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A Comparative Analysis of the Performance of Flat and Inclined Monocrystalline Solar Panels

Anyiam T. Stephen[1], Onyema N. Hypolitus[1], Ozuomba U.Cornelius[2] , Emmanuel Anthony[1], Ewurum Ngozi B. B. [1], Ozoumba J.Okanandu[1]
[1]*(Department of Physics/ Imo State University, Owerri, Nigeria)*
[2]*(Department of Archirecture/ Caritas University, Amorji-Nike, Enugu, Nigeria)*

A photovoltaic (PV) panel, also called a solar panel, is a device that converts sunlight into electricity by means of the photovoltaic effect. The photovoltaic effect occurs when certain materials are exposed to light, generating an electric current that converts light energy into electrical energy and is an essential component of a solar energy system, responsible for harnessing the sun's renewable energy. This research investigates the impact of temperature on the performance of mono-crystalline solar panels. Two mono-crystalline Canadian solar panels were installed outdoors near the Auditorium of Imo State University Owerri, Nigeria. One of the solar panels was positioned at an angle, while the other was placed on a flat platform. The outdoor experiment was conducted to observe the real-time behavior of voltage, current, and power. The measurements were taken during the day time at one hour intervals. The corresponding values of temperature were also recorded. The outdoor experiment was carried out for eight non-consecutive days in the month of October 2023. The results of this study reveal a clear relationship between temperature and the electrical power generated by the photovoltaic panels. The flat panel generated an overall maximum power of 214 watts, while the slanting panel produced a maximum power of 159.9 watts. Overall, the flat panel exhibited better photovoltaic performance than the slanting panel.

***Key Words**: Solar Panel, PV, Mono-crystalline, voltage-current (I-V) characteristics, temperature.*

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I. Introduction

Renewable energy sources are considered clean, but their large-scale adoption is hindered by the high cost of generated energy and low utilization factors[1]. To address the country's energy crisis, the Nigerian government has adopted the Renewable Energy Master Plan (REMP). This plan aims to increase Nigeria's current generation capacity from 5,000 MW to 16,000 MW by 2015 through the exploration of renewable energy resources[2]. Photovoltaic (PV) systems consist of cells that generate power using light. Each cell contains layers of a semiconducting material. When light strikes the cell, it creates an electric field that travels between these layers, allowing electricity to flow through the cell. The amount of electrical power produced by each cell depends on the light's intensity. Solar cells, which utilize the photovoltaic effect to directly convert solar radiation into electrical energy, are the primary components of photovoltaic power systems. Silicon is one of the most crucial raw materials for manufacturing solar cells and is also used by the PV industry to produce poly-silicon.[4,5] Titanium dioxide is a common wide band gap semiconductor that is used in many applications including pigments, protective coatings and thin film optical devices such as photovoltaics[6]. A component of solar energy, silicon solar cells have prospective uses, particularly in the area of photovoltaic technology for power systems. Because crystalline silicon (c-Si) is primarily employed in the integrated circuit sector, it is the most developed and well-understood of the several photovoltaic (PV) technologies currently in use[7]. There is a generation of DC current during solar radiation. The PV efficiency is impacted by the panel's temperature. As the temperature rises, power output falls in relation to the 25°C STC (Standard Testing Condition). Temperature and variations in solar radiation cause adjustments to the parameters of solar photovoltaic panels. The performance of solar cells, namely their open-circuit voltage, is mostly influenced by temperature[8]. The Photovoltaic Geographic Information System (PVGIS) is a free online tool that is used to estimate the amount of solar electricity that can be produced by any photovoltaic (PV) system, at any location worldwide[9]. Time of day, location, latitude, elevation, and seasons all affect solar energy availability. The main determinants of solar energy availability, however, are cloud cover and other location- and time-specific industrial and meteorological elements and conditions. Photovoltaic solar panels are those that use solar radiation to produce direct current electricity. A wired, packaged arrangement of solar cells with different voltages and wattages is called a photovoltaic (PV) module. In most commercial PV devices, PV cells are connected in series to form a module in order to obtain the necessary working voltage. To provide the required power output, PV modules are then coupled in a series-parallel configuration[10]. One of the most significant environmental factors affecting solar panel performance is temperature. As solar panels absorb sunlight and convert it into electricity, they are exposed to varying temperatures, which can have a profound impact on their efficiency and output. Temperature influences the physical properties of the materials used in solar panels and affects the behavior of the photovoltaic cells within them.

Emerging as a viable renewable energy source, solar energy provides a sustainable and eco-friendly substitute for conventional fossil fuel-based power generation. Photovoltaic (PV) panels, also referred to as solar panels, are essential for utilizing solar energy as they transform sunlight into electrical power. However, the performance of solar panels is influenced by various environmental factors, with temperature being one of the most significant parameters affecting their efficiency and output.

When the solar module is not connected to any electrical load, the open circuit voltage (V_{OC}) is measured. A multi-meter with voltmeter capabilities and a high enough scale to read the open circuit voltage must be used to measure the voltage across the open terminals.

Temperature is a critical factor in determining the behavior of solar panels due to its direct impact on the physical properties of the materials used in their construction. As solar panels absorb sunlight, they convert the energy into electrical energy through the photovoltaic effect. The temperature dependence of solar panels is a complex phenomenon that affects their current-voltage (I-V) characteristics. These characteristics, including open-circuit voltage (V_{OC})), short-circuit current (I_{sc}), fill factor (FF), and maximum power point (MPP), determine the overall efficiency and power output of the solar panel. Therefore, understanding the impact of temperature variations on the I-V characteristics is crucial for accurately assessing the performance of solar panels in real-world conditions.

Photovoltaic (PV) parameters are key characteristics that describe the performance and behavior of a photovoltaic system or panel. These parameters provide valuable information about the electrical output, efficiency, and operating conditions of the PV system. This research explores how temperature affects the performance of mono-crystalline solar panels. Two mono-crystalline Canadian solar panels were installed outdoors near the Auditorium of Imo State University in Owerri, Nigeria. One panel was mounted at an angle, and the other was placed on a flat platform.

Here are some commonly used photovoltaic parameters:

i. **Open-Circuit Voltage (V_{OC}):** When the entire generated photocurrent passes through the internal diode, the voltage across it is known as the open circuit voltage (V_{OC}). The temperature has a significant impact on the open circuit voltage. This needs to be taken into account because solar cells placed outside can achieve temperatures up to 40 K above the surrounding air temperature, depending on the installation (such as ventilation options). V_{OC}, for an ideal p-n connection, can be expressed as

$$V_{oc} = \frac{KT}{q} ln$$

Where, K, is Boltzmann constant, T, is the temperature, q is the electronic charge, I_{ph} is the photocurrent, and I_s is the diode saturation current.

ii. **Short-Circuit Current (I_{sc}):** The temperature was shown to affect the short circuit current (I_{sc}).It is discovered that the short circuit current tends to decrease at high temperatures 7 after increasing with temperature and becoming saturated at a maximum value. I_{sc}, the ideal p-n junction, can be expressed as

$$I_{sc} = I_s \; [\exp\frac{q*V_{oc}}{KT} - 1] - I_{ph}$$

iii. **Maximum Power Point (MPP):** The operating point of a photovoltaic panel that optimizes its power output is known as the maximum power point. The electrical properties of the panel are represented by the intersection of the current-voltage (I-V) curve.

iv. **Maximum Power Point Voltage (V_{mpp}):** The voltage at which a photovoltaic panel produces its highest production of power is known as the maximum power point voltage.

v. **Maximum Power Point Current (I_{mpp}):** The current at which a photovoltaic panel produces its highest production of power is known as the maximum power point current.

vi. **Fill Factor (FF):** A PV panel's quality is indicated by a parameter called fill factor, which is calculated by multiplying the maximum power output by the product of the open-circuit voltage and short-circuit current. It can be computed as the ratio between the product of $V_{OC}$and I_{sc} and the greatest power point.

$$\text{Fill factor} = \frac{V_{mpp} \times I_{mpp}}{V_{oc} \times I_{sc}}$$

vii. **Efficiency:** The efficiency with which a photovoltaic panel transforms sunlight into useable power is known as its efficiency. It is calculated as the ratio of the panel's maximum power output to its incident solar power.

$$\eta(\%) = \frac{V_{OC} * I_{SC} * FF}{Pin}$$

Where Pin is the power input

viii. **Temperature Coefficient:** PV panels are temperature-sensitive, and the rate at which the electrical property of the panel (V_{OC},I_{sc},V_{MPP}, etc.) change with temperature is indicated by the temperature coefficient.

ix. **Operating Voltage and Current:** These parameters represent the voltage and current at which the PV panel is operating under specific load conditions.

The Photovoltaic performance of solar panels is affected by temperature and some other environmental factors. Tilt angle and cardinal positioning are among the factors affecting the performance of a PV panel. This study will surely be a guide to solar panel installers.

II. Material And Methods

The two solar panels (Canadian solar panels), thread (Rope), thermometer (glass-filled mercury thermometer), meter rule, analog ammeter, and analog voltmeter, solar panel stand, and stopper (Mounting Structure) make up the experiment's setup. In addition to using an Android phone compass to display the direction to the geographical cardinal points, an analog voltmeter and analog ammeter were utilized to measure the voltage and current outputs from the panel. This can be seen in Figure 1. The outdoor experiment was conducted in the month of October 2023 for eight (8) non-consecutive days between 9:00 to 4:00pm. The PV solar panels were exposed to sun light and taken the readings of open circuit voltage (V_{oc}), short circuit current (I_{sc}) and temperature also was recorded. The experiments were repeated for every hour up to 4:00PM. Angle of inclination used for the second panel (slanting panel) through-out the experiment is 64.32 degree. All the readings were noted. The Region covered in Imo State University is Imo state university auditorium opposite Physics department lab popularly known as old physics lab (latitude 5.50661 N5^0 30’23.79” & longitude 7.0458 E7^0 2’44.868”).

Table 1.300 watt mono-crystalline solar panel specification

1	Maximum Power/P_{max} (w)	300 W
2	Maximum Power Tolerance	+ 3%
3	Open Circuit Voltage (V_{OC})	40.7V
4	Short Circuit Current (I_{SC})	9.83A
5	Max Power Voltage	36
6	Max Power Current	8.35
7	Weight (kg)	20.5
8	Dimensions (mm)	1000
9	Maximum System Voltage	1000 V
10	Maximum Series Fuse Rating (A)	15A
11	Application Class	CLASS A
12	Fire Rating	CLASS A

Figure 1. Diagram of a PV Panels mounted on appropriate site.

III. Results and Discussion

The results of this investigation on average power per day is tabulated in Table 2. Based on the data presented in the table, the average power output in watts can be observed. It is evident that the generated power varies with changes in ambient temperature. This relationship underscores the impact of temperature on the efficiency and performance of the solar panels. Figure 2 shows a broader range of power variation observed, ranging between 180 watts and 170 watts, with power remaining nearly constant between 30°C and 31.5°C. At around 2:00 pm, the temperature peaked, leading to an increase in power output. Panel B, which is slanted, received more sunlight around 4:00 pm compared to Panel A, which is horizontal and facing the sky.

Table 2. Average Power for Each Day

DAYS	$P_{AvgF}(WATT)$**For Flat Panel**	$P_{Avg}(WATT)$**For Slanting Panel**	**Average Temperature (^{0}C)**
Day one	87.36	57.61	31.00
Day two	108.25	74.74	32.06
Day three	100.00	57.70	32.00
Day Four	100.34	57.81	31.06
Day Five	79.61	51.19	31.06
Day Six	74.40	46.52	30.75
Day seven	86.18	58.78	31.38
Day eight	83.80	54.21	30.75

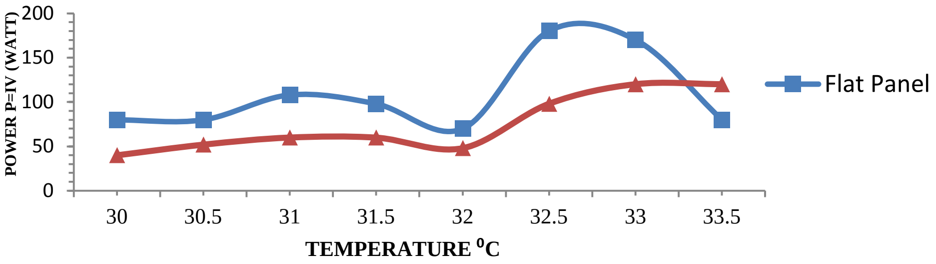

Figure 2.*Variation of Power against Temperature of the Solar Panel for Day Two*

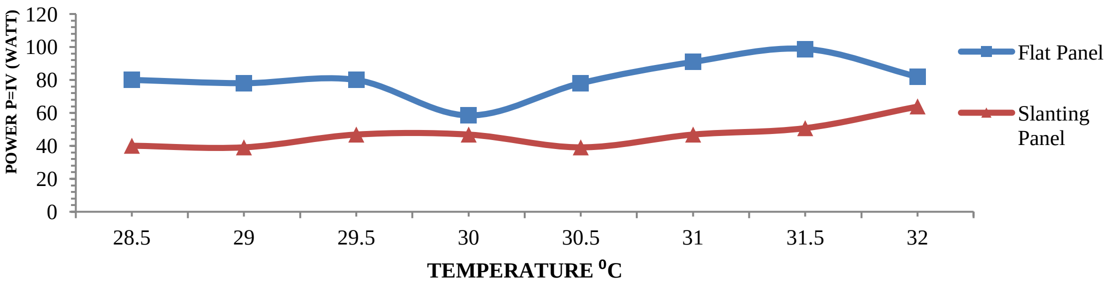

Figure 3.*Variation of Power against Temperature of the Solar Panel for Day Six*

It was overcast today. It has been noted that cloudy weather lowers the solar panel's ability to measure sunlight intensity, which lowers power output. The graph indicates that when the temperature rises or falls, the power produced changes.

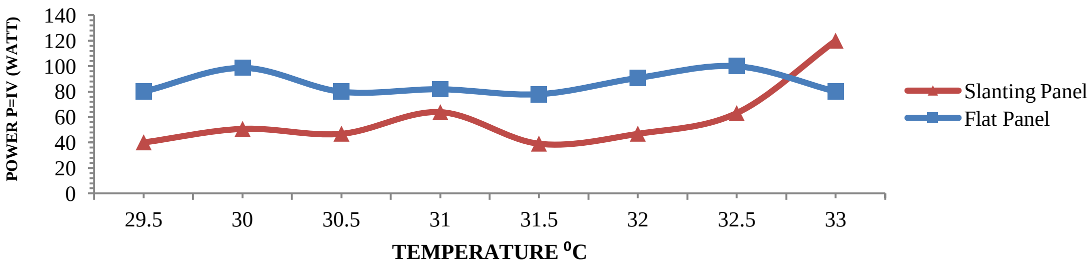

Figure 8. Variation of Power against Temperature of the Solar Panel For Day Seven

It was noted that the temperature and sunshine levels were both high at 33 degrees Celsius. Because panel B (the slanting PV panel), got more sunlight, it was able to produce more power than panel A, the horizontally facing PV panel. Between 12:00 and 1:00 pm, there was a power outage from maximum to minimum, and the electricity then fluctuated with the temperature.

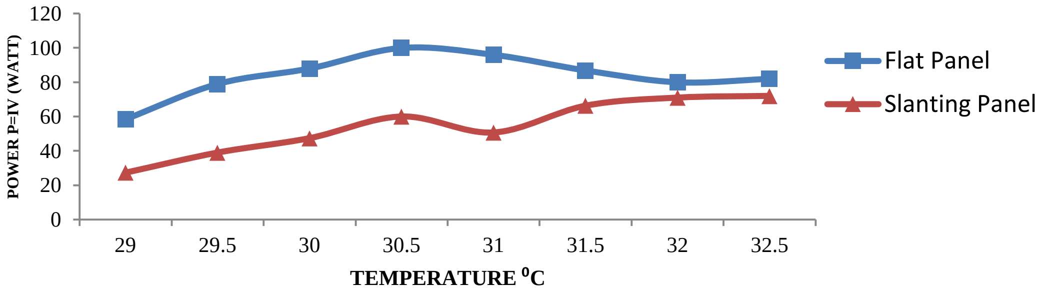

Figure 9.*Variation of Power against Temperature of the Solar Panel for Day Eight*

The entire day was overcast with little to no sunshine. In contrast to previous days, not much power was generated. It has been noted that cloudy weather lowers the amount of sunshine that reaches the solar panel, which lowers power output. To put it another way, clouds serve as a barrier that scatters and absorbs sunlight, lowering irradiance—the quantity of solar energy that hits a surface.

IV. Conclusion

A comparative analysis of the performance of flat and inclined mono-crystalline solar panel was successfully demonstrated in this research work. The experimental setup was located at Imo state university, Owerri Nigeria, with two solar panels, one positioned at 0 degree and the other placed in a slanting position of 64.32^0 . From the experiment, we found out that as the temperature rises, the current output of the panels increases while the voltage output remains relatively stable. This behavior can be attributed to several temperature-dependent factors. Generally, when the temperature of the day is high, the electrical power generated is high. It was also observed that the solar panel position at 0^0 performed better than the slanting panel. Solar electricity installer are advised to place the solar panel at a flat or nearly flat position for better performance. However, further studies can be conducted for other regions as the result of this experiment may be applicable to Imo State and may differ for other region in Nigeria, as well as world at large.

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