum Power (Pmax)	365W
MPP Voltage (Vmpp)	36.7V
MPP Current (Impp)	9.95A
Open Circuit Voltage (Voc)	42.8V
Short Circuit Current (Isc)	10.8A
Temperature coefficient of Voc	-0.24 %/°C
Module Efficiency	21.1%
Power Tolerance	±3%

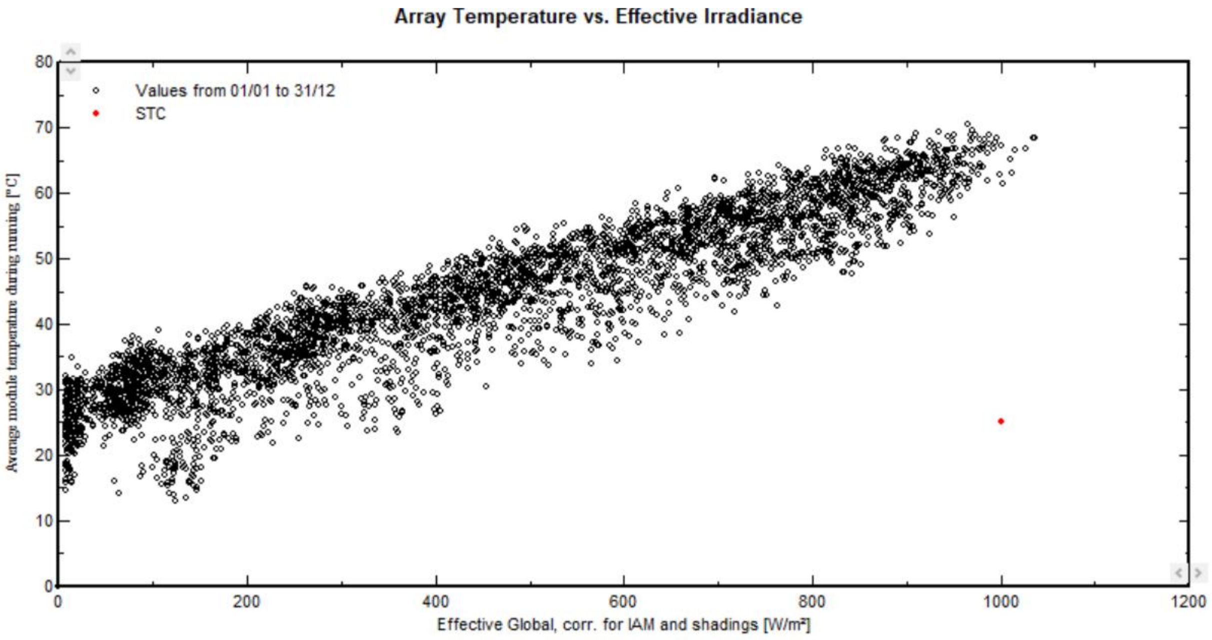

Figure 5.5: Solar array temperature vs effective irradiance plot

5.4.2 Inverter Selection

Next, we have to select an inverter for the system which will convert the DC output voltage of the modules into usable AC electric power. The inverter we selected is the PVI-55.0 model manufactured by the ABB company. It is a centralized type of inverter which is suitable for large grid-tied PV systems. If one of the modules fails or degrades in performance it does not let the overall performance get affected. The important properties of the chosen inverter are mentioned in table 5.3.

5.4.3 String Size Calculation

Several modules connected in series form a string. The number of modules we can connect in series is limited so that it does not exceed the maximum allowed input voltage of the inverter. So it is very important to determine the appropriate string size for a PV system. The equation for calculating the maximum allowable string size for a particular PV system is:

$$\text{Maximum string size} = \text{Inverter Vmax} \div \text{Module Voc\_max}$$

Table 5.3: Inverter Properties

Model Number	PVI-55.0
Manufacturer	ABB
Nominal AC Power	55kW
Frequency	50Hz
Minimum MPP Voltage	485V
Maximum MPP Voltage	800V
Maximum Input Voltage	1000V
Maximum Input Current	116.3
Power Threshold	275W
Maximum Efficiency	97.94%

We can get the maximum inverter input voltage(Inverter Vmax) from the module datasheet. It is 1000V for the chosen inverter. But we have to calculate the maximum module open circuit voltage(module Voc_max) from the following equation:

$$Voc\_max = Voc \times [1 + (Tmin - Tstc) \times (Tk\_Voc \div 100)]$$

Where,

Voc = Module open circuit voltage = 42.8V

Tmin = Lowest expected ambient temperature = 17.11°C.

Tstc = Temperature at standard test condition = 25°C

Tk_Voc = Temperature coefficient of Voc = -0.24 %/°C

We calculated Voc_max to be 43.61 V. This gave us a maximum string size of around 22. Now for the minimum string size the following equation is used:

$$\text{Minimum string size} = \text{Inverter Vmin} \div \text{Module Vmp\_min}$$

Here,

$$\text{Vmp\_min} = \text{Vmp} \times [1 + (\text{Tmax} + \text{Tadd} - \text{Tstc}) \times (\text{Tk\_Vmp} \div 100)]$$

From this, we calculated the minimum allowed panels per string to be 15. Now we want to choose as many panels as possible in one string but we do not want to get at the input voltage limit specified for our inverter. So we chose our string size to be 20. As these modules were connected in series their voltages would add up.

5.4.4 Mounting modules

The panels were mounted in façade tilt system where there will be support holding the panels on the sides of the bridge. The production of energy depends heavily on the orientation and tilt of solar panels. In order to optimize the incident irradiance on our PV system, the PV modules should often be placed under a certain tilt angle. Estimating how much diffused irradiance the modules are getting depends on the sky radiance model. These models differ in complexity but in general, all of them depend on these factors:

- Diffuse Horizontal Irradiance
- Angle of incidence
- Sky view factor

Among these factors, we do not have control over the first two ones as they are determined naturally. But it is possible to have some control over the third one which is the sky view factor. SVF represents the portion of the sky seen by the module which depends on what angle PV modules are tilted at.

Assuming that the radiation is coming isotropically (which is the ideal condition), SVF can be expressed as,

$$\text{SVF} = (1 + \cos \beta)/2$$

Where,

β = Tilt angle of the receiving surface from horizontal

[17] As the tilt angle increases, the portion of the sky that the module faces decreases. Now when we built the model, we used trial and error to compare electricity production at different angles with PVSOL software suggested optimum tilt angle. For the north side, it was found to be 30°, the same as suggested. But it was selected to be 27° for the south side whereas the suggested was 29°. The azimuth angle refers to which direction the modules should be facing. It is fixed for a particular side which is 0° for north-facing and 180° for the south.

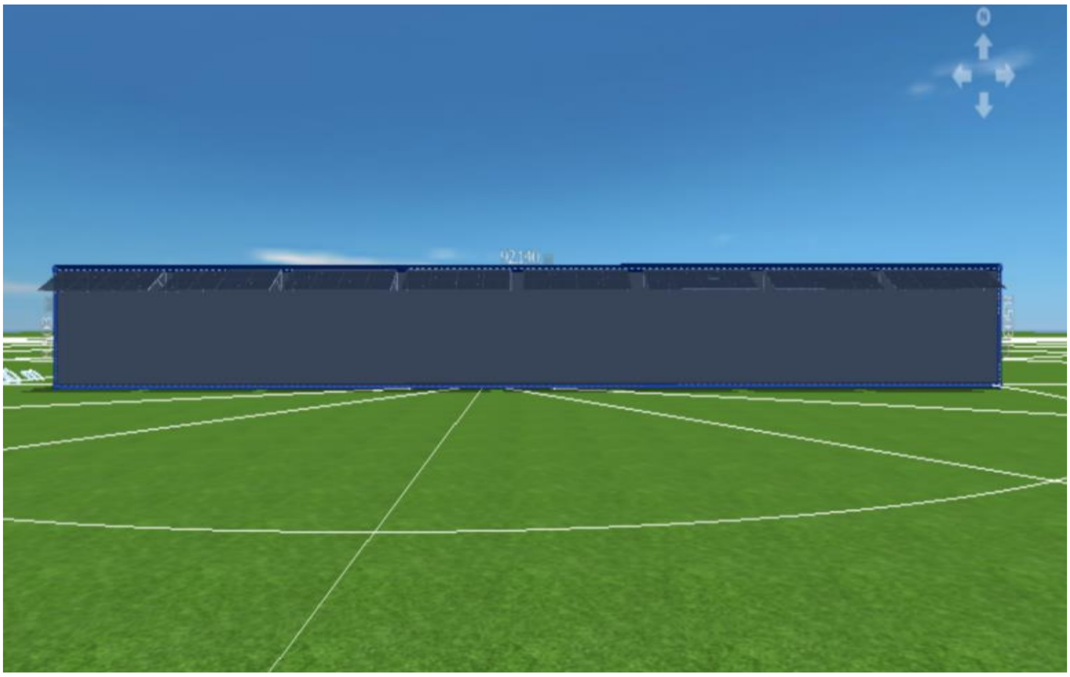

Figure 5.6: Front view of a single span of the bridge with solar panels in PVSOL

Figure 5.7: A skeptical illustration of Jamuna bridge with PV panels installed

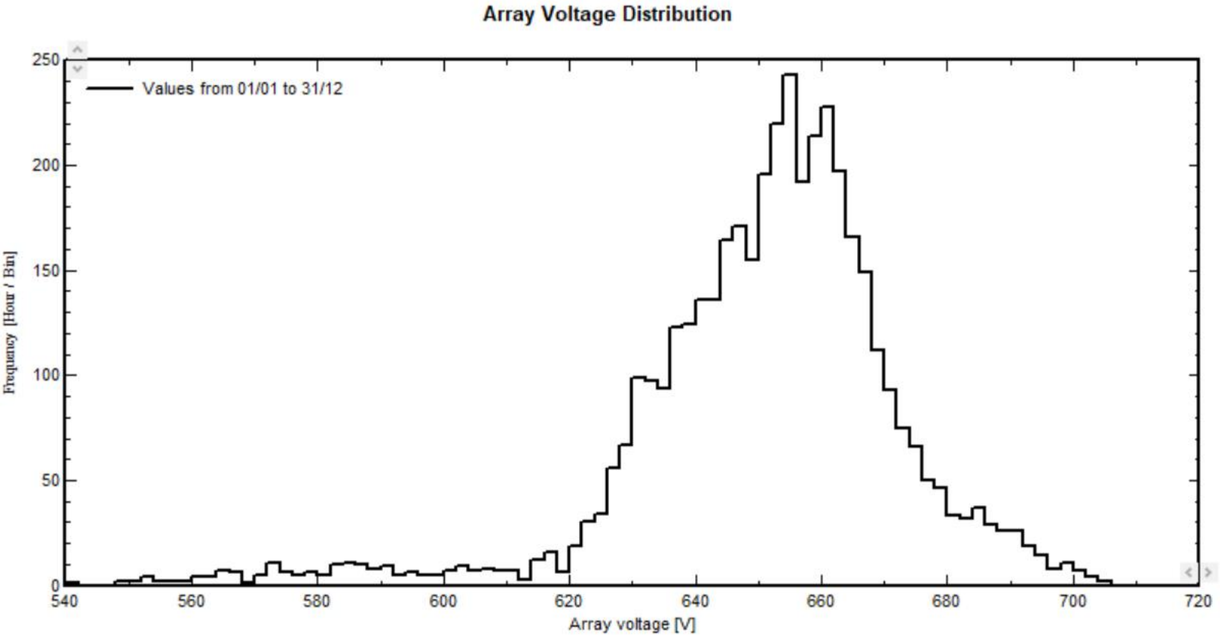

Figure 5.8: Voltage distribution in the solar array of designed system

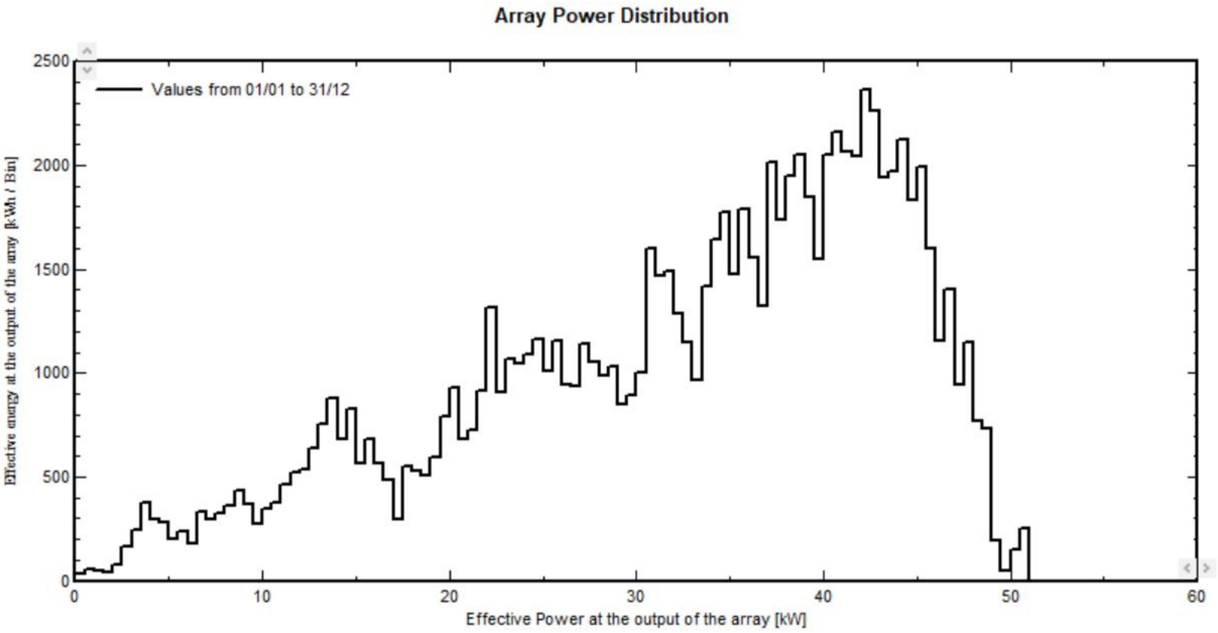

Figure 5.9: Power distribution in the solar array of designed system

5.5 Grid Integration

To use the generated electricity it is required to connect our designed PV system to a high voltage grid line. If the goal is to contribute to meeting local area demand, the system should be connected with an 11kV transmission line of the area. It could also be connected to the 230kV high voltage line that runs just above the bridge. In this case, transmission is expected to be quite cost-efficient. The solar panels are to be connected in series through a junction box which serves as a safety fuse for PV string. They have reverse blocking diode which will not let reverse power be drawn from the grid in absence of sunlight.

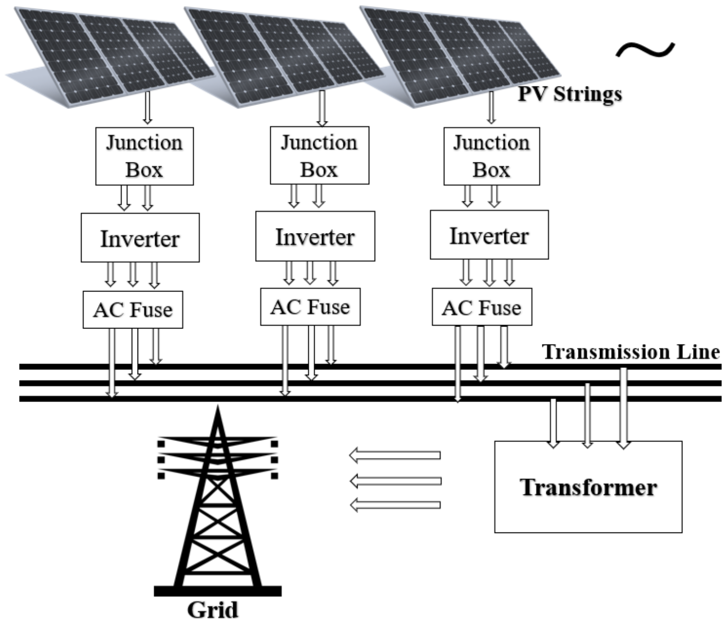

Figure 5.10: A skeptical illustration of grid connection

A certain number of PV strings could be connected in parallel to reduce the number of inverters required. But it definitely depends on how much current will add up and the limit set on the level of current allowed. Next, the inverters could be connected in modular way so that we have increased output voltage. This will reduce losses and increase transmission efficiency. Again depending on the limit there could be a need for a step-up transformer. Inverters will be converting the output DC power obtained from panels into AC power which can be transmitted to the grid. A hypothetical grid connection has been illustrated in the figure 5.10.

Chapter 6

RESULTS AND ANALYSIS

6.1 Energy Profile Analysis

6.1.1 Orientation-1 (North)

PVSOL produces 141000kWh of electricity in the first month, gradually increasing to 184963.8kWh in February, and nearly doubling the quantity of energy in March, creating 292662.3kWh. The generated energy is 351611.7kWh in April and 386424.6kWh in May, making it the year's greatest energy output. And, when output increases in the positive direction from January to May, a growing deviation is noted, with the largest deviation occurring in March, at 107700.5kWh, due to the seasonal transition from Winter to Spring. The energy production in June is 328201kWh with a negative departure of 58223.6kWh, however the production in July is 333601.3kWh with a positive variance of 5400.3kWh.

Table 6.1: Energy profile extracted from PVSOL (North)

Month	Production (kWh)	Deviation (kWh)
January	141000	0
February	184963.8	43963.8
March	292664.3	107700.5
April	351611.7	58947.4
May	386424.6	34812.9
June	328201	-58223.6
July	333601.3	5400.3
August	305274.4	-28326.9
September	266786.1	-38488.3
October	223593.1	-43193
November	153887.4	-69705.7
December	115070.1	-38817.3

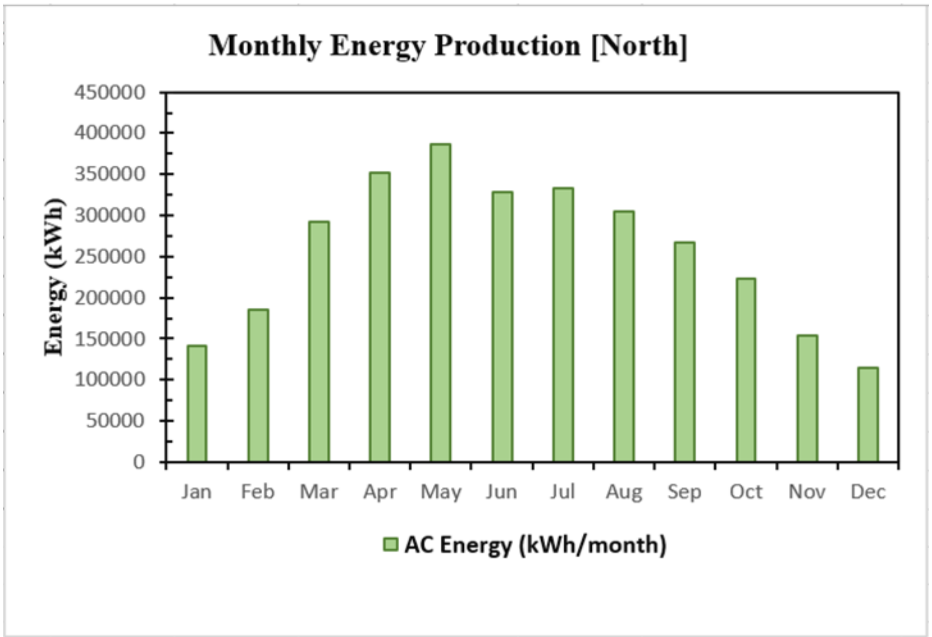

Figure 6.1: Monthly energy production in PVSOL (North)

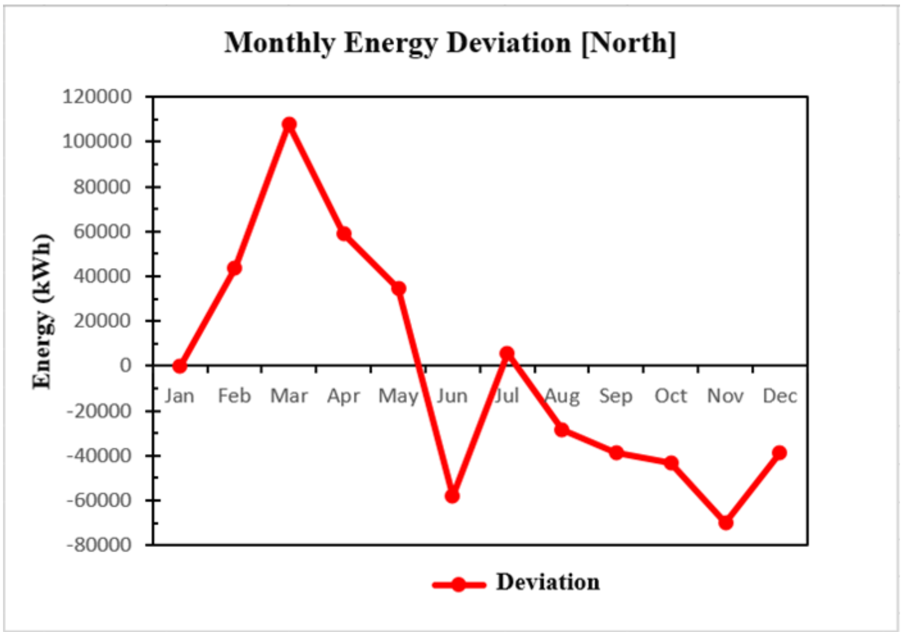

Figure 6.2: Monthly energy deviation in PVSOL (North)

In PVsyst, energy yield is 126477kWh in January, rising to 175357kWh in February, with a positive deviation of 48880kWh. Similar to PVSOL, the biggest divergence is 105703kWh in March, producing 281060kWh of energy, followed by 350338kWh of energy in April, with a 69278kWh deviation. May generates a maximum power of 384977kWh, a deviation of

34639kWh. However, unlike PVSOL, in this case, the deviation continues to decrease over time, resulting in a gradual decrease in energy production in each month. For example, energy yields in June, July, and November, December are 328953Kwh, 320587kWh, and 132916kWh, 111014kWh, respectively, with power deviations of -56024kwh, -8366kWh, -76234kWh, -21902kWh.

Table 6.2: Energy profile extracted from PVsyst (North)

Month	{Production (kWh)	Deviation (kWh)
January	126477	0
February	175357	48880
March	281060	105703
April	350338	69278
May	384977	34639
June	328953	-56024
July	320587	-8366
August	302022	-18565
September	261931	-40091
October	209150	-52781
November	132916	-76234
December	111014	-21902

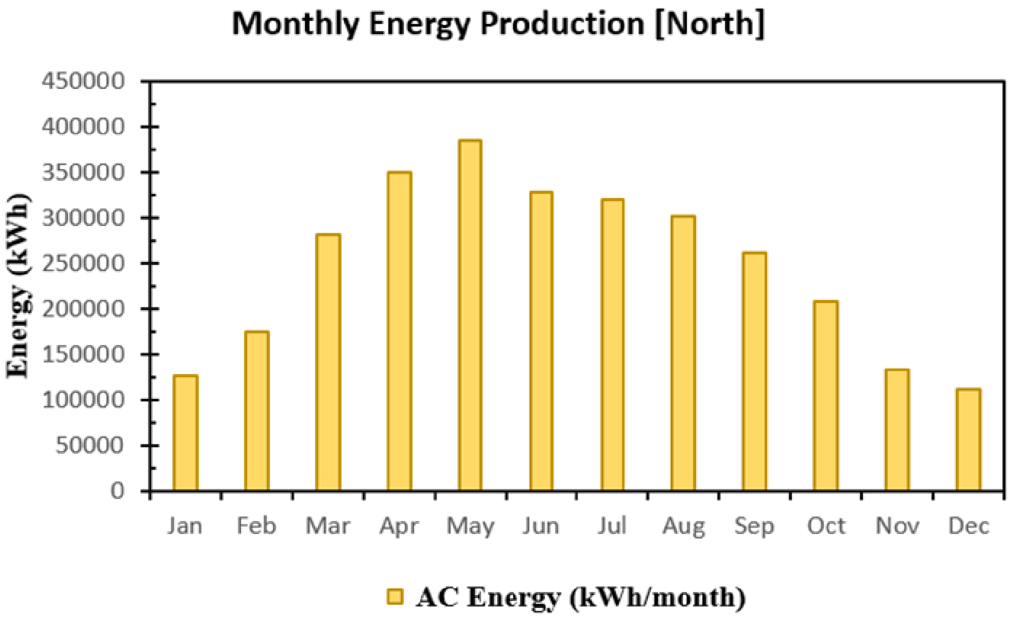

Figure 6.3: Monthly energy production in PVsyst (North)

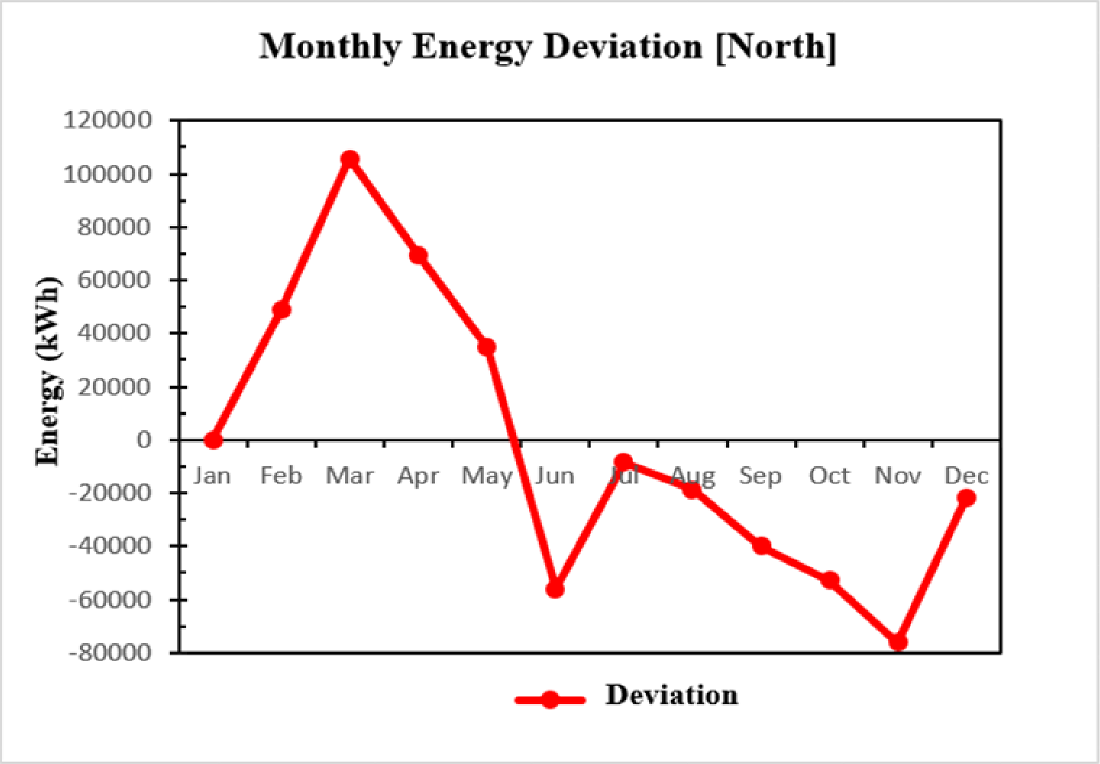

Figure 6.4: Monthly energy deviation in PVsyst (North)

Similarly, solar power output peaks in May at 365983.83 kWh in SAM. Starting in January, the energy yield is 102399.37kWh, gradually increasing to 144859.17kWh, 249298.81kWh, and 323904.26kWh in February, March, and April, with positive deviations of 42459.8kWh, 104439.64kWh, and 74605.45kWh in February, March, and April, respectively. After May, the energy yield decreases with negative deviation. Finally, in November and December, energy yields reached 134136.87kWh and 97086.49kWh, respectively, with negative deviations of 71535.22kWh and 37050.38kWh.

Table 6.3: Energy profile extracted from SAM (North)

Month	Production (kWh)	Deviation (kWh)
January	102399.37	0
February	144859.17	42459.8
March	249298.81	104439.64
April	323904.26	74605.45
May	365983.83	42079.57
June	325385.83	-40598
July	303268.24	-22117.59
August	278187.83	-25080.41
September	247494.48	-30693.35
October	205672.09	-41822.39
November	134136.87	-71535.22
December	97086.49	-37050.38

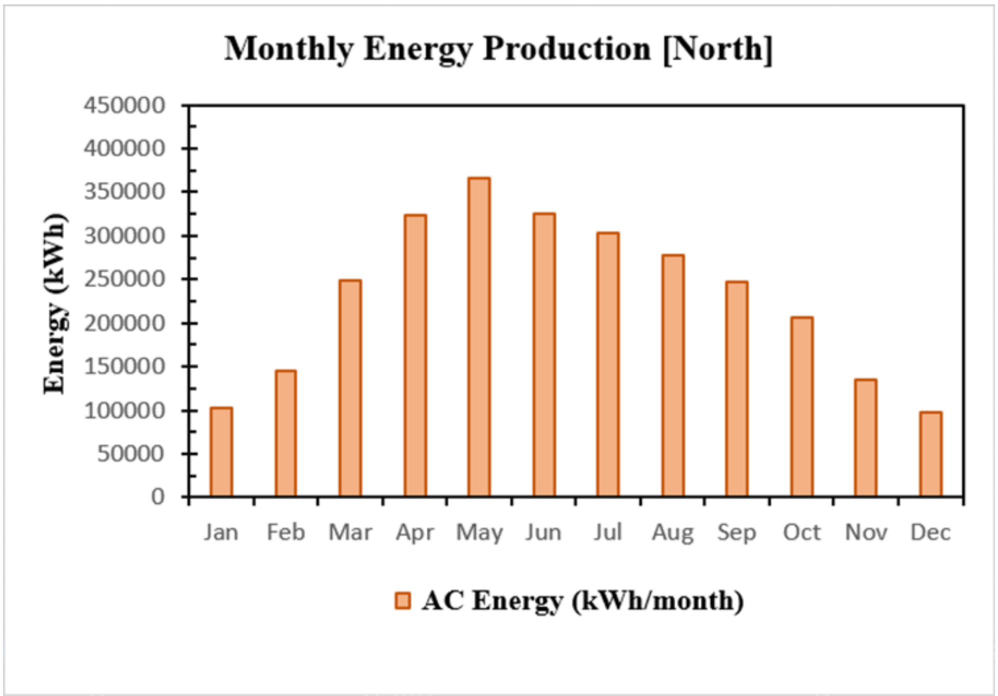

Figure 6.5: Monthly energy production in SAM (North)

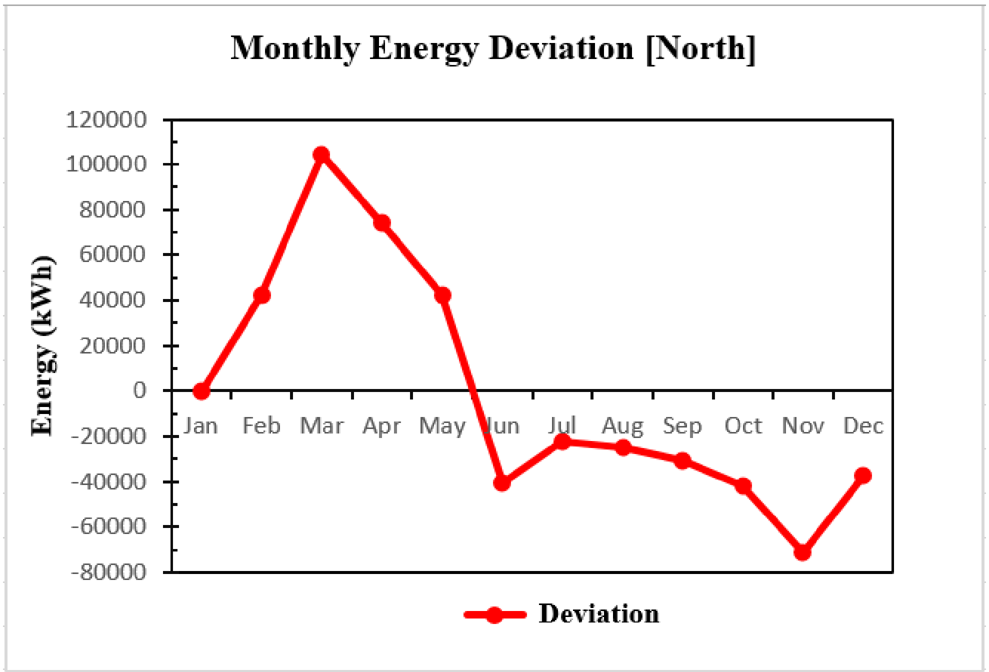

Figure 6.6: Monthly energy deviation in SAM (North)

6.1.2 Orientation-2 (South)

Because solar solar cells are hypersensitive to operating temperature, which fluctuates with climatic circumstances, the energy output for the south facing side of the bridge is not comparable to the north windward side. The temperature is most suited for solar cells to perform at maximum efficiency during the winter, when there are clear sky and minimal rain, allowing for longer exposure to sunlight and increasing energy harvest in solar panels. When the sky is cloudy, the amount of direct sunlight reaching the solar panels is reduced. This means that the position of the sun above PV panels at various times of the year affects energy output, hence energy production in this orientation is different than north side. Using PVSOL we determined the following:

Table 6.4: energy profile extracted from PVSOL (South)

Month	Production (kWh)	Deviation (kWh)
January	392450	0
February	388722.9	-3727.1
March	426008	37285.1
April	391044.7	-34963.3
May	348119.6	-42925.1
June	274954.7	-73164.9
July	285059.7	10105
August	307408.2	22348.5
September	331486.3	24078.1
October	358882.6	27396.3
November	419399.8	60517.2
December	415409.5	-3990.3

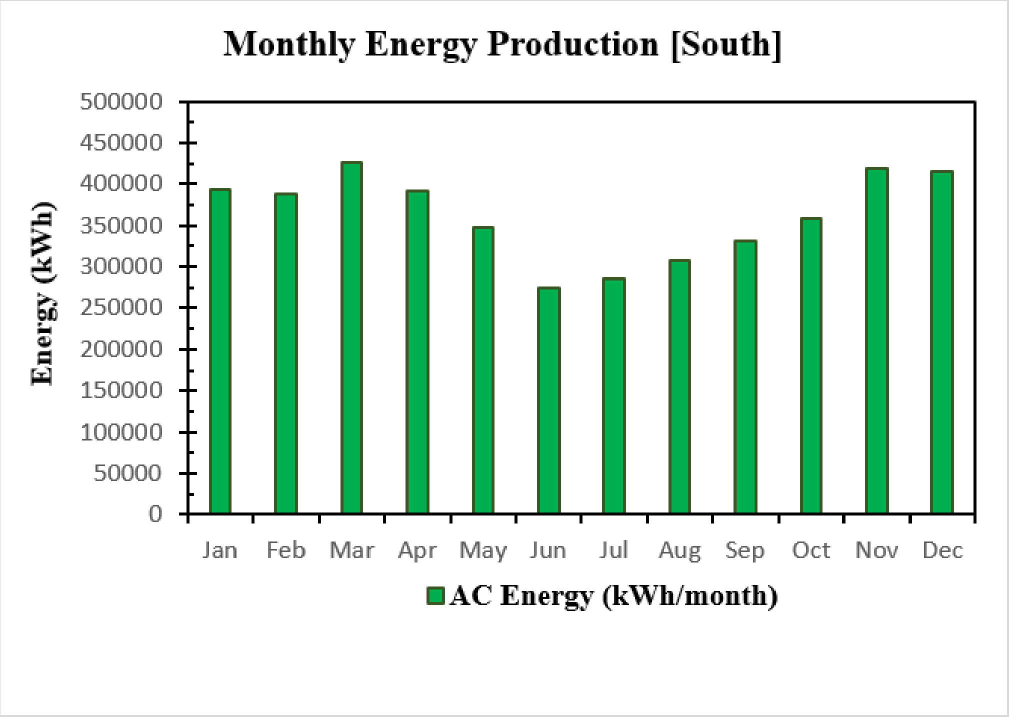

Figure 6.7: Monthly energy production in PVSOL (South)

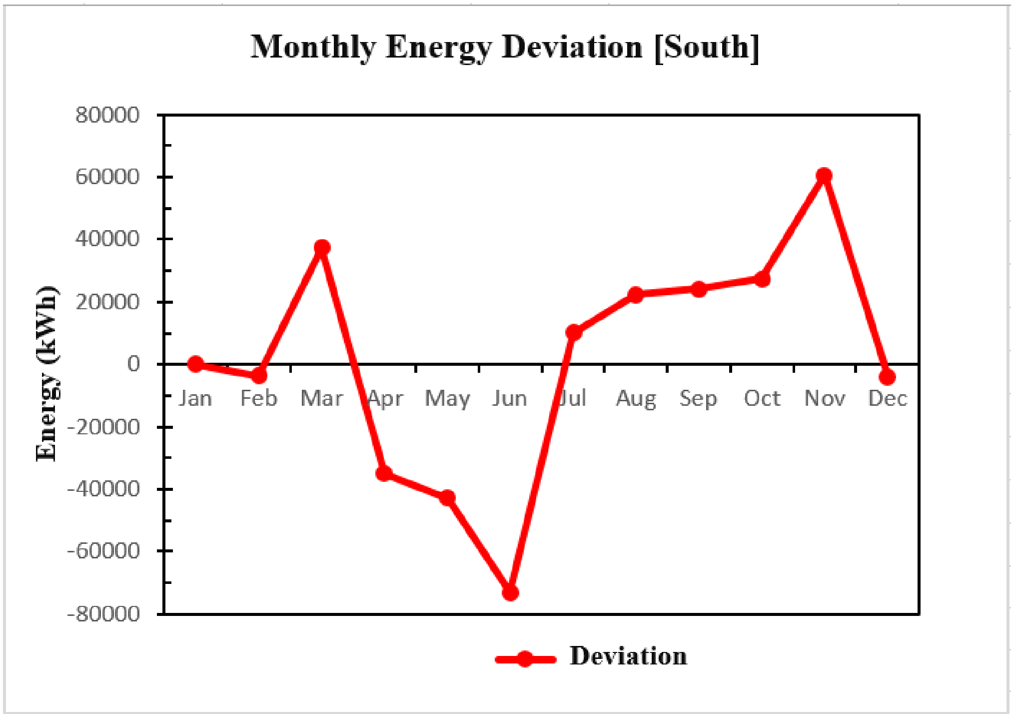

Figure 6.8: Monthly energy deviation in PVSOL (South)

Using PVsyst we determined the following:

Table 6.5: energy profile extracted from PVsyst (South)

Month	Production (kWh)	Deviation (kWh)
January	398090	0
February	368245	-29845
March	436207	67962
April	417454	-18753
May	386857	-30597
June	311375	-75482
July	309448	-1927
August	322702	13254
September	348928	26226
October	379055	30127
November	426337	47282
December	405422	-20915

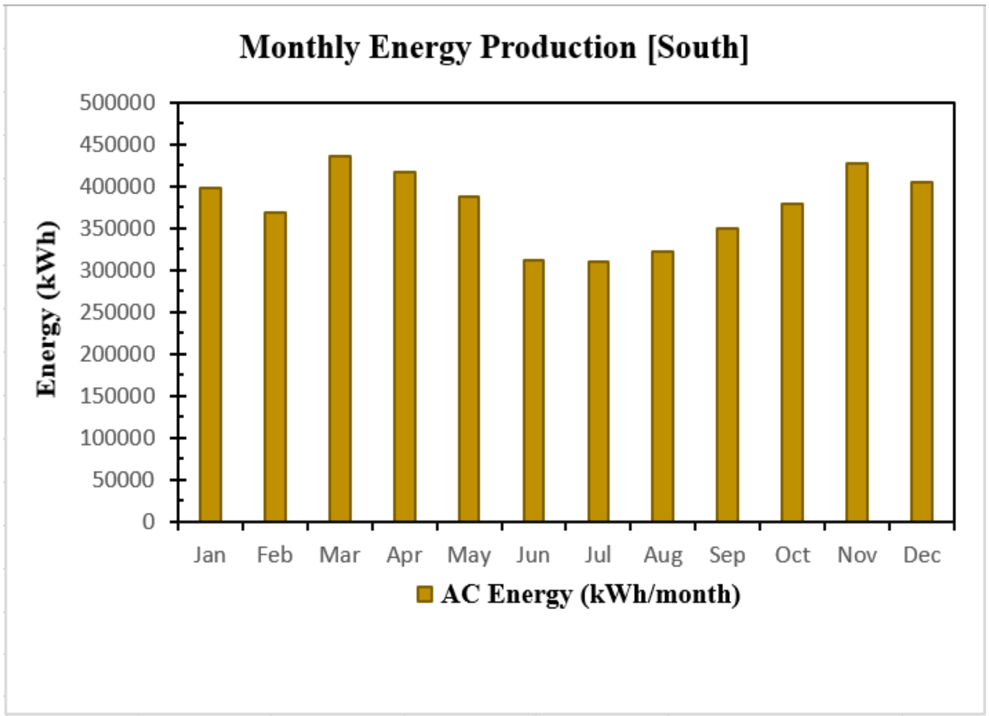

Figure 6.9: Monthly energy production in PVsyst (South)

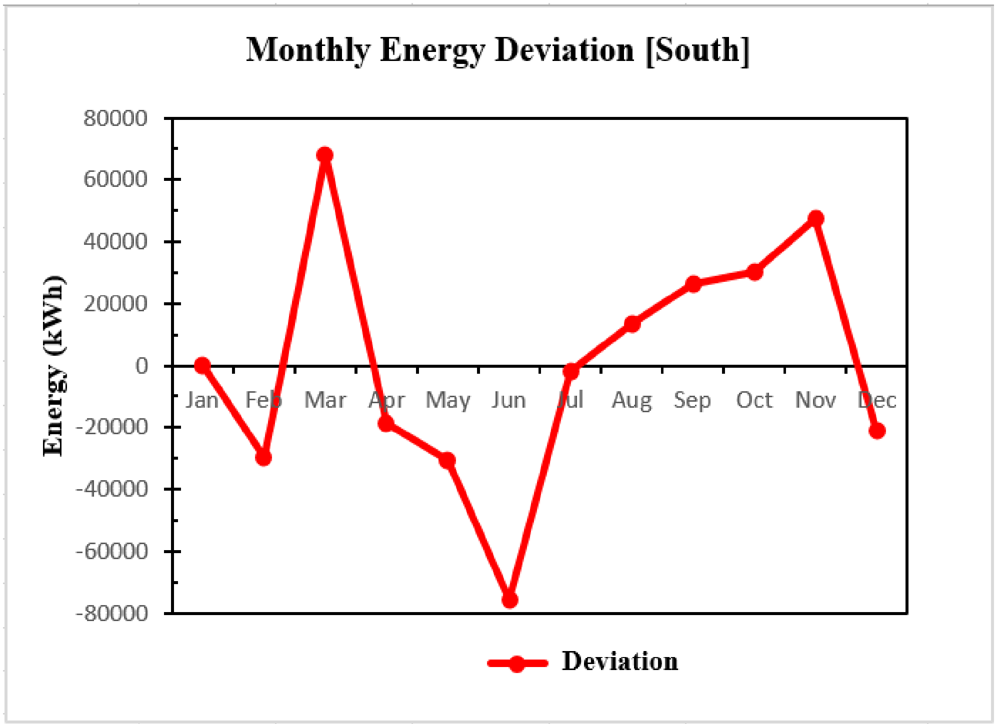

Figure 6.10: Monthly energy deviation in PVsyst (South)

Using SAM we determined the following:

Table 6.6: energy profile extracted from SAM (South)

Month	Production (kWh)	Deviation (kWh)
January	373689.47	0
February	358846.36	-14843.11
March	407508.23	48661.87
April	387265.37	-20242.86
May	348625.4	-38639.97
June	283810.95	-64814.45
July	270323.83	-13487.12
August	295811.15	25487.32
September	321962.53	26151.38
October	351680.11	29717.58
November	407493.16	55813.05
December	389801.3	-17691.86

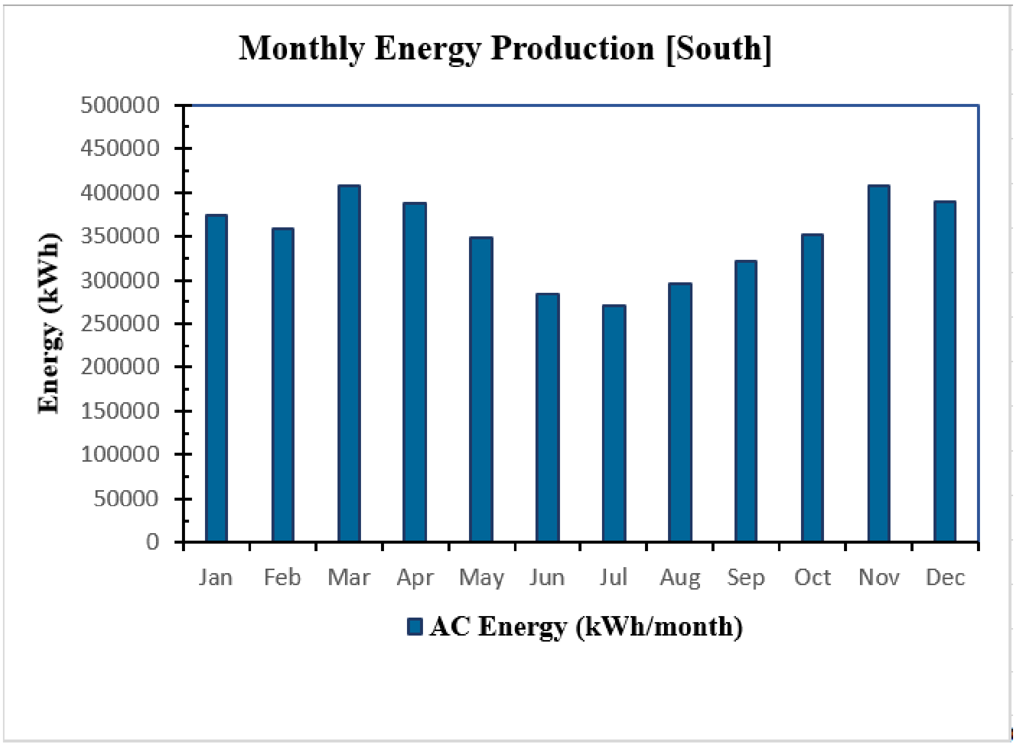

Figure 6.11: Monthly energy production in SAM (South)

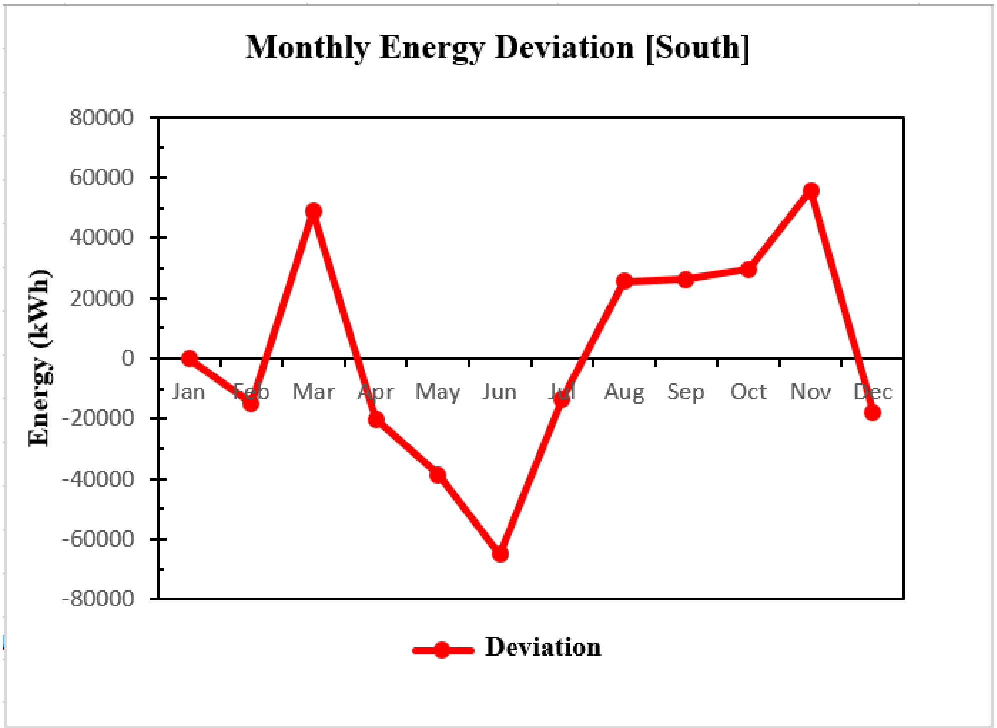

Figure 6.12: Monthly energy deviation in SAM (South)

6.2 Comparative Analysis:

6.2.1 Software Comparison for Orientation-1 (North):

The monthly energy production in three software packages is compared after the harvest of solar energy, and the average number is highlighted for inclusion in the energy profile study. The following is a monthly energy profile for the North side in three software programs, along with its mean value:

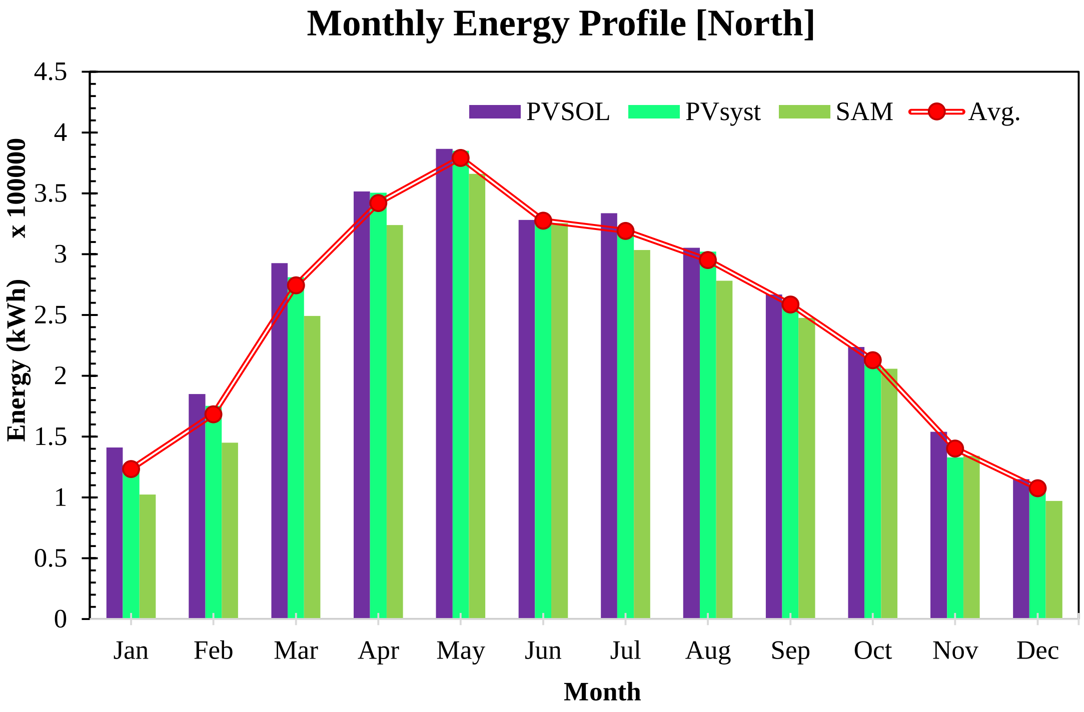

Figure 6.13: Energy profile comparison between three different software for north

The energy yield along with the energy deviation is to be compared for proper energy analysis and accuracy of the software. The comparison of monthly deviation profile in the three software for North side is given below:

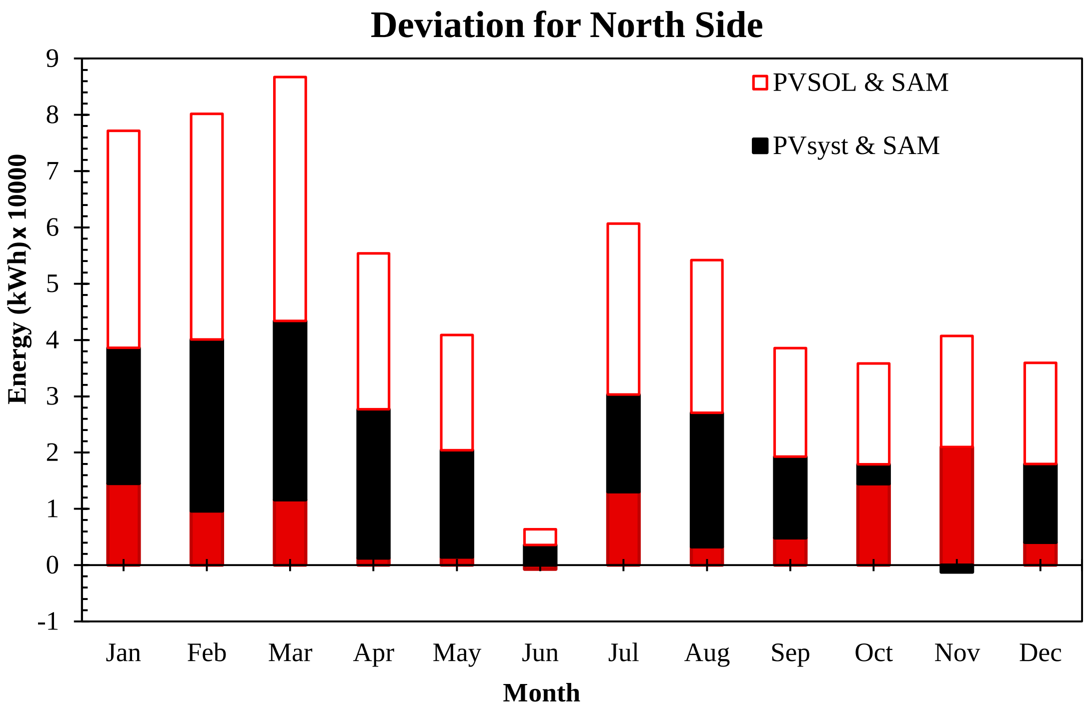

Figure 6.14: Energy deviation comparison between three different software for north

6.2.2 Software Comparison for Orientation-2 (South):

Monthly energy profile for South side in three software with their mean value is given below:

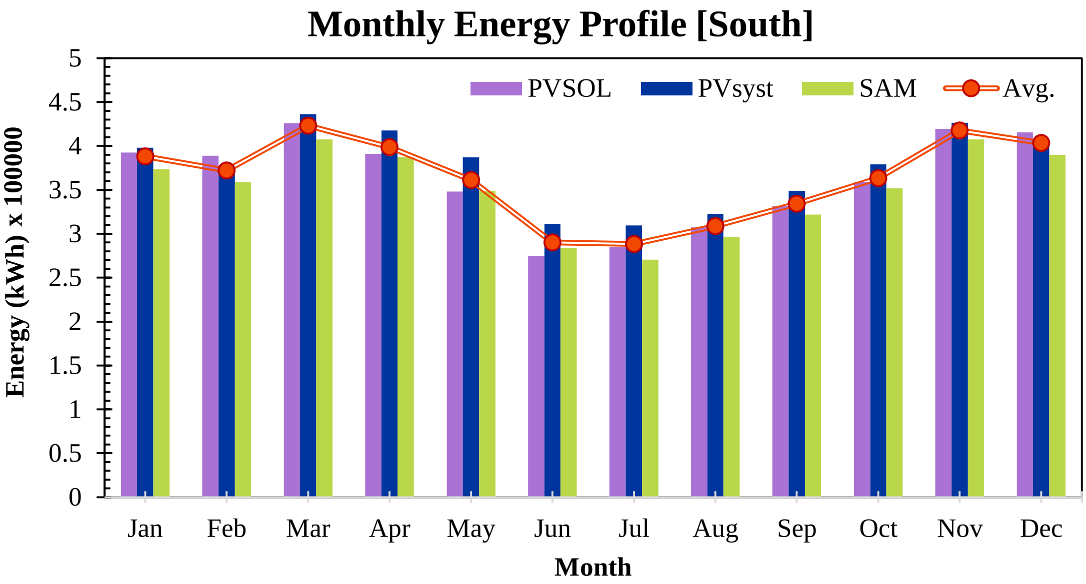

Figure 6.15: Energy profile comparison between three different software for south

The comparison of monthly deviation profile in the three software for South side is given below:

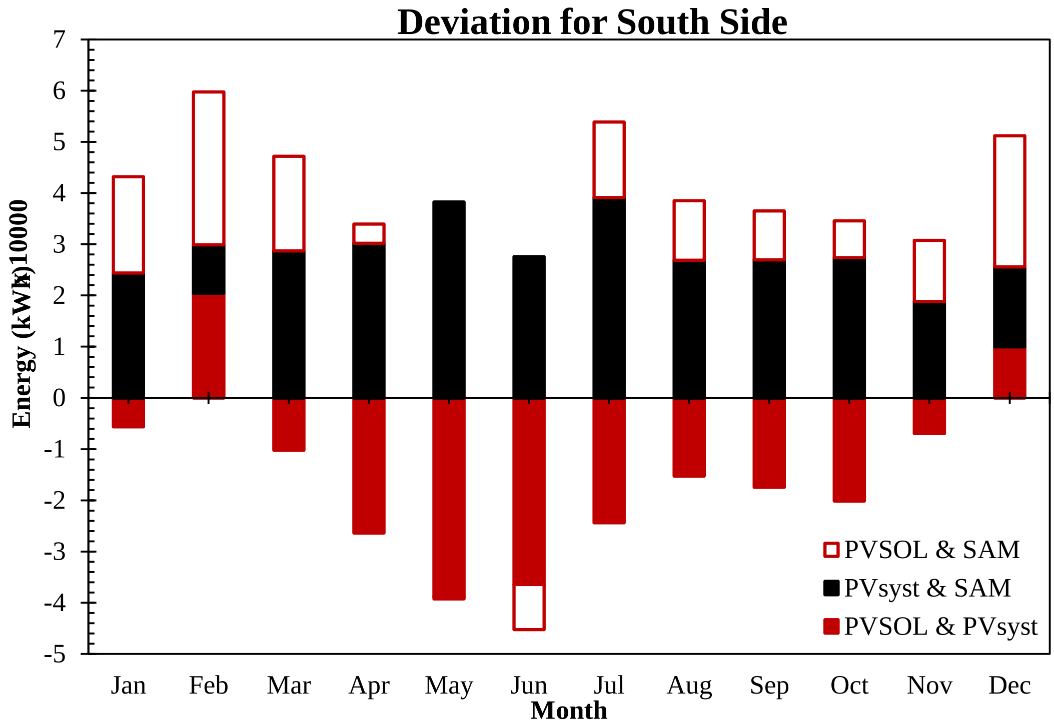

Figure 6.16: Energy deviation comparison between three different software for south

6.2.3 Software Comparison and Analysis for Both Sides Together:

Following independent energy and deviation analyses for the North and South sides of the Bangabandhu bridge, solar panels were installed on both sides, i.e., on both the North and South sides combined, and the yield was monitored in the three software. The yield is the combination of the yields from the north and south sides. Immediately after the end of individual energy and deviation assessments for the North and South sides of the Bangabandhu bridge, solar panels were mounted on both sides, i.e., on both the North and South sides, and the yield was measured using the three software.

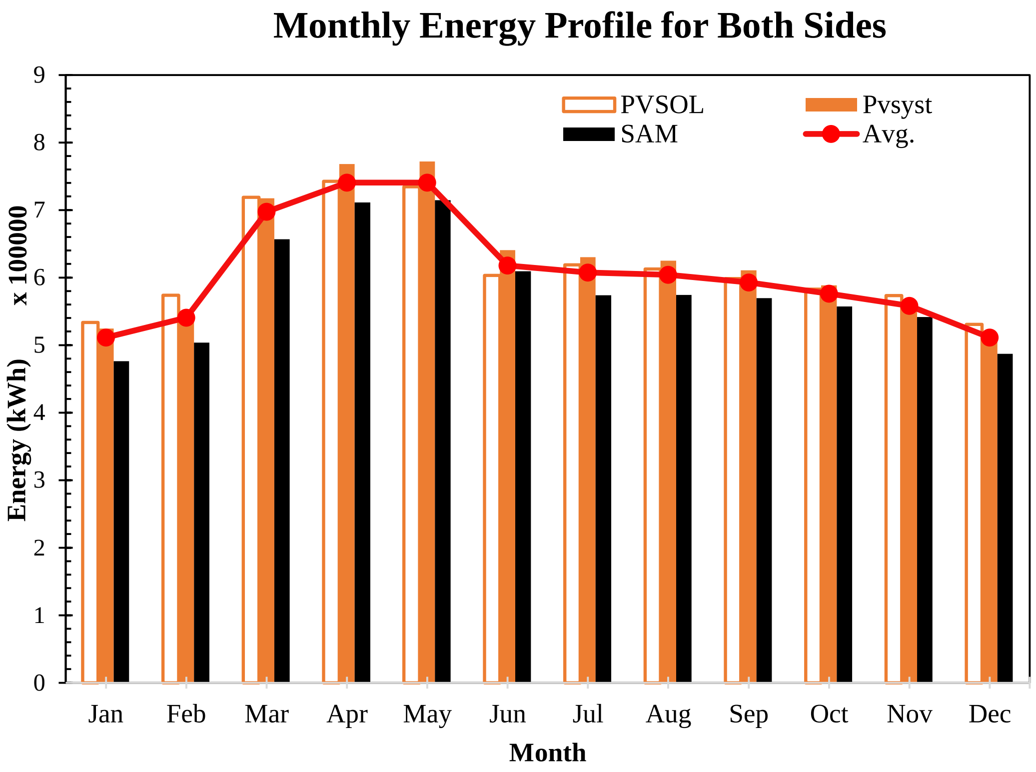

Figure 6.17: Monthly energy profile for both orientation

6.3 RMSE analysis:

The RMSE statistic allows a term-by-term comparison of the actual difference between the estimated and measured value, which offers information on a model's short-term performance. RMSE is the root mean square error. We determine the RSME value for PVsyst, PVSOL, and SAM for higher accuracy and assess them by comparing the data.

6.3.1 RSME for North side:

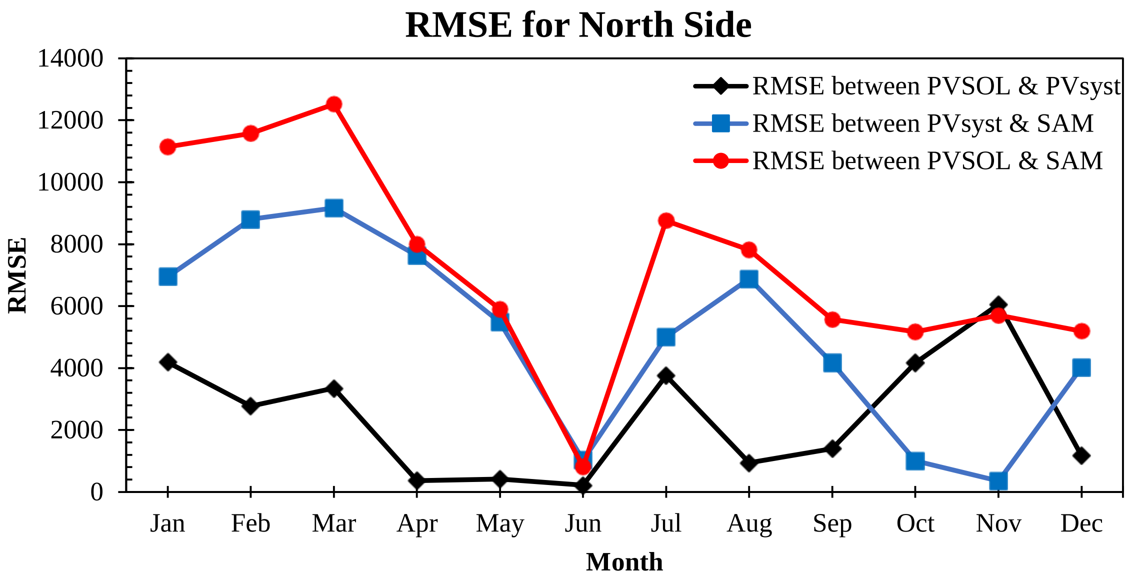

Figure 6.18: RMSE analysis for north side

6.3.2 RSME for South side:

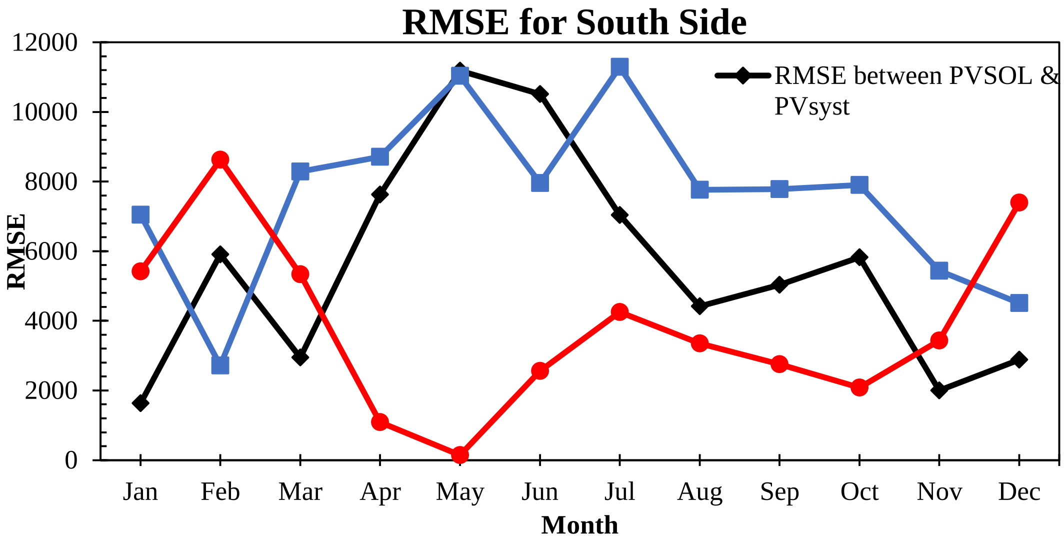

Figure 6.19: RMSE analysis for south side

Chapter 7

CONCLUSION

7.1 Challenges

Even though the study went smoothly and we got the desired findings after putting our proposal into the software simulation, we ran across several issues that couldn't be ignored. Such as:

1. Most values in the software were taken with precision, which isn't always practical. As a result, the software's estimation may change to an unreasonably significant level when applying the original energy yield.
2. While solar panels require little upkeep, the initial investment is very significant. Installation and initial investment (including the cost of solar panels, inverters, mounting hardware, wiring, installation, permits, repairs, monitoring, and other operational and overhead costs) are quite high, but because we are connecting to the local energy grid, the energy storage is not considered.
3. Another unconventional factor is that the availability of power is subjected to variation owing to many factors such as irradiation, temperature, shadow, weather etc. and often effected due to poor conversion efficiency.
4. The non-linear properties of solar PV impose limits on solar power generation.
5. Because sunlight is a low density energy source, it is a dispersed fuel source with unpredictably variable hourly or daily production, which may be ineffective in an unfavorable climate.
6. There are different types of system losses, such as thermal loss, shading loss, dust and dirt, array mismatch, reflection, DC cable loss, spectral loss, inverter loss, irradiation, and AC cable loss.

7.2 Our Contribution

1. Unique proposal:
   Solar PV installation on bridge abutments is a revolutionary idea in Bangladesh. It is not only environmentally beneficial, but it also assures optimum resource usage.

2. Utilization of space:
   Bangladesh is already a densely populated country with limited living space. And, in order to produce the energy we did, a lot of space would have to be consumed. Our study assures that no additional room is required.

3. Easier transmission:
   We connected our PV plant to the national grid in order to consume the generated power. The three-phase output of the inverter is routed into a step-up transformer. In order to distribute the generated power to the surrounding region, the output must be linked to the area's 11kv transmission line.

4. Energy yield:
   Average energy yield at North side of the bridge is 2948512kWh, whereas at South, it is 4348628kWh. And combined, total energy stands at 7297140kWh per annum.

7.3 Future Scope

The goal of this research is to build a solar system on the Bangabandhu Bridge and generate green electricity. We may say that directly harnessing the Sun to create electricity is an environmentally benign way. We used technologies that were also practical, according to our research. There is plenty of space for further new technologies to be included into this system-optimization endeavor. The project has the ability to address some of the most pressing energy and electrical issues facing our country. Produced energy can be utilized to deliver power to locations where it is currently unavailable, such as the local neighborhood of the project site. It can also assist fulfill rising energy demand by increasing overall power generation. This project has the potential to alleviate youth unemployment by providing job opportunities. It is a significant step forward in the energy sector of our country. At the moment, deciding which one is the most suited and viable to plant boils down to funding and system optimization.

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