Performance Comparison Between Fixed Panel, Single-axis and Dual-axis Sun Tracking Solar Panel System

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Declaration

We do hereby declare that the thesis titled "Performance comparison between fixed panel, single-axis and dual-axis sun tracking solar panel system" submitted to the Department of Electrical and Electronic Engineering of BRAC University in the partial fulfillment of the Bachelor of Science in Electrical and Electronic Engineering is our original work and was not submitted elsewhere for the award of any other degree or any other publication.

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ABSTRACT

Solar energy is one of the most reliable alternative energy source in this modern era. Thousand researches on improving the efficiency of photovoltaic (PV) system are ongoing to make it more competitive among all other available renewable energy sources. Photovoltaic panels are used to collect solar energy and convert it into electrical energy. But these photovoltaic panels are inefficient as they are fixed only at a particular angle. But we can easily overcome this problem by using sun tracking solar panel system. Solar tracking system is one of the best aupproach to harvest more solar energy from PV system compared to fixed panel system. Solar tracker follows the position of the sun throughout the day from east to west in a daily and seasonal basis. This paper presents the performance comparison between fixed panel, single-axis and dual-axis sun tracking solar panel systm. On the basis of solar irradiance, output power and total energy have been calculated for three different solar panel system throughout a year including every single month. Moreover, this paper contains graphical comparison of output power and total energy for three different systems and also for different months including various seasons.

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Chapter 1

Introduction

1.1 Introduction to Solar Energy:

Solar energy is now one of the most reliable sources of energy as it uses only sun light for producing electricity. Sun works like a nuclear reactor. It releases energy in forms of tiny packets called photons. The way to convert these tiny packets to electrical energy is known as solar energy.

At first solar energy was not suitable for generating electricity as it requires vast area of land, expensive solar panels, constant source of sunlight etc. But research and numerous developments made solar energy accessible to people by reducing the price of solar panel and improve efficiency. After 1970's drastic change in the development of solar energy took place. In present condition, it is possible to get 24% efficiency using single crystal silicon under laboratory techniques. Commercially we can achieve typically 13% to 14% efficient solar energy from a panel. Laboratory techniques are unsuited to industrial use as:

- In laboratory, cost is not considered as efficiency is considered only. So, cost escalated automatically. This irrespective ratio of cost to efficiency is not suitable for industrial use. For industrial use it is desired to have a moderate efficiency system with lowest possible costing.

- Complexity of processing or throughout is another reason as in laboratory; complex methods are taken place to create panels. These panels are suitable of research developments, not for industrial use.

Bangladesh has huge potential for solar energy as this country is blessed with round sunshine. As Bangladesh is currently going through energy crisis, it needs to find better and sustainable sources of Energy. Bangladesh hugely depends on natural gas and coal as well as importing electricity from neighboring country India. A survey finds out that Bangladesh will surely run out of natural gas soon. So, solar energy is needed to provide electricity for the citizens in near future.

1.2 Solar panel:

Solar panel is the main part of any photovoltaic system. A solar panel is a flat construction resembling a window, built with technology that allows it to passively harvest the heat of the sun or create electricity from its energy through photovoltaic. It is used to generate electricity through photovoltaic effect. These cells are arranged in a grid like pattern on the surface of solar panels. Thus, it may also be described as a set of photovoltaic modules, mounted on a structure supporting it. A photovoltaic (PV) module is a packaged and connected assembly of 6x10 solar cells.

Installation of solar panels in homes helps in combating the harmful emissions of greenhouse gases and thus helps reduce global warming. Solar panels do not lead to any form of pollution and are clean. They also decrease our reliance on fossil fuels (which are limited) and traditional power sources. These days, solar panels are used in wide-ranging electronic equipment like calculators, which work as long as sunlight is available. So, sunlight is a great factor in here. However, the only major drawback of solar panels is that they are quite costly. Also, solar panels are installed outdoors as they need sunlight to get charged.

1.2.1 Components of PV cells:

Photovoltaic (PV) solar panels are made up of many solar cells. Solar cells are made of silicon, like semiconductors. They are constructed with a positive layer and a negative layer, which together create an electric field, just like in a battery.

The most important components of a PV cell are two layers of semiconductor material commonly composed of silicon crystals. On its own, crystallized silicon is not a very good conductor of electricity, but when impurities are intentionally addedthe stage is set for creating an electric current. The bottom layer of the PV cell is usually doped with boron, which bonds with the silicon to facilitate a positive charge (P), while the top layer is doped with phosphorus, which bonds with the silicon to facilitate a negative charge (N).The surface between the resulting "p-type" and "n-type" semiconductors is called the *P-N junction.* Electron movement at this surface produces an electric field that allows electrons to flow only from the p-type layer to the n-type layer. When sunlight enters the cell, its energy knocks electrons loose in both layers. Because of the opposite charges of the layers, the electrons want to flow from the n-type layer to the p-type layer. But the electric field at the P-N junction prevents this from happening. The presence of an external circuit, however, provides the necessary path for electrons in the n-type layer to travel to the p-type layer. The electrons flow through this circuit typically thin wires running along the top of the n-type layer provide the cell's owner with a supply of electricity. Most PV systems are based on individual square cells a few inches on a side. Alone, each cell generates very little power (a few watts), so they are grouped together as *modules* or *panels.*The panels are then either used as separate units or grouped into larger *arrays.*

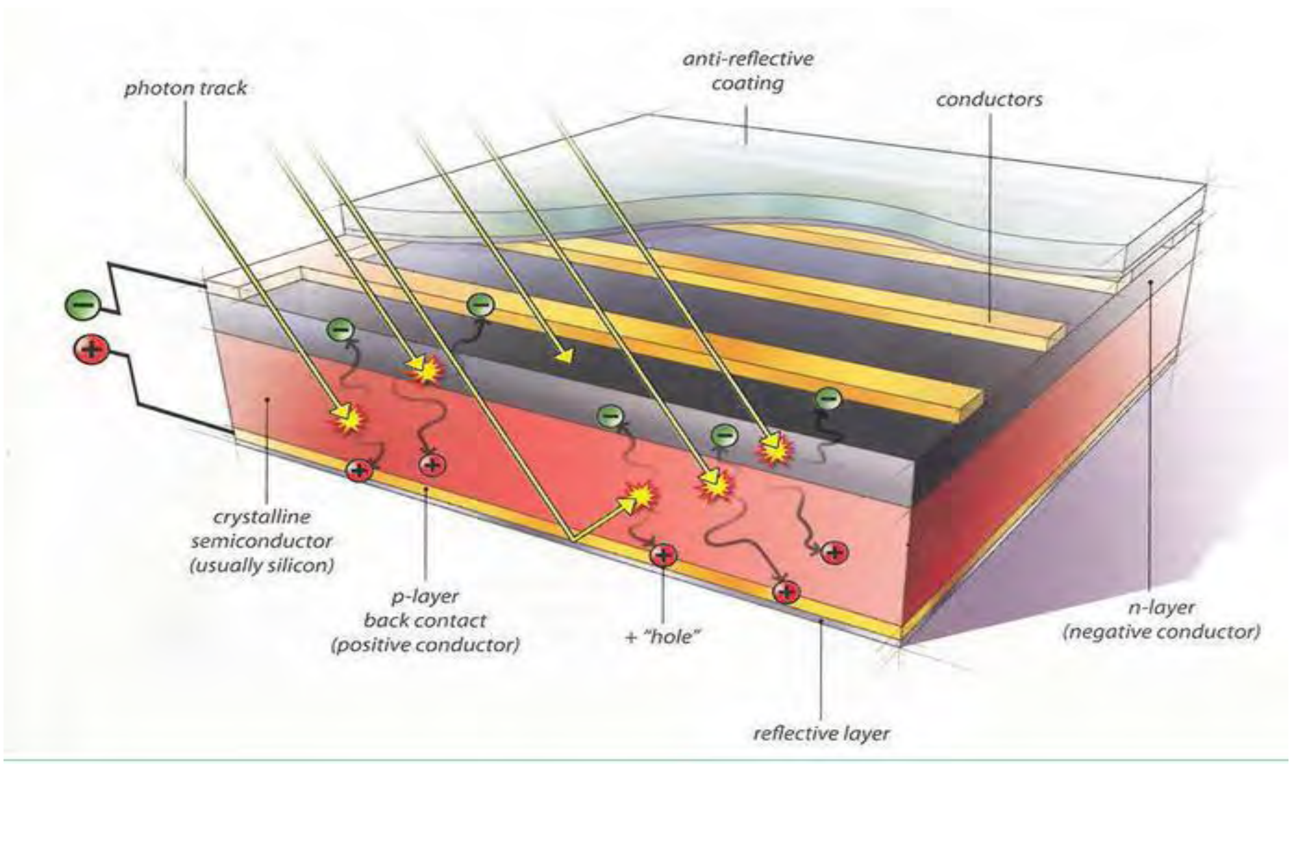

Figure: 1.2.1Mechanism of Photovoltaic system at molecular level

1.2.2 Operations of solar panel:

Fundamentally, when photons from sunlight hit the cell, the semiconductor material gets ionized and consequently the atoms of the outermost layers break-free. Owing to the structure of the semiconductor, when the electrons pass the P-N junction situated near the upper surface of the panel, they cannot return easily and hence the upper side of the panel facing the sun forms negative voltage and the holes or the positive charges of the P-N junction stick to the rear surface of the panel creating a positive voltage. The rear and upper sides can be connected via a circuit to extract electricity and voltage. A number of solar cells could be electrically connected and mounted on a structure to be called a photovoltaic module.

1.2.3Electricity generation:

PV solar panels generate direct current (DC) electricity. With DC electricity, electrons flow in one direction around a circuit. This example shows a battery powering a light bulb. The electrons move from the negative side of the battery, through the lamp, and return to the positive side of the battery. With AC (alternating current) electricity, electrons are pushed and pulled periodically reversing direction

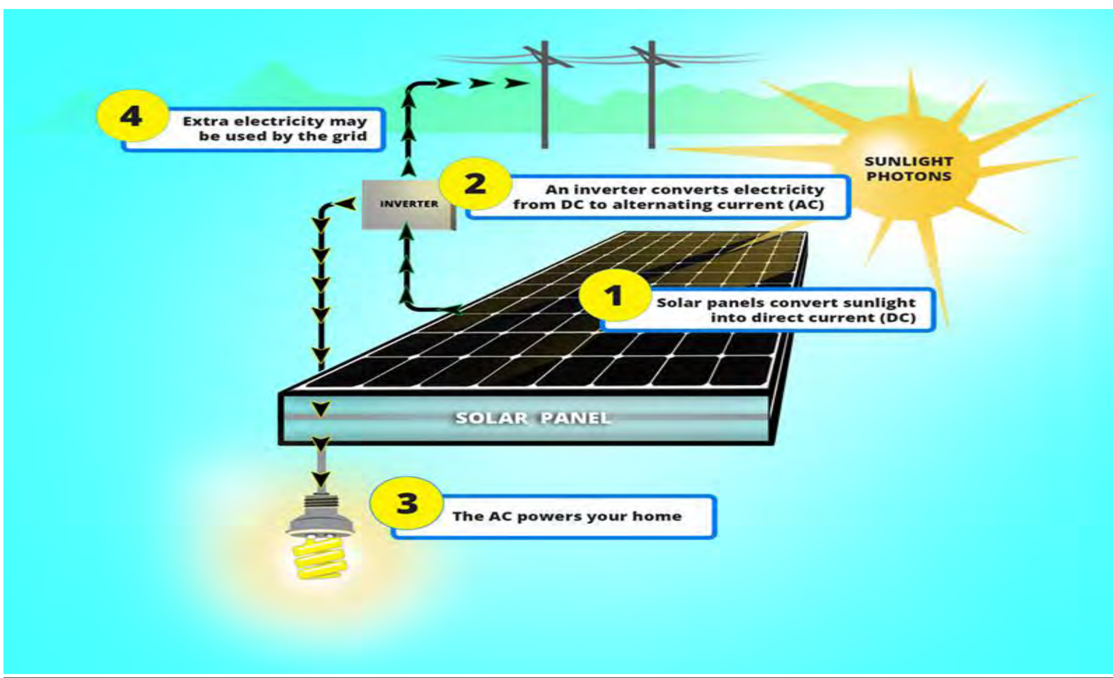

Figure: 1.2.3 Generating electricity by solar panel

1.3 Solar tracking system:

Solar Trackers are used to increase the energy output from solar panels and solar receivers. Solar tracker is a device which follows the movement of the sun as it rotates from the east to the west every day. Solar Trackers are used to keep solar collectors or solar panels oriented directly towards the sun as it moves through the sky every day. Using solar trackers increases the amount of solar energy which is received by the solar energy collector and improves the energy output of the heat or electricity which is generated. In short, trackers direct solar panels or modules toward the sun. These devices change their orientation throughout the day to follow the sun's path to maximize energy capture. In photovoltaic systems, trackers help minimize the angle of incidence (the angle that a ray of light makes with a line perpendicular to the surface) between the incoming light and the panel, which increases the amount of energy the installation produces. Concentrated solar photovoltaic and concentrated solar thermal have optics that directly accept sunlight, so solar trackers must be angled correctly to collect energy. All concentrated solar systems have trackers because the systems do not produce energy unless directed correctly toward the sun.

Selecting a solar tracker depends on system size, electric rates, land constraints, latitude and weather. Utility scale and large projects usually use horizontal single-axis solar trackers, while dual-axis trackers are mostly used in smaller residential applications and locations with high government Feed-In-Tariffs. Vertical-axis trackers are suitable for high latitudes because of their fixed or adjustable angles. The use of solar trackers can increase electricity production by around a third, and some claim by as much as 40% in some regions, compared with modules at a fixed angle. In any solar application, the conversion efficiency is improved when the modules are continually adjusted to the optimum angle as the sun traverses the sky. As improved efficiency means improved yield, use of trackers can make quite a difference to the income from a large plant. This is why utility scale solar installations are increasingly being mounted on tracking systems.

1.3.1Fixed axis solar panel:

Fixed Tilt Arrays are arrays of Solar Panels placed at a fixed angle which is usually the optimum tilt. To obtain maximum efficiency from the solar panels they need to be pointed in the direction that captures the most sun. Fixed tilt arrays, being immobile, are simple in construction, easy to design and maintain.Since they have no moving parts, fixed systems are resilient and need little maintenance. This system won't be optimally aligned. This means it will produce less energy.

Figure: 1.3.1 Fixed axis Solar Panel

1.3.2 Single axis sun tracker:

Single axis trackers have one degree of freedom that acts as an axis of rotation. The axis of rotation of single axis trackers is typically aligned along a true North meridian. It is possible to align them in any cardinal direction with advanced tracking algorithms. There are several common implementations of single axis trackers. These include horizontal single axis trackers, horizontal single axis tracker with tilted modules, vertical single axis trackers, tilted single axis trackers and polar aligned single axis trackers. The orientation of the module with respect to the tracker axis is important when modeling performance. The horizontal type is used in tropical regions where the sun gets very high at noon but the days are short. On the other hand, the vertical type is used in high latitudes where the sun is not very high but summer days can be very long.

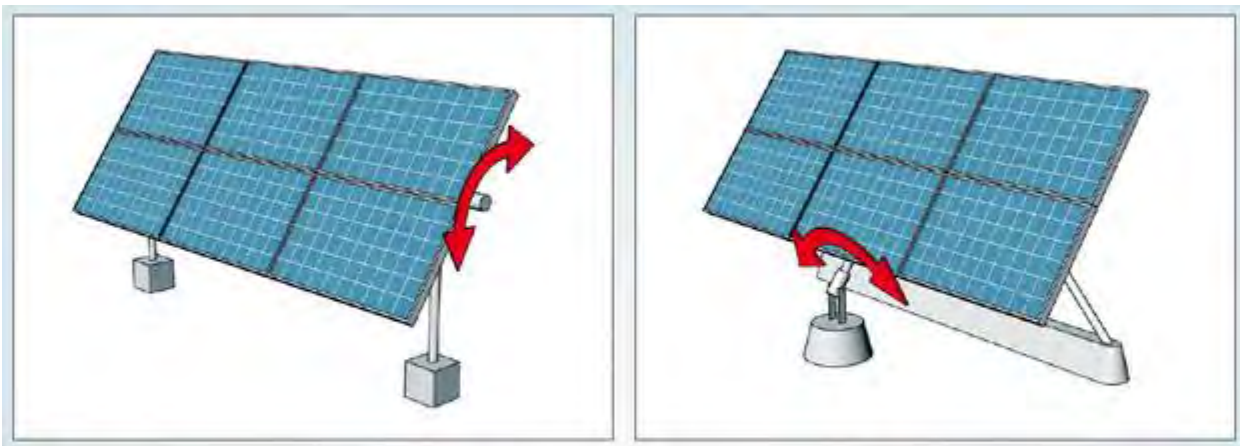

Figure: 1.3.2 Horizontal and tilted single axis solar panel

1.3.3 Dual axis sun tracker:

Dual axis trackers have two degrees of freedom that act as axes of rotation. These axes are typically normal to one another. The axis that is fixed with respect to the ground can be considered a primary axis. The axis that is referenced to the primary axis can be considered a secondary axis. There are several common implementations of dual axis trackers. They are classified by the orientation of their primary axes with respect to the ground. Two common implementations are tip-tilt dual axis trackers and azimuth-altitude dual axis trackers. The orientation of the module with respect to the tracker axis is important when modeling performance. Dual axis trackers typically have modules oriented parallel to the secondary axis of rotation. No matter where the Sun is in the sky, dual axis trackers are able to angle themselves to be in direct contact with the Sun.

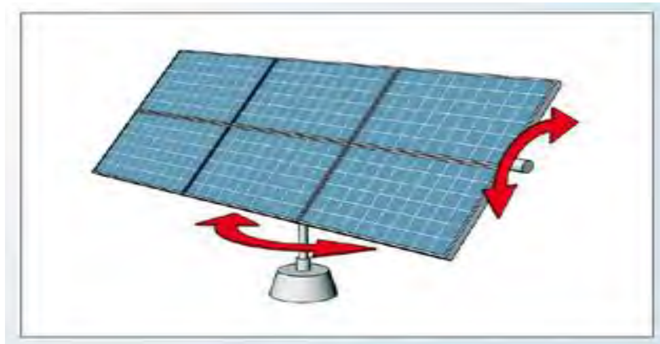

Figure: 1.3.3 Dual axis solar panel

1.4 Drawbacks of traditional energy sources:

There are many energy sources. Among them-fossil fuel and nuclear power are notable example. These traditional energy sources are the main sources of energy as more than 90% total energy is produced by these. Petroleum (crude oil), coals and natural gas are the three forms of fossil fuels. These are formed from animals and plants which have been buried in underneath of earth's surface for millions of years and after collecting, it is transformed into combustible substances. In Bangladesh, power generation is mostly depended on natural gas and coals. Currently, 79% country's power is generated from these two types of fossil fuels. Another source of energy is, nuclear energy. This type of energy is produced by fission requirement of naturally radioactive materials e.g. Uranium. When mined Uranium is used for fueling nuclear generators with Uranium-235 isotope, it produces heat which is eventually used to power up turbines to generate electricity.

Although sources mentioned above are used widespread then renewable energy but these sources have numerous drawbacks. First of all, they all are non-renewable, means they can be used only once. They are also present on earth in limited number and one day they will be finished. So, dependency on them can bring catastrophe. Secondly, these sources cause pollution. When they are combusted; they produces CO_2, CFC and various types of particles which can cause harm in earth's atmosphere. Emission of CO_2 is creating global warming, as a result icebergs of both poles are melting. Therefore, sea-level height is increasing day by day. As a result, countries like

Bangladesh, Maldives, Netherland etc. are in danger as they might go under sea water in the near future. Thirdly, they possess a great threat toward wildlife. To produce energy by these sources, huge plant should be made. To build these plants, deforestation is occurring. So, wild life's natural habitants are vanishing. As a result, many of wild life are facing extinction. Air is also polluting by the toxic gasses emitted from these plants which results in degradation of human health. Finally, nuclear plants are very risky. If a nuclear plant is not maintained properly, it might bring catastrophe. Chernobyl, Fukushima is the examples that what nuclear disaster can bring to earth. Depending on these energy sources is not a wise thing to do as it does not ensure safety. The harsh truth is, one day all fossil fuels would be finished and nuclear energy could not substitute it as it is too risky and also very expensive.

1.5 Motivation:

Developing countries like Bangladesh is facing many problems and providing electricity to its inhabitants is one of them. Bangladesh is notoriously known for having large population despite having relatively low land area and the rate of population is increasing day by day. To provide this mass population with electricity is a challenge, as roughly 70% of the population having access to electricity. According to Bangladesh Power Development Board (BPDB), present installed generation capacity of electricity as on 30 September, 2017 is 13,621 MW. This generation is not enough to satisfy the demand of the consumer. This shortage of generation have many adverse outcomes and occurrence of load shedding is the main one. To eradicate the problem, countries like Bangladesh should priorities more sustainable renewable energy sources. Renewable sources are abundant and harmless in nature. Among these energy sources, solar energy has the potential to meet the unprecedented energy demand as Bangladesh is geographically a good location for solar energy utilization. Bangladesh is situated between 20°30´ and 26°38´ north latitude and also 88°04´ and 92°44´ east longitude with annual solar radiation availability is as high as 1700 kWh per square meter. As summer season prevails in Bangladesh, almost ten months are considered as summer days and maximum solar radiation can be obtained in summer season. For these reasons, Bangladesh should adopt to solar energy.

1.6 Project Overview:

For the project, we have worked on the performance evaluation of the three types of solar power systems which are fixed panel, single-axis and dual-axis sun tracker.

The fixed panel solar system is generally mounted on top of a roof or in the open space where there's no blockage from trees or buildings. As the name suggests, this particular system will be fixated in a certain position and will not be moving with the course of a day or a year. As in, the changes of solar intensity with respect to the changes of the solar position will have no effect on the positioning of the panel.

The single axis solar panel will possess the capacity to track the sun as the sun moves from east to west throughout the day. It should be notable that single axis refers to the changes in the position of the tracker to be following the sun's one dimensional movement. The sun's changing position with respect to seasons, will not be taken into account by the single axis tracker. A single axis tracker should be able to generate considerably more energy than what a fixed axis does.

The dual axis suntracker is essentially able to follow the sun as it changes its positioning throughout a day as well as a year. As we are all aware of, the sun doesn't only shift from east to west on a daily basis as seasons change. The sun's position also varies moving from north to south. The dual axis tracker essentially follows the sun's two-dimensional movement to ensure the angle of incidence between the sun ray and the panel is always kept minimum. This way the system is able to absorb maximum sunlight and therefore should be capable of producing more energy than single and fixed axis trackers.

The objective of this work is to calculate the output powerand cumulative energy for three different systems yield respectively and evaluate as well as compare the performances of the systems with respect to Bangladesh for a particular place and also for particular time. For our project purpose, we have collected practical hour basis average solar radiation data for a specific year from Bangladesh meteorological department which was for only dual axis sun tracker system. We have calculated solar radiation for fixed panel and single axis sun tracker system from that. By following steps, we have calculated the other parameters like output power and cumulative energy. Average solar radiation data of three types of solar panel system for different months are given below,

Fixed Panel :

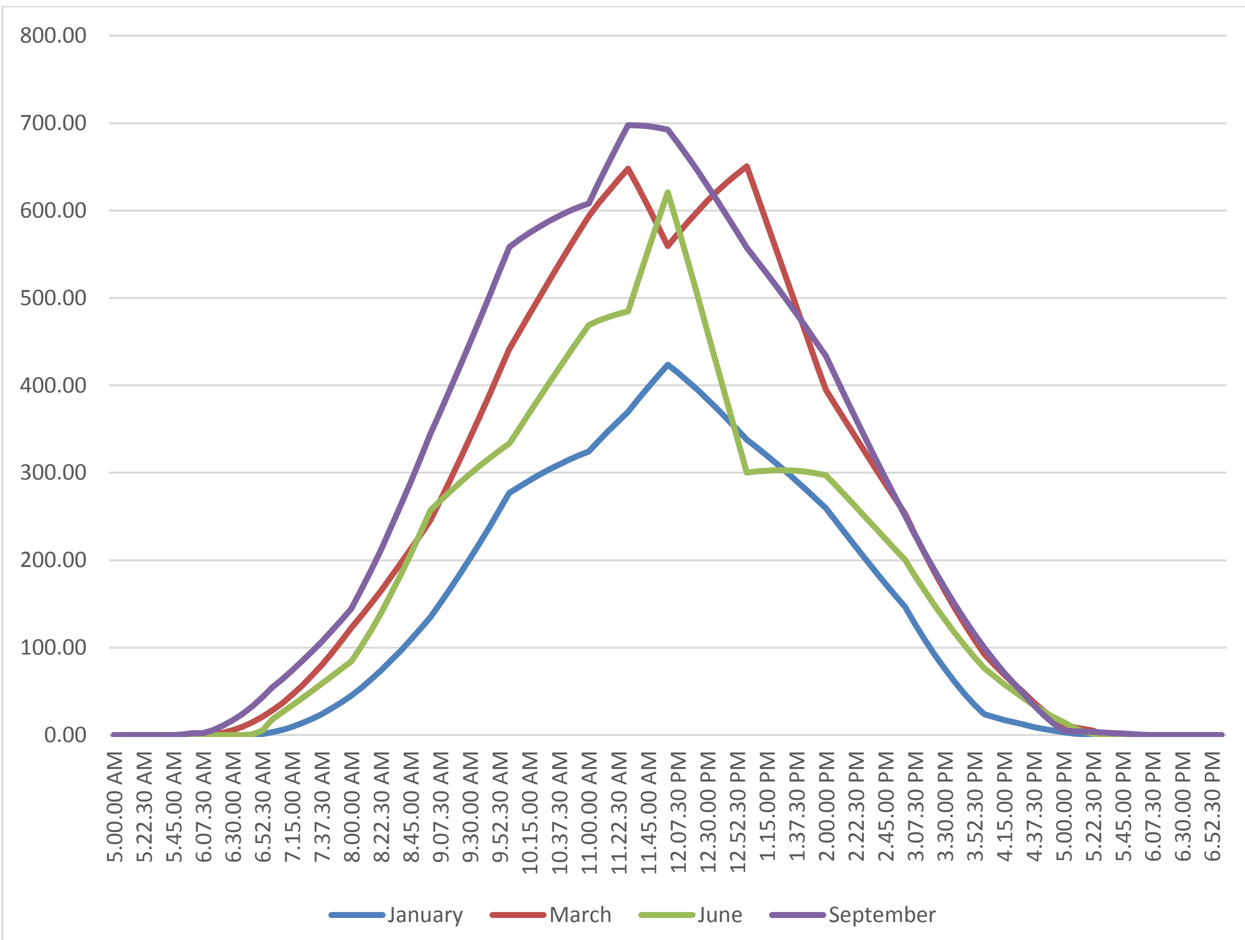

Figure: 1.6 Average solar radiation (W/m^2) for different months

<u>Single-Axis:</u>

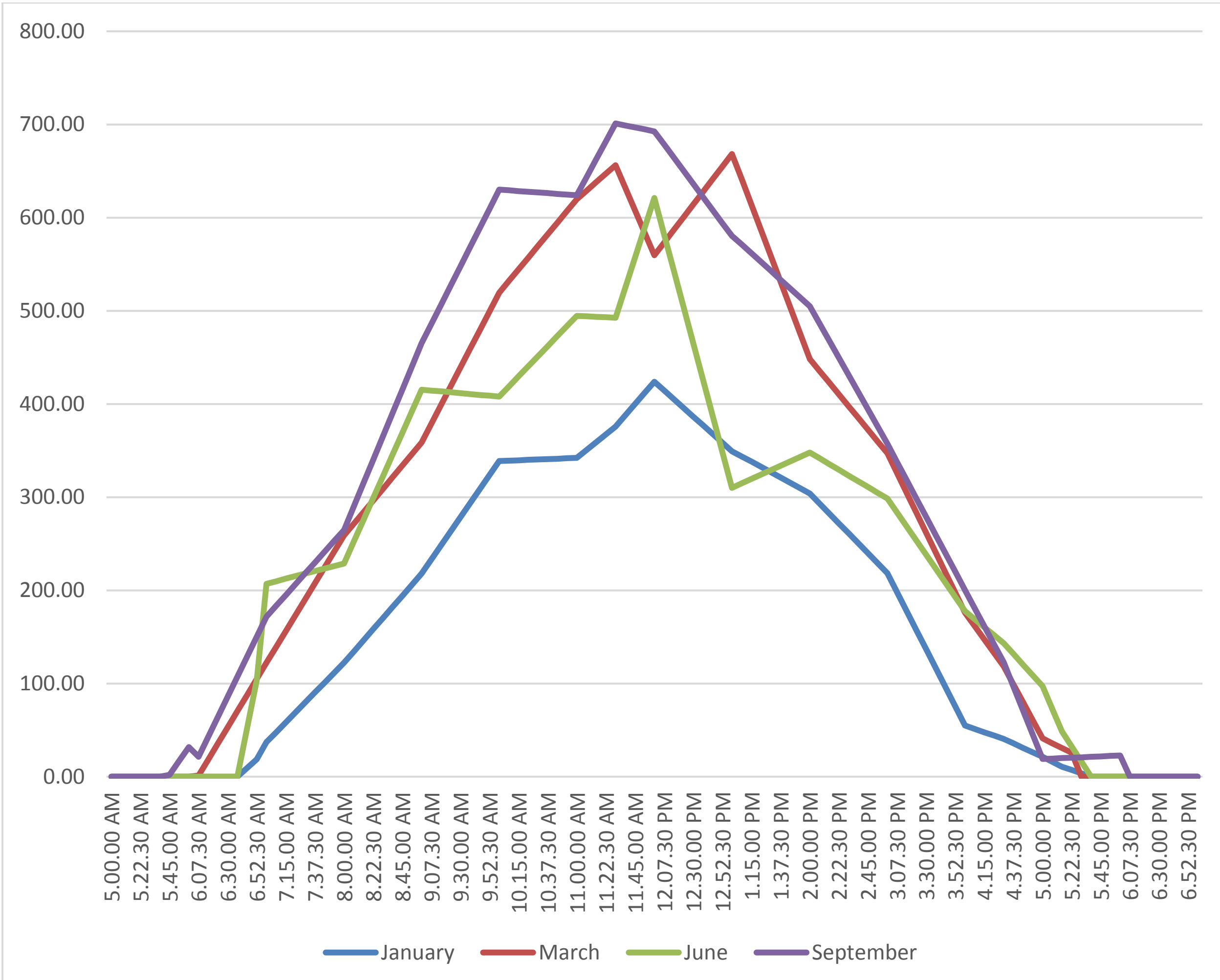

Figure: 1.7 Average solar radiation (W/m^2) for different months

Dual-Axis:

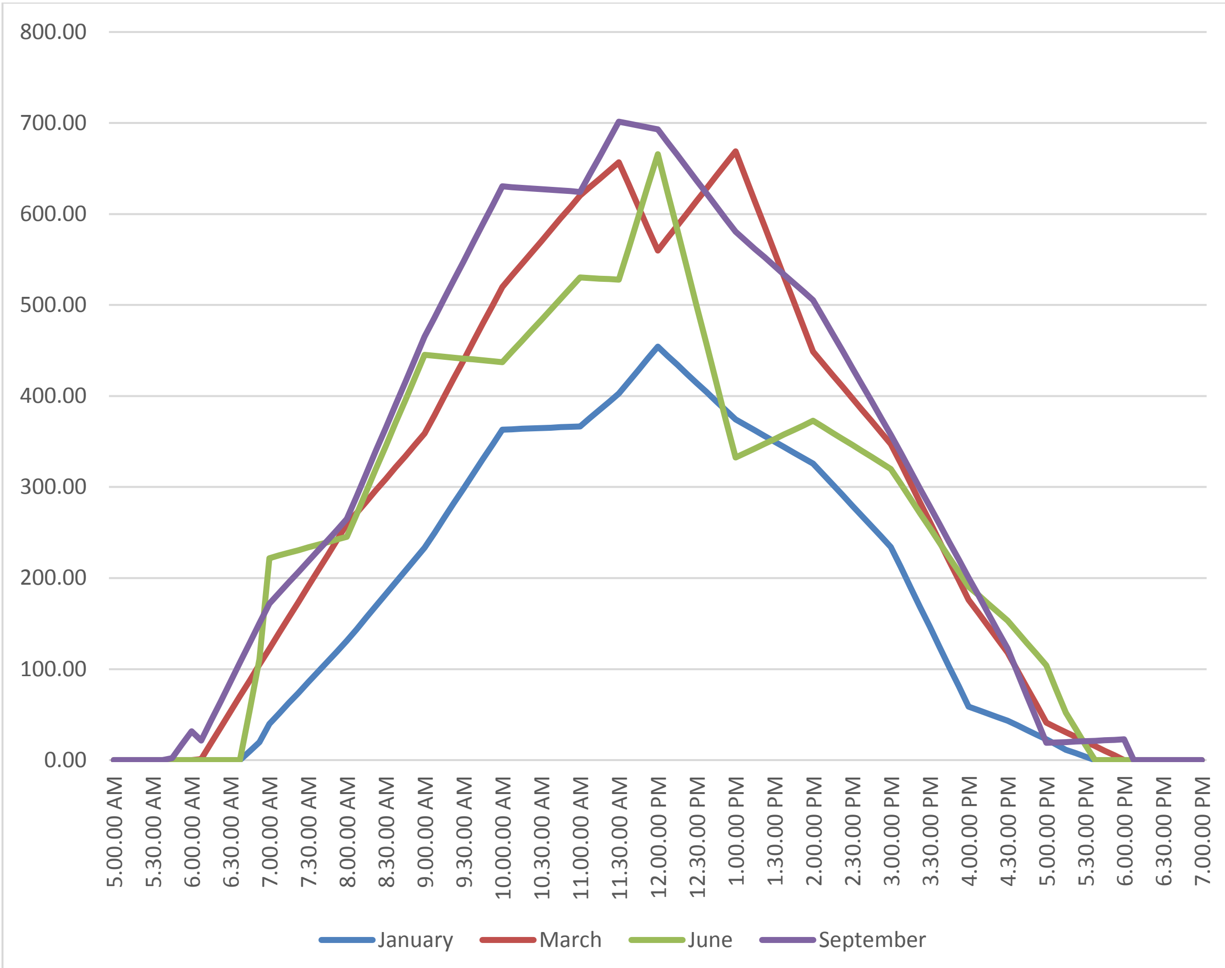

Figure: 1.8 Average solar radiation (W/m^2) for different months

For calculating solar panel output we have taken a solar panel as reference. We have calculated all the parameters which are module current and open circuit voltage according to the parameters of that reference solar panel specifications. The parameters of that specific solar panel are given below;

Maximum Power, Pmax =	180W
Short Circuit Current, Isc =	11.31A
Open Circuit Voltage, Voc =	21.6V
No. of cells in Series, Nsm =	2
No. of cells in Parallel, Npm =	36
Dark Saturation Current, Io =	10^(-10.88)

Chapter 2

Theoretical Overview

2.1 Defining Solar Angles and Respective Equations:

2.1.1. Solar Altitude:

Solar altitude refers to the angle of the sun relative to the Earth's horizon. Solar altitude is measured in degrees. The value of the solar altitude varies based on the time of day, the time of year and the latitude on Earth. Solar altitude is defined as (α) in figure below,

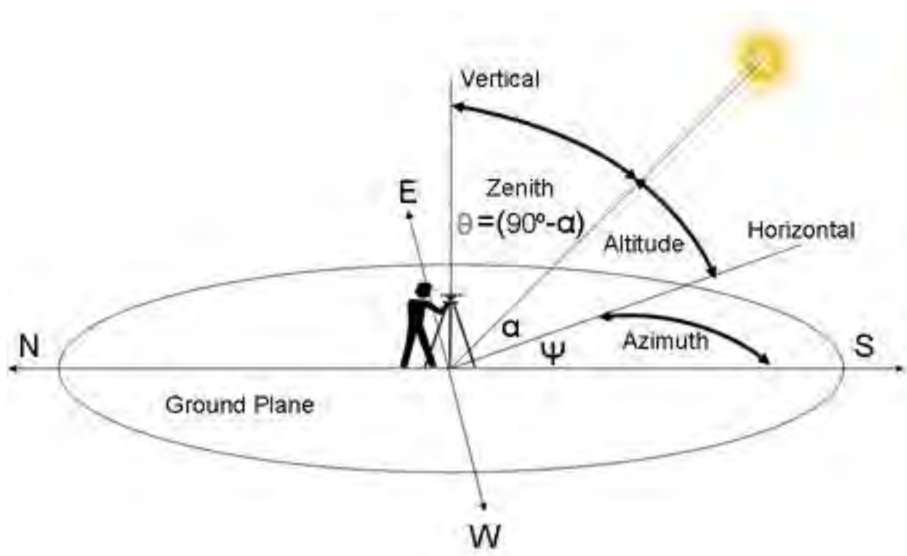

Figure: 2.1.1 Solar Altitude (α)

Solar Altitude can be calculated through the equation below,

$$\alpha = \sin-1(\sin\delta\sin\varphi + \cos\delta\cos\varphi\cos\omega)$$

……...………2.1

2.1.2. Zenith Angle:

The solar zenith angle is the angle between the zenith and the center of the sun's disc. The solar elevation angle is the altitude of the Sun, the angle between the horizon and the center of the Sun's disc. Since these two angles are complementary, the cosine of either one of them equals the sine of the other. Zenith Angle is shown in Figure2.1.1 where, θz is known as Zenith Angle. The equation of Zenith angle is given below,

$$\boldsymbol{\theta z = 90° - \alpha} \qquad \text{……………..2.2}$$

2.1.3. Declination Angle:

The declination angle (δ) varies seasonally due to the tilt of the earth on its axis of rotation and the rotation of the earth around the sun. If the earth were not tilted on its axis of rotation, the declination would always be 0°. However, the earth is tilted by 23.45° and the declination angle varies plus or minus this amount. Only at the spring and fall equinoxes is the declination angle equal to 0°.

$$\delta = 23.45° \sin \left[\frac{360(n-80)}{365}\right] \qquad \text{…………..2.3}$$

Here, n = number of a particular day.

2.1.4. Latitude Angle:

Latitude is defined with respect to an equatorial reference plane. This plane passes through the center O of the sphere, and also contains the great circle representing the equator. The latitude of a point P on the surface is defined as the angle that a straight line, passing through both P and O, subtends with respect to the equatorial plane. If P is above the reference plane, the latitude is positive (or northerly); if P is below the reference plane, the latitude is negative (or southerly). Latitude angles can range up to +90 degrees (or 90 degrees north), and down to -90 degrees (or 90 degrees south). Latitudes of +90 and -90 degrees correspond to the north and south geographic poles on the earth.

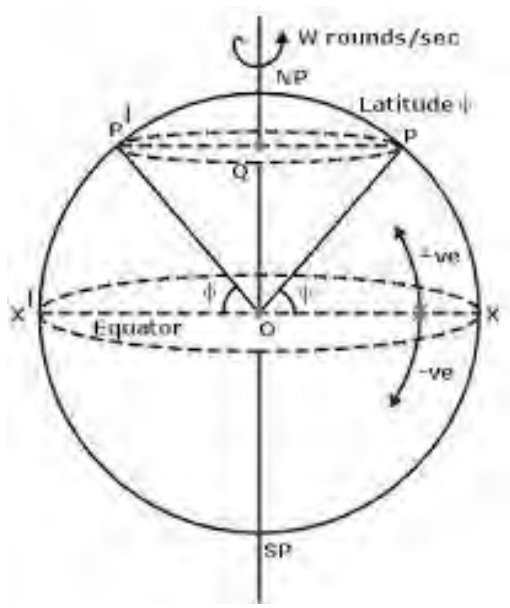

Figure 2.1.4 Latitude Angle (φ)

2.1.5. Hour Angle:

Observing the sun from earth, the solar hour angle is an expression of time which is expressed in angular measurement, usually degrees from solar noon. At solar noon, the hour angle is 0.000 degree; with the time before solar noon expressed as negative degrees and the local time after solar noon expressed as positive degrees. For example, at 10:30 AM local apparent time the hour angle is - 22.5°. The Equation expressing hour angle is,

$$\theta = \frac{180*(t - t_{SR})}{t_{SS} - t_{SR}} \qquad \text{..............2.4}$$

Here,

t = Particular time of a day

t_{SR} = Sunrise time of a particular day

t_{SS} = Sunset time of a particular day

2.2 Defining Factors for Finding Solar Energy:

2.2.1 Solar Irradiance:

Solar irradiance is the power per unit area received from the sun in the form of electromagnetic radiation in the wavelength range of the measuring instrument. Irradiance may be measured in space or at the Earth surface after atmospheric absorption and scattering. It is measured perpendicular to the incoming sunlight. This Solar Irradiance hits the surface of the earth in two forms, beam (Gb) and diffuse (Gd). The beam component comes directly as irradiance from the sun, while the diffuse component reaches the earth indirectly and is scattered or reflected from the atmosphere or cloud cover. The total irradiance on a surface is G = Gb + Gd (beam and diffuse)

For Dual Axis:

For this project, we have collected practical data of solar irradiance for dual axis sun tracker throughout the year. That data contains the solar irradiance value of a particular place from sunset to sunrise which is an hourly basis average data and it is denoted by I_0. We have calculated incidental solar radiation by the method of finding slope from this hour basis average data.

For Single Axis:

Solar irradiance value for single axis sun tracker is denoted by I_1. The equation of calculating solar irradiance for single axis is,

$$\text{Solar Irradiance } (I_1) = \text{Cos } (\delta) * I_0 \qquad \text{.............2.5}$$

Here, δ = Declination Angle

For Fixed Panel:

Solar irradiance value for fixed panel is denoted by I_2. The equation of calculating solar irradiance for fixed panel is,

$$\text{Solar Irradiance } (I_2) = I_0 * \text{Cos } (\delta) * \text{Sin } (\boldsymbol{\theta}) \qquad \text{...........2.6}$$

Here, θ = Hour Angle

δ = Declination Angle

2.2.2 Output Power:

2.2.2.1. Module Current:

Cells are normally grouped into modules which are encapsulated with various materials to protect the cells and the electrical connectors from the environment. The manufacturers supply PV cells in modules, consisting of N_{PM} which is parallel branches, each with N_{SM} solar cells in series. The PV module's current I^M under arbitrary operating conditions can thus be described as:

$$I^M = I_{SC}^M \left[1 - \exp\left(\frac{V^M - V_{OC}^M + R_S^M \cdot I^M}{N_{SM} V_t^C} \right) \right]$$ **…………2.7**

The expression of the PV module's current I^M is an implicit function, being depended on:

- The short circuit current of the module, $I_{SC}^M = N_{PM} . I_{SC}^C$
- The open circuit voltage of the module, $V_{OC}^M = N_{SM} . V_{OC}^C$
- The equivalent serial resistance of the module,

$$R_S^M = \frac{N_{SM}}{N_{PM}} \cdot R_S^C$$ **……………..2.8**

- The thermal voltage in the semiconductor of a single solar cell,

$$V_t^C = \frac{mkT^C}{e}$$ **..……………2.9**

The steps of calculating PV module current are as following:

1) Manufacturer's catalogues provide information about the PV module for standard conditions:

- Maximum power, $P_{max,0}^M$
- Short circuit current, $I_{SC,0}^M$
- Open circuit voltage, $V_{OC,0}^M$
- Number of cells in series, N_{SM}
- Number of cells in parallel, N_{PM}

2) The next step is to compute the cell's data for standard conditions: $P_{max,0}^C$, $V_{OC,0}^C$, $I_{SC,0}^C$, R_S^C

$$P^{C}_{\max,0} = P^{M}_{\max,0} / (N_{SM}\ N_{PM})$$
$$V^{C}_{OC,0} = V^{M}_{OC,0} / N_{SM}$$
$$I^{C}_{SC,0} = I^{M}_{SC,0} / N_{PM}$$

3) The next step is to determine the characteristic parameters of the cell under the operating conditions (V^{M}, T_a, G_a). Thus, the short circuit current of a solar cell is computed based on its linear dependency on the irradiation G_a.

$$I^{C}_{SC} = C_1\ G_a$$

The working temperature of the cells T^{C} depends exclusively on the irradiation G_a and on the ambient temperature T_a, According to the empirical linear relation:

$$T^{C} = T_a + C_2 G_a$$

Where the constant C_2 is computed as:

$$C_2 = \frac{T^{C}_{ref} - T_{a,ref}}{G_{a,ref}}$$

When T^{C}_{ref} is not known, it is reasonable to approximate $C_{2=}$ 0.03 Cm^2 /W. The open circuit voltage of the cell depends exclusively on the temperature of the solar cell

$$V^{C}_{OC} = V^{C}_{OC,0} + C_3\ (T^{C} - T^{C}_{0})$$

Where the constant C_3 is usually considered to be: C_3= -2.3 mV/C

$$V_t^C = m\,k\,(273 + T^{\,C})/e$$

$$V^M = V_t^C * N_{SC}$$

4) The final stage is to determine the module current for operating condition.

$$I^M = N_{PM}\, I_{SC}^C\,[1 - \exp((V^M - N_{SM}\, V_{OC}^C + I^M\, R_S^C\, N_{SM}/N_{PM})/(N_{SM}\, V_t^C))] \quad \text{....2.10}$$

<u>2.2.2.2 Open Circuit Voltage:</u>

The open-circuit voltage (V_{OC}) is the maximum voltage available from a solar cell, and this occurs at zero current. The open-circuit voltage corresponds to the amount of forward bias on the solar cell due to the bias of the solar cell junction with the light-generated current.

$$V_{OC} = \frac{mKT_C}{e} \ln\left(\frac{I_M}{I_0} + 1\right) \quad \text{...........2.11}$$

Here,

Dark Saturation Current, $I_0 = 10^{-10.88}$ A

Ideality Factor, m = 1

<u>2.2.2.3 Output Power Calculation:</u>

The power output of photovoltaic solar panels is approximately proportional to the sun's intensity. At a given intensity, a solar panel's output current and operating voltage are determined by the characteristics of the load. If that load is a battery, the battery's internal resistance will dictate the module's operating voltage.

$$P_{OUT} = V_{OC} * I_M \quad \text{.........2.12}$$

2.2.2.4 Cumulative Energy Calculation:

Cumulative Incident energy is total of all intensity values calculated over a given time period. We can calculate total energy generation for particular time period such as for a day, for a month or even for a year. For a particular day we can use numerical integration of intensity for a given time period like total number of hours available from dawn to dusk. In terms of months we multiply the value with the total number of days available for that particular month and for year we add up all the values for 12 months.

$$\text{Cumulative Energy} = \int_{t_{start}}^{t_{end}} P_{out}$$

Chapter 3

Result and Comparison

In this chapter, we are going to evaluate the outputs of fixed panel, single-axis and dual-axis solar panel systems. According that, we will calculate total energy throughout a year and also for different months individually. By following that, we will also compare the output power and total energy for different systems.

3.1 Output Power of Fixed Panel:

In this part, we will observe the output energy (W/m^2) of fixed axis solar photovoltaic panel for different months. Based on dual axis incidental irradiation value that we have collected, we have calculated the incidental irradiation values of fixed axis PV panel as per Equation: 2.6. In Equation: 2.10 and Equation: 2.11 we will be using the value obtained from Equation: 2.6. After that, putting the value obtained from Equation: 2.10 and 2.11 in Equation: 2.12, we are attempting to sort out the monthly average output power of fixed axis PV Panel system.

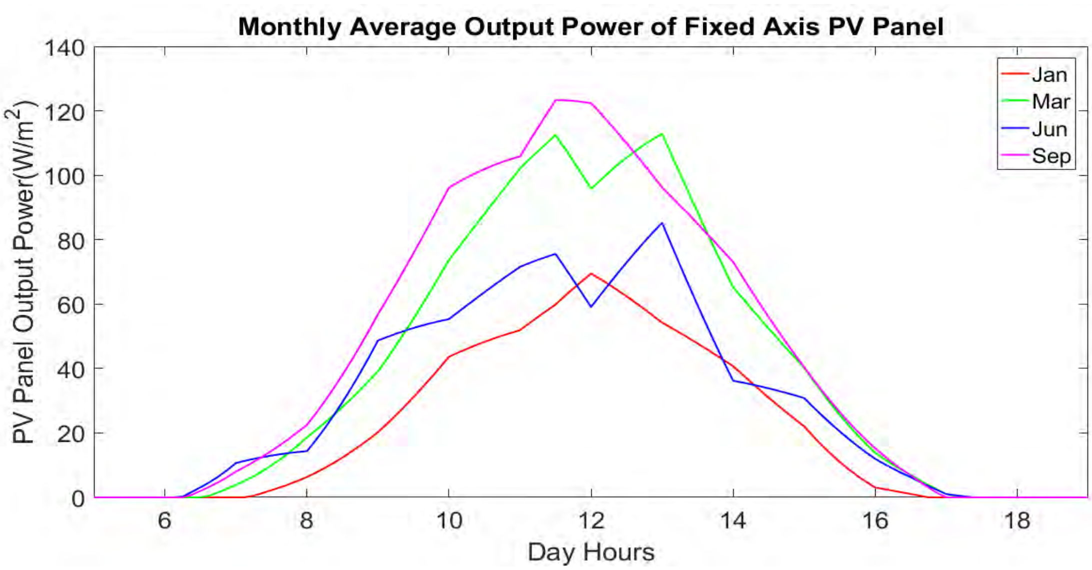

Figure: 3.1

Plots of monthly average PV panel output power for a particular day for the months of January, March, June, September, calculated for fixed panel system.

From the above graph, we can interpret that, in context of Bangladesh the output power value of fixed axis PV Panel remains at the peak position during the month of September, so also the output power value remains at a close extent of the peak value during March. On the contrary, the value gradually plummet during January. But in the month of June, the output power of fixed axis PV panel remains in between the highest and the lowest value.

3.2 Output Power of Single-Axis:

In this part we will see the output energy (W/m^2) of single axis solar photovoltaic panel for different months. Here, we are going to use Equation: 2.5 in order to trace the incidental irradiation value and will follow the same procedure as we did to calculate the output power of fixed axis PV panel.

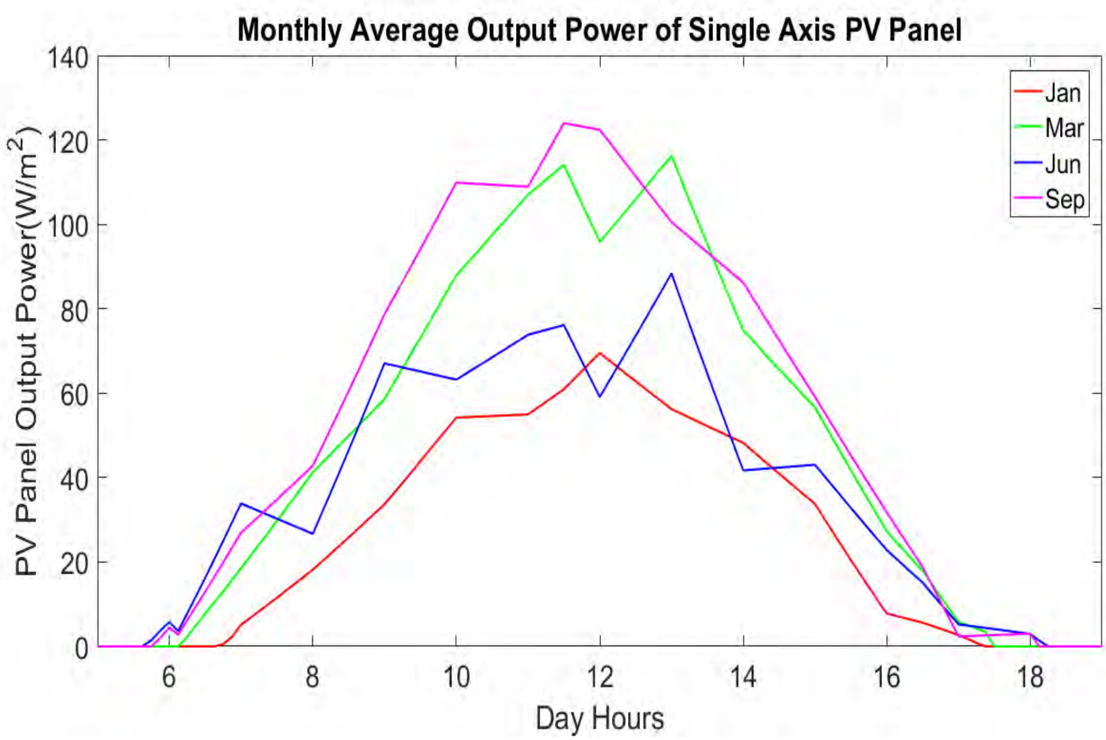

Figure: 3.2

Plots of monthly average PV panel output power for a particular day for the months of January, March, June, September, calculated for single axis panel system.

From the shown graph of Fig-3.2, we observe that it portrays almost the same scenario as that of fixed axis PV Panel; the only difference is the values obtained in single axis PV panel is higher than that of fixed axis PV Panel.

3.3 Output Power of Dual-Axis:

In this part we will see the output energy (W/m^2) of dual axis solar photovoltaic panel for different months. Here, we are going to calculate the output power from the data (*mentioned in appendix*) that was collected. Sequentially, we are going to follow the same procedure to determine the output power value of dual axis PV Panel as used in case of fixed axis and single axis PV panel.

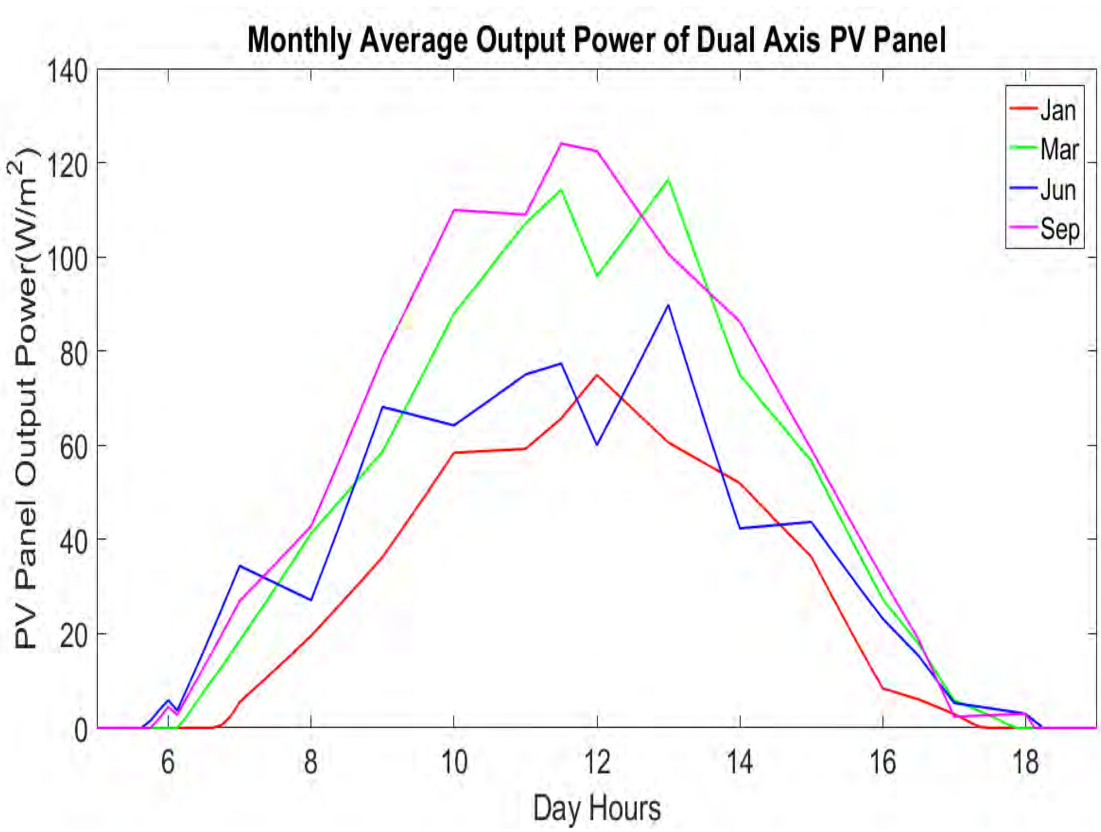

Figure: 3.3

Plots of monthly average PV panel output power for a particular day for the months of January, March, June, September, calculated for dual axis panel system.

Monthly average output power value of dual axis PV Panel graph illustrates that, the highest and the lowest value of this axis PV Panel is slightly higher than that of single axis PV Panel.

3.4 Comparing Intensity and Energy collected by Different Axis:

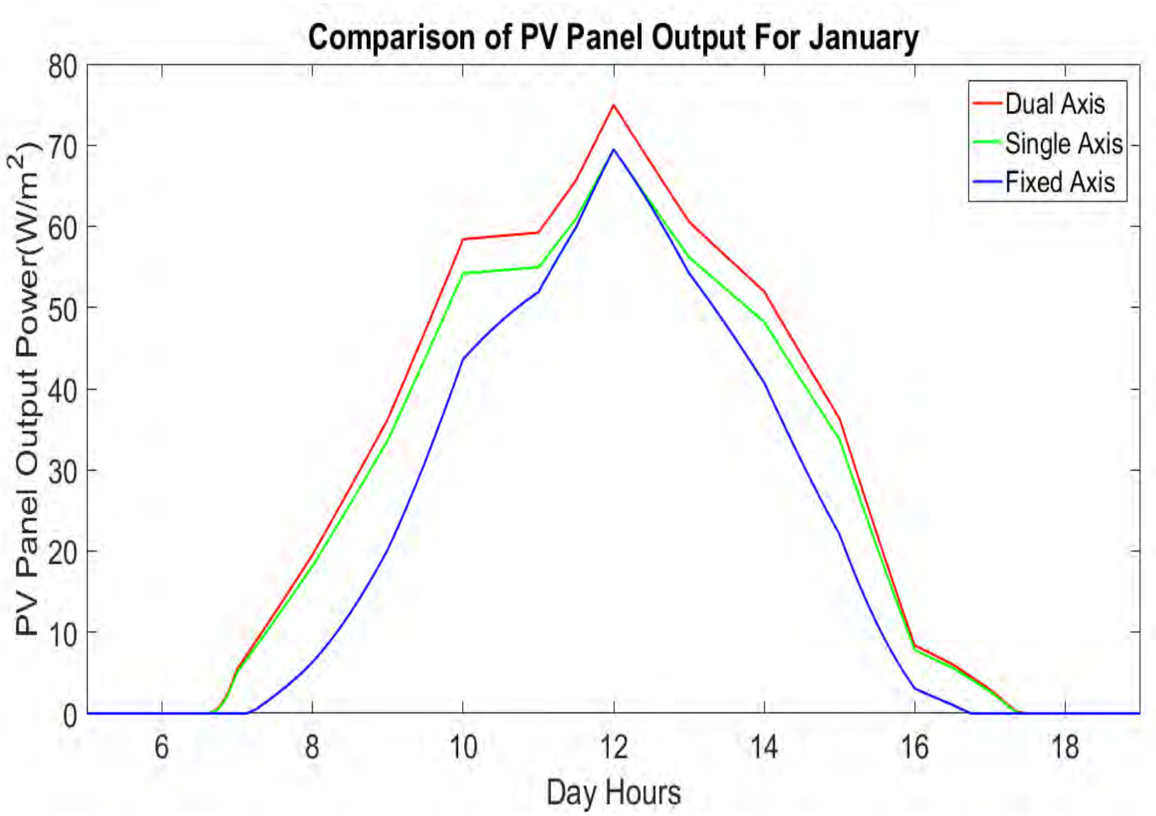

Figure 3.4.1

Comparison of PV panel output power for January month on the basis of fixed axis, single axis and dual axis.

The graph of Fig: 3.4.1 for January, clearly shows that, the output power value as per dual axis PV Panel is the highest, whereas the value as per fixed axis PV Panel is the lowest. Here, we can also assume well that, the single axis PV Panel output power value is at the moderate level amongst these three axis. It is to be mentioned that, due to higher declination angle, the difference between the single axis and dual axis output power escalates around the solar noon period (time during 10AM to 2 PM).

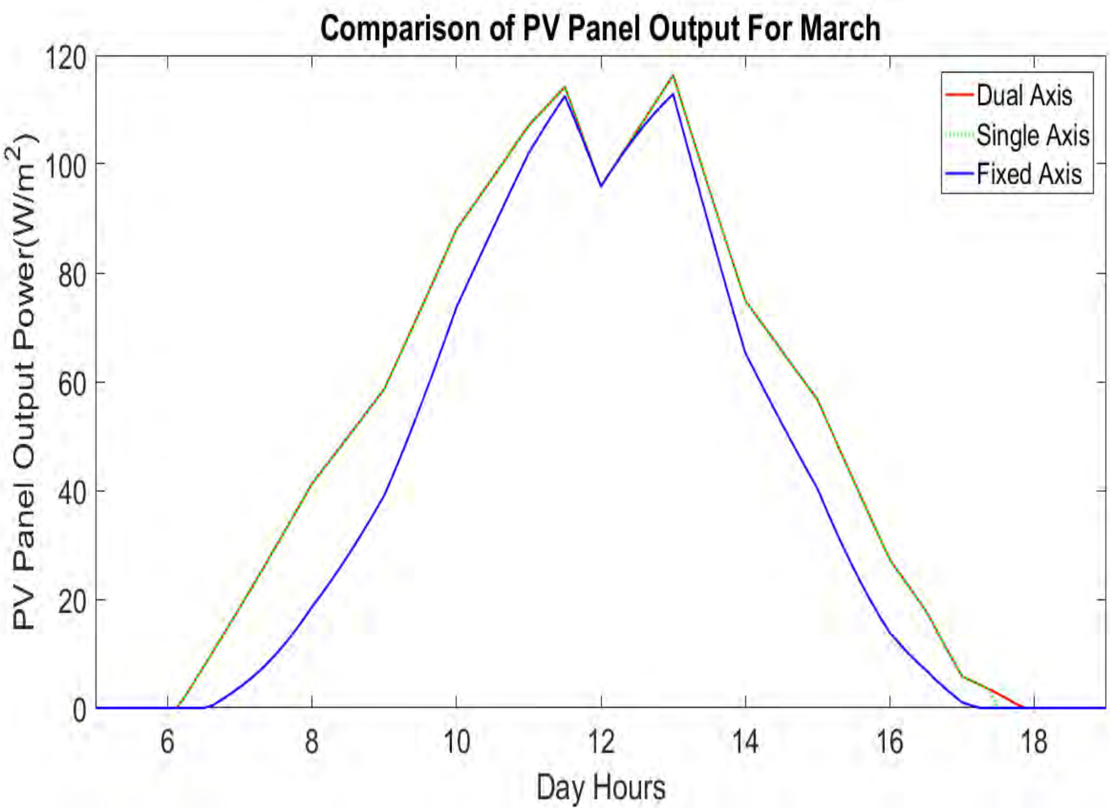

Figure: 3.4.2

Comparison of PV panel output power for March month on the basis of fixed axis, single axis and dual axis.

Fig.3.4.2 demonstrates the comparison of PV Panel output power for March. Here, the peak positions of the three respective axis PV Panels are almost at the same points and because of low declination angle dual axis and single PV Panels output are almost same around the whole day.

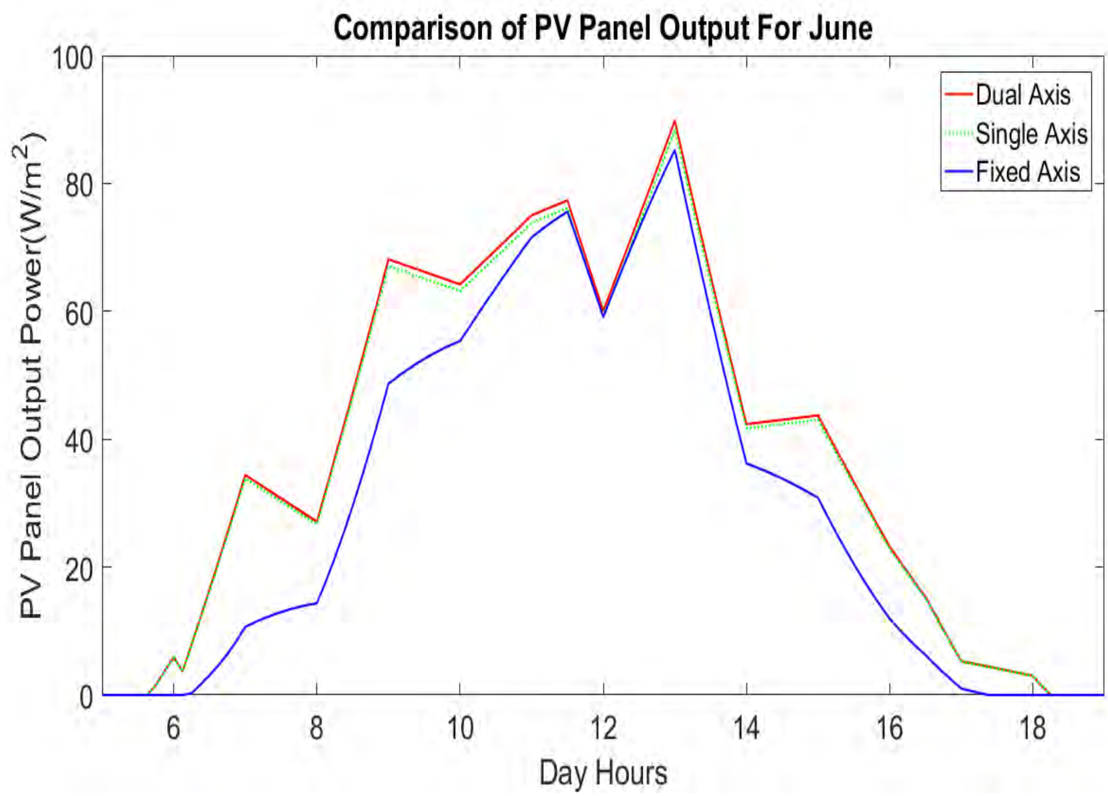

Figure: 3.4.3

Comparison of PV panel output power for June month on the basis of fixed axis, single axis and dual axis.

Here in Fig.3.4.3 illustrates that the output curve for the month of June in case of the three respective axis PV panel almost coincide with one another while being plotted on the graph. Such happens because the declination angle becomes least during June.

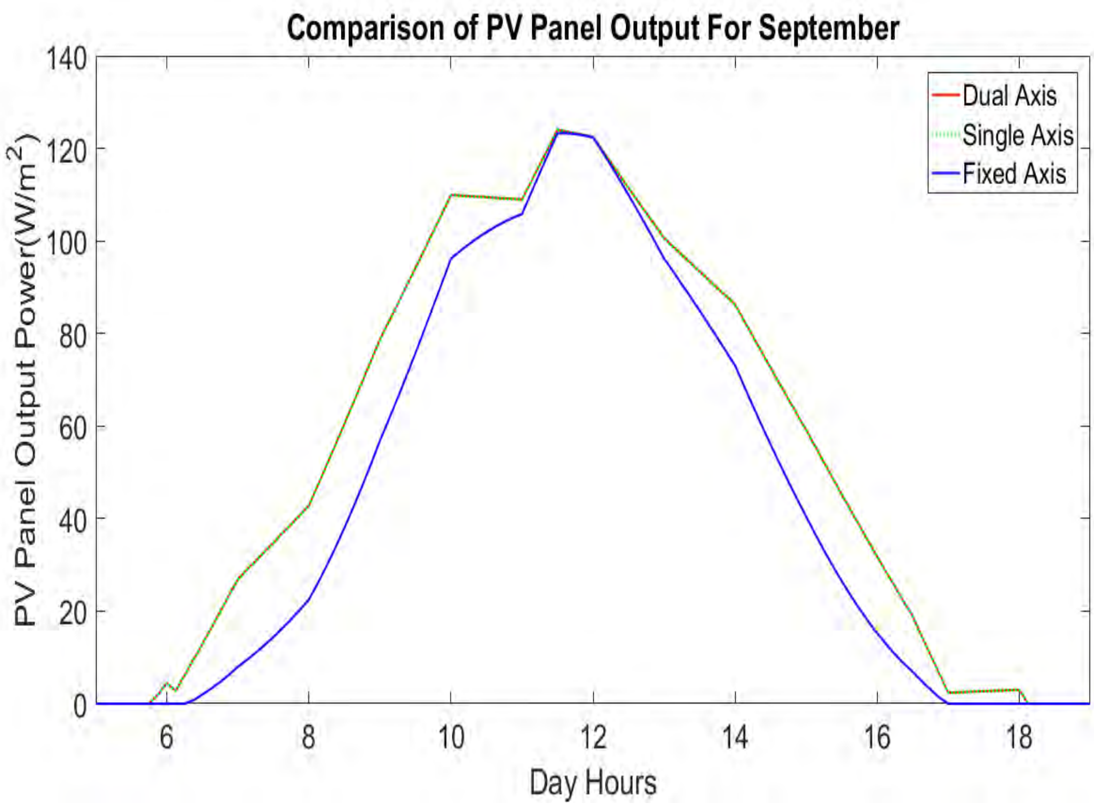

Figure: 3.4.4

Comparison of PV panel output power for September month on the basis of fixed axis, single axis and dual axis.

PV Panel graph of output power for September in Fig: 3.4.4 shows that the output power of the three respective axis PV panels are almost at the same position in the graph at solar noon. Due to low declination angle during the month of September, the output power values of single axis PV Panel and dual axis PV Panel almost always remain nearer.

3.5 Comparing Energy for Different Axis:

In this segment of chapter 3, we are going to elaborately discuss the comparison of total energy of three different systems.

3.5.1 Particular Day’s Total Energy:

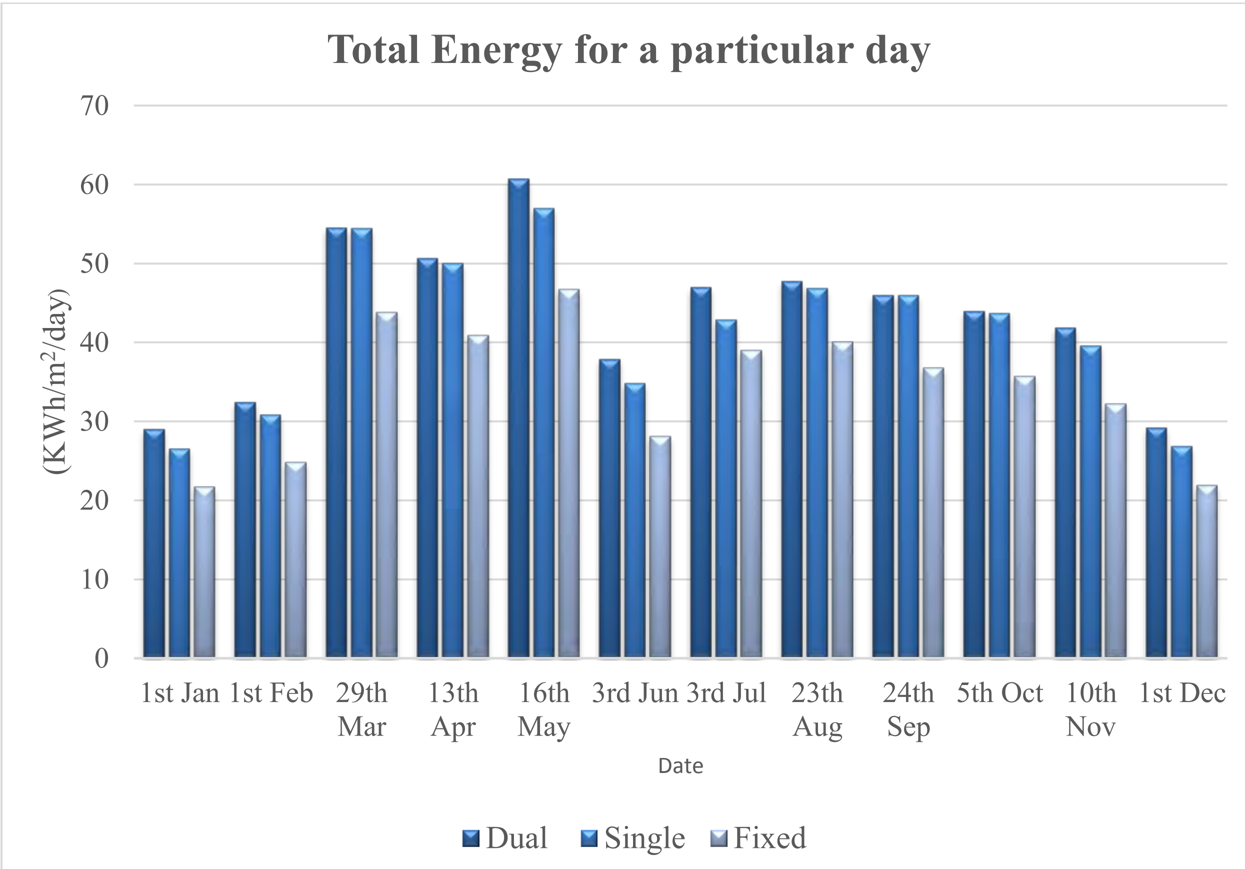

Figure: 3.5.1

Comparison of total energy for three different PV panel systems (Fixed axis, dual axis and single axis) for a particular day in a year.

In this graph of Fig: 3.5.1, we are representing the total energy of a particular day in a year. Here, due to less declination angle, the difference between the dual axis and the single axis PV Panel systems remains negligible during some of the months around the year (i.e. the month of March, April, September and October). Other than that, their difference for total energy is more because of escalation of declination angle (viz: during January, February, May, June, July and

December). Besides, it is visual that the total energy as per fixed axis PV Panel system is significantly less than that of the total energy as per dual axis and single axis PV Panel systems throughout the year.

3.5.2 Daily Average Energy for Different Months:

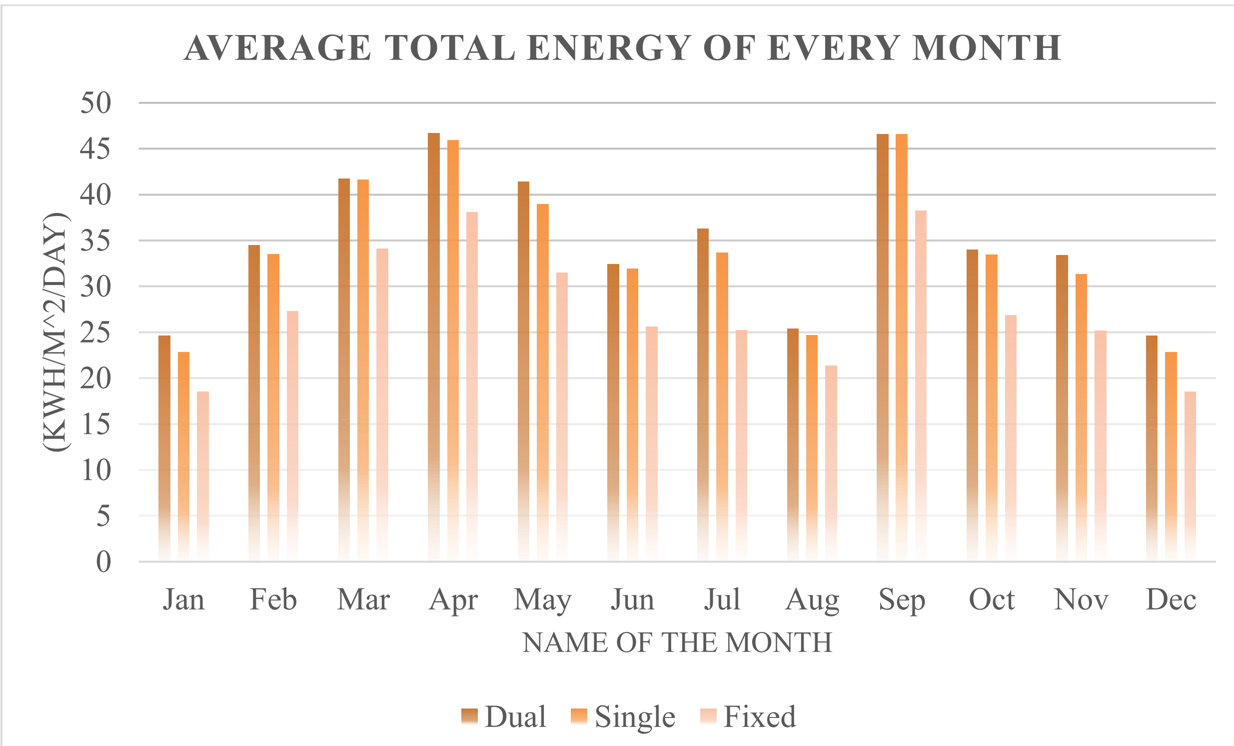

Figure: 3.5.2

Comparison of average total energy for three different PV Panel system (Fixed, single and dual axis) of every months.

This graph of Fig: 3.5.2 illustrate the average total energy of every month in a year. Due to less declination angle, the difference between the dual axis and the single axis PV Panel systems remains minor during some months around the year (i.e. the month of March, April, September and October). Other than that, their difference for average total energy is more because of escalation of declination angle (viz: during January, February, May, June, July and December). Besides, it is visual that the total energy as per fixed axis PV Panel system is significantly less than that of the total energy as per dual axis and single axis PV Panel systems throughout the year.

In context of Bangladesh, the average total energy value irrespective of the three different axis PV Panel systems remains at a lower range during January, which gradually increases at a linear direction till April. After that, the curve does not follow a stable nature. However, the curve reaches the peak in the month of September and gradually falls again in the later periods of the year. This trend is again repeated from January.

3.5.3 Season-wise Comparison :

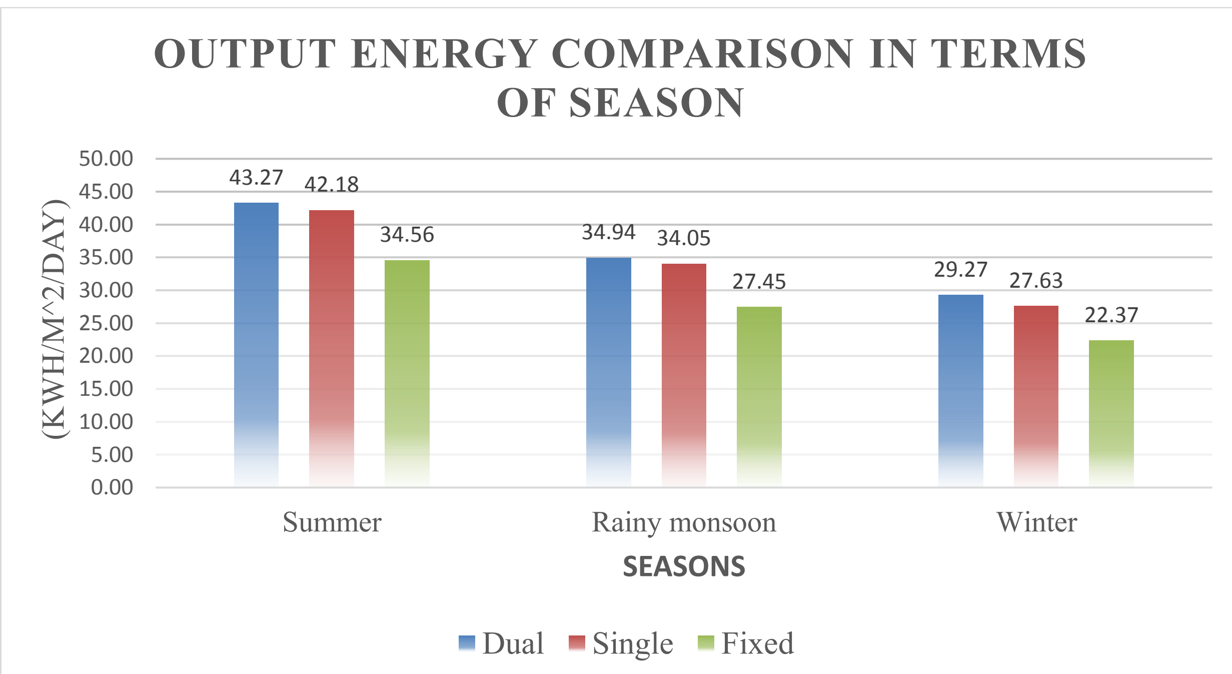

Figure: 3.5.3

Comparison of output energy for three different PV Panel systems (Fixed, single and dual axis) in terms of season.

The output energy comparison in terms of seasons is represented in this graph of Fig: 3.5.3. It is to be noted that, the output energy as per three different PV Panel systems has higher value during summer and the lowest during winter season. For example: the dual axis PV panel system's output energy is 43.27KWh/m^2/day during summer, whereas it is 34.94 KWh/m^2/day and 29.27 KWh/m^2/day during rainy season and winter season respectively.

Then again, in each season, the output energy as per three different PV Panel systems also varies. As in, the output energy value on the basis of dual axis and single axis PV Panel systems do not vary much, but there is a significant alteration of fixed axis PV Panel system's output energy value with the other two. For instance, the output energy value of single axis PV Panel system in summer is 42.18 KWh/m^2/day which is closer to dual axis's output energy value 43.27 KWh/m^2/day. On the contrary, the value is 34.56 KWh/m^2/day as per fixed axis PV Panel system, which is very less than the other two.

3.6 Comparison of Monthly Energy with Respect to Fixed Panel:

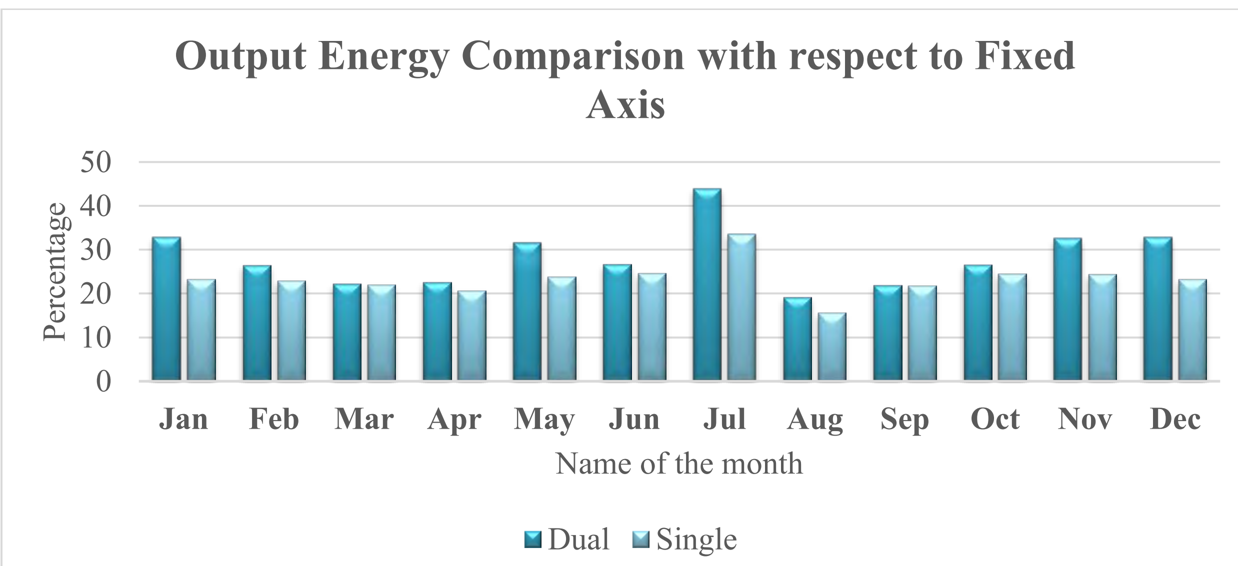

Figure: 3.6

Comparison of output energy of dual axis and single axis PV Panel system with respect to fixed axis for every month of a year.

This graph shows the difference between fixed axis with that of dual axis and single axis PV Panel systems. In comparison to output energy value of fixed axis PV panel system, the values as per dual axis and single axis PV panel are at an average range of 20% mostly. In our observation, we find, the difference between dual axis and single axis PV Panel's output energy values is very negligible during most of the months. In spite of having very close values, there are some months when there is a slight difference in their values.

3.7 Comparison of Yearly Energy with Respect to Fixed Panel:

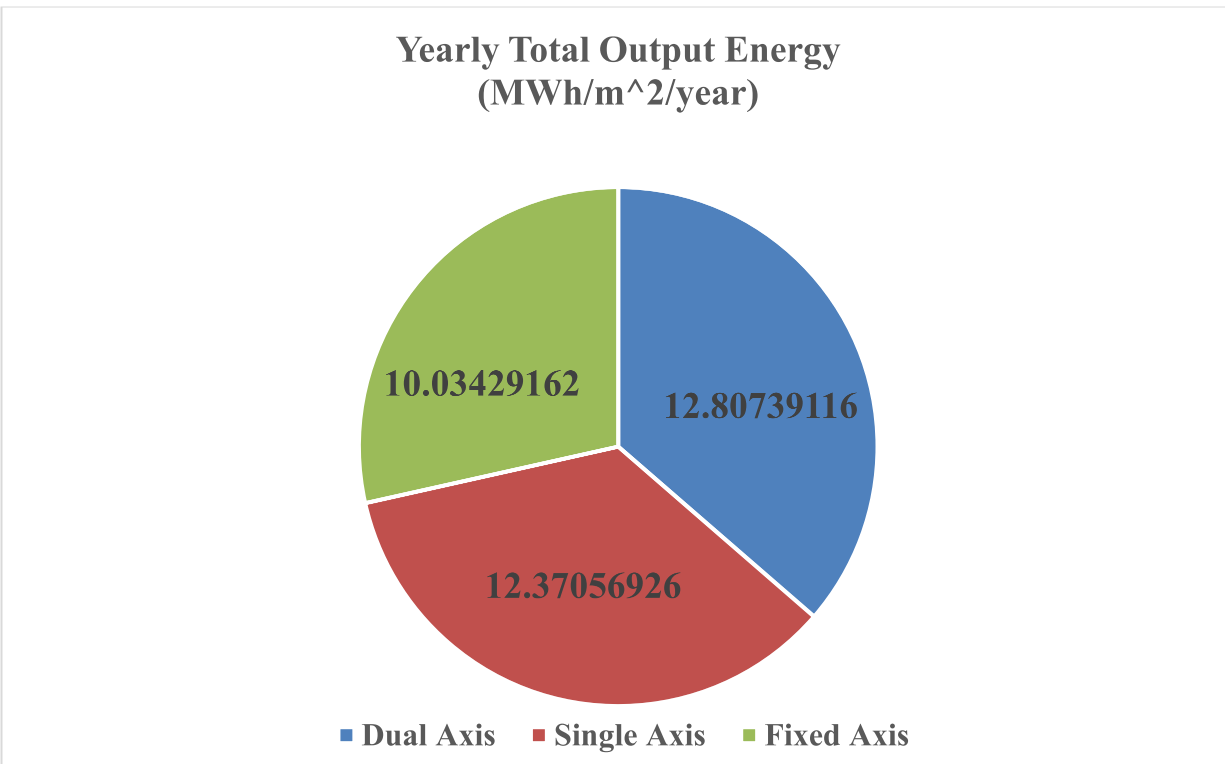

Figure: 3.7

Pie chart of yearly output energy of three different PV panel system (fixed axis, single axis and dual system)

Yearly Total Output Energy Difference with respect to fixed Axis	Percentage
Dual Axis	27.64%
Single axis	23.28%

At the end of the year, dual axis PV Panel system gives output energy value of 12.81 $MWh/m^2/day$ and single axis gives 12.37 $MWh/m^2/day$. But, output energy value is 10.034 $MWh/m^2/day$ under fixed axis PV Panel system which is significantly lesser than the other two axis PV Panels.

Chapter: 4

Constructive Discussion

4.1 Discussion:

Throughout the project, we have discussed about output power and total energy for three different systems which are fixed panel, single-axis and dual-axis sun tracking solar panel system. We have compared the output power and total energy for different months throughout the year for every single month. By comparing three different systems in different types of criteria, we have found that dual-axis sun tracking solar panel system is more efficient in terms of output power and generating total energy. The difference between single-axis sun tracking system and dual-axis sun tracking system is very close. Moreover, in several months the output power for these two different systems are almost equal. There is another most concerning fact which is cost effectiveness. In terms of this fact, single-axis sun tracker is more preferable. Dual-axis sun tracking system is most expensive than the single-axis sun tracking system. Since the precision and efficiency between these two is slight, so we can consider single-axis teacking system over dual-axis tracking system. By calculating total energy for a single year we have found that the total output energy for single-axis sun tracking system is 12.37 MW/m^2/year where the dual-axis sun tracking system's one is 12.80 MW/m^2/year. In short, though dual-axis sun tracker is most efficient but in terms of cost effectiveness single-axis is more preferable.

4.2 Factors that Affect Solar Power:

There are several factors that can affect the efficiency of different solar panel systems. Some of these factors have been studied to either increase or decrease the power production from the three types of solar panel system such as sun intensity, cloud cover, relative humidity, and heat buildup. When the sun is in its peak, during mid-day, the most solar energy is collected; therefore, there is an increase in the power output. Cloudy days contribute to the decrease in sunlight collection effectiveness since clouds reflect some of the sun's rays and limit the amount of sun absorption by the panels. Solar energy output is also affected by weather and seasonal variations. The angle of the sun to the solar panel changes with the time of day and seasonal variations. During summer days when the temperature is at its highest and heat is built up quickly, the solar power output is reduced by 10% to 25% for the reason that too much heat increases the conductivity of semiconductor making the charges balance and reducing the magnitude of the electric field. In addition, if humidity enters into the solar panel frame, this can reduce the panel's performance producing less amount of power and worse can permanently weaken the performance of the modules.

4.3 Future Work:

Commercially, dual-axis sun tracking system is still rare even in countries where a significant part of electricity is being generated by solar energy as they claim that single-axis sun tracking system is doing the job. But dual-axis sun tracking system can significantly increase the efficiency. So, there is a scope to improve the performance of single-axis sun tracking system from different aspects which will be more cost effective. In this project, we have worked on different sun angles and mainly the solar radiation for different systems. We have ignored different factors like humidity, sun intensity etc. So, here is a scope to improve it more and make it more accurate. The other most important fact is practical data of solar radiation what we have collected. Because a few number of data was missing in there. If we are able to collect more accurate data, the result would be more accurate.

4.4 Conclusion:

In conclusion, it can be said that the systems have no significant difference in between them while considering all the factors what affect the output power of solar panel. According to comparison, the electrical output is quite little of single-axis sun tracking solar panel system and has no significance over dual-axis sun tracking solar panel system's electrical output. In terms of cost effectiveness, single-axis sun tracking solar panel system is more preferable over dual-axis sun tracking solar panel system.

The values would have diverged more between dual and single axis if the location is different. But in terms of Bangladesh, the main fact is that the declination angles varies from month to month throughout the year is quite small. If the deviation of the angle is larger than the solar energy absorbed over the year would have been even much larger. In short, considering all the factors performance of three different systems are very close to each other though it varies in different regions. According to all the calculations, dual-axis sun tracking system is ahead of other systems but as a whole the performance of three different systems do not vary that much. In our this contribution we have tried to explain the comparison between three different solar panel systems in different criteria. Our contribution is not criticism of the previous works but merely a clarification. We wish to carry on our work from here and onwards.

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Appendix

Hourly Average Solar Radiation (Dual-Axis) Data for the year 2016 (Dhaka) :

Time	January	February	March	April	May	June	July	August	September	October	November	December
	KWh/m^2	KWh/m^2	KWh/m^2	KWh/m^2	KWh/m^2	KWh/m^2	KWh/m^2	KWh/m^2	KWh/m^2	KWh/m^2	KWh/m^2	KWh/m^2
5am to 6am	0.000	0.000	0.011	0.016	0.022	0.020	0.030	0.027	0.016	0.012	0.009	0.009
6am to 7am	0.020	0.036	0.061	0.086	0.115	0.108	0.104	0.107	0.086	0.093	0.087	0.028
7am to 8am	0.085	0.133	0.191	0.218	0.247	0.194	0.214	0.217	0.218	0.227	0.231	0.073
8am to 9am	0.182	0.274	0.309	0.365	0.373	0.290	0.312	0.358	0.365	0.335	0.341	0.195
9am to 10am	0.298	0.404	0.439	0.548	0.494	0.396	0.394	0.434	0.548	0.452	0.435	0.274
10am to 11am	0.365	0.508	0.570	0.627	0.532	0.414	0.425	0.508	0.627	0.555	0.574	0.388
11am to 12pm	0.403	0.549	0.657	0.701	0.605	0.455	0.468	0.580	0.701	0.533	0.523	0.413
12pm to 1pm	0.414	0.519	0.614	0.637	0.523	0.441	0.427	0.410	0.637	0.445	0.483	0.465
1pm to 2pm	0.350	0.455	0.559	0.543	0.494	0.392	0.322	0.389	0.543	0.356	0.396	0.380
2pm to 3pm	0.280	0.344	0.398	0.431	0.364	0.265	0.318	0.290	0.431	0.252	0.289	0.295
3pm to 4pm	0.146	0.210	0.262	0.279	0.240	0.209	0.237	0.239	0.279	0.127	0.178	0.178
4pm to 5pm	0.043	0.080	0.118	0.123	0.119	0.101	0.146	0.150	0.123	0.033	0.078	0.067
5pm to 6pm	0.011	0.011	0.021	0.021	0.031	0.030	0.041	0.039	0.021	0.011	0.028	0.018
6pm to 7pm	0.000	0.000	0.011	0.011	0.013	0.011	0.010	0.014	0.011	0.011	0.012	0.000