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Evaluation of solar panel for improved performances

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ABSTRACT

Solar energy is an energy source that uses the sun energy to produce electricity. Solar panel are technologies used to harness the sun's energy for electricity production. Mono-crystalline and poly-crystalline are the most commercially used technology. The objective of this paper is to perform solar panel operation assessment for improved performance. Simulation was done on a solar panel simulation software called PSIM to observe the behavior of voltage, current and power. Outdoor experiment was also done to observe the behavior of voltage, current and power in real time. The outdoor experiment was conducted for three months. Tilt angle and panel orientation were investigated. Solar panel was placed facing North, South, East, West cardinal point. The tilt angle was varied between 0° to 90° with an increment of 5°. Tilt angle of 15° was observed to produce the highest average power output for the cardinal positions. It produced 40.80W facing north, 54.45W facing south, 47.13W facing east and 48.43W facing west cardinal position.

Keywords: Solar Panel, PV, Monocrystalline, Polycrystalline, Tilt Angle, Orientation, cardinal point

1. INTRODUCTION

The availability of solar energy is influenced by location, latitude, elevation, seasons and time of the day. However, the largest factors affecting the availability of solar energy are cloud cover, and other industrial and meteorological parameters and conditions which vary with location and time. Solar panels that absorbs energy from the sun to yield direct current electricity are known as photovoltaics. A photovoltaic (PV) module is a wired, packaged assembly of photovoltaic solar cells that come with various voltages and wattages. To get the adequate working voltage, PV cells are normally linked in series to form a module in majority of commercial PV products. PV modules are then connected in a series-parallel configuration to obtain the desired power output [1]. A solar panel is made up of 6x10 solar cells in most cases. Depending on the form and quality of solar cells employed, the efficiency and wattage production can vary. A solar module's energy output can vary from 100 to 365W of Direct Current electricity. The higher the wattage output, the more energy per solar module is generated [1].

The effectiveness of an outdoor PV module's is resolute by a variation of factors. Some of these issues are caused by the module itself, while others are caused by the place and surroundings. Solar irradiance, tilt-angle, shading, module temperature, fill-factor, material degradation, soiling, PID, parasitic resistances, and other major factors are just a few of them. Solar PV systems producers usually guarantee the modules efficiency for about 25 years. The initial years of the panel life, solar PV panels normally degrade at a faster rate. Solar panels' rated power output degrades at a rate of about 0.5% per year. Materials of low quality or production defects. Module failures and output losses are most often the result of gradual accumulated damages caused by long-term outdoor exposure in harsh environments [2]. PV module output can vary greatly depending on light conditions, which has a large outcome on PV device yield. Many of the parameters of a PV module are affected by changes in the strength of solar radiation falling on it including I_{sc}, V_{oc}, power, Fill Factor and efficiency. The PV cell temperature, just as other semiconductor device, is tremendously sensitive. A PV cell's efficiency and power output decrease as its temperature rises. This is because of increased internal carrier recombination rates as a result of higher carrier concentrations. PV module temperature rises as temperature of air and solar radiation rises, but falls as wind speed rises. The temperature of a PV module can reach 60°C to 65°C about noontime during summer when the irradiance is very high.

The performance of solar panel is affected by variations in output performance due to the effect of tilt angle and cardinal positioning. This study will serve as a guide to solar panel installers taking into consideration the tilt angle and cardinal positioning when installing solar.

2. REVIEW OF RELATED RESEARCHES

Incident angle is the angle between the radiation falling on the surface directly and the normal of that surface. Tilt angle is the angle between the panels and the horizontal plane [3].

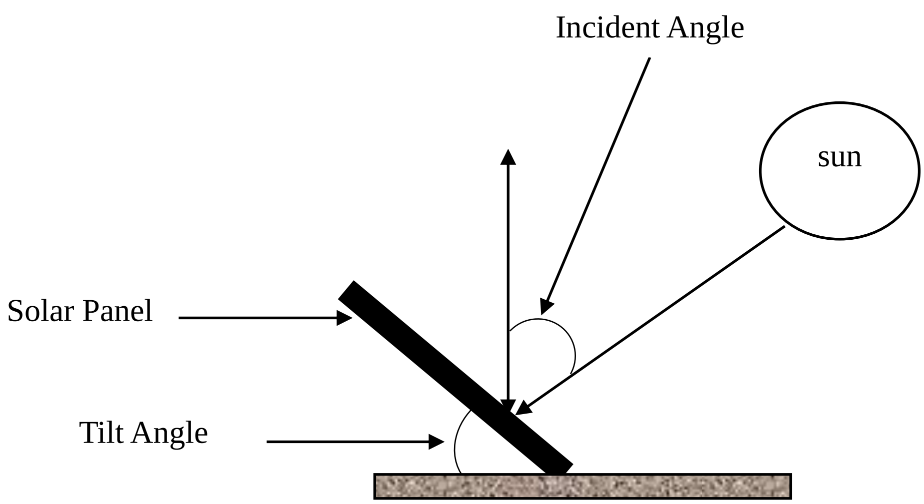

Fig 1.Tilt Angle

The best angle for any photovoltaic array, according to Mondoc and Pop [4], is the one that generates the highest annual energy production for that specific location. This is the angle between the horizontal plane and the solar panel that can be set or modified to maximize seasonal or annual energy collection. The angle of incident of sunrays to the panel cannot be calculated since the sun path is east to west, As a result, the angle of tilt of the panel to the horizontal plane must be changed to achieve the best incident angle of the sun on the panel, resulting in the panel's best results.

Dauta et al [5] aimed at determining the electrical characteristics of solar irradiance and solar energy, as well as their relationships to PV module performance. They analyzed the solar radiation and solar energy in Perlis, Malaysia's northernmost state. According to their findings, the power output of a PV array is shaped by a diversity of environmental agents, including solar irradiance. In order to calculate the amount of energy absorb by the PV cell, the value of solar irradiation G(t) must be known.

Applying the open circuit condition, $I = 0$, to the I (V) equation is given in

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$$I = I_{sc} - I_0(e^{\frac{V_{oc}}{V_t}} - 1) \quad (2.1)$$

The open circuit voltage is given by:

$$V_{oc} = V_t \ln(1 + \frac{I_{sc}}{I_0}) \quad (2.2)$$

The total energy, Ec, of PV cell is thus

$$E_c = \rho\alpha\tau G(t) \quad (2.3)$$

The solar cell will transform the insolation it absorbs into electrical energy, E_{ce} and the equations is given below;

$$E_{ce} = \eta\rho\tau G(t) \quad (2.4)$$

Where;

G(t) is the monthly average value of solar irradiance.
ρ is the cell packing factor.
τ is a fraction transmitted through the front glass.
η is cell efficiency.

A daily data set was obtained and analyzed from a weather station, and it shows that solar irradiance and solar energy have a direct proportional relationship.

Ajao et al [6] conducted an outdoor experiment to determine the best tilt angle for solar pv panel in Ilorin, Nigeria. The experiment was done for 10 days and the solar panel was tilted between 0° to 30° at an increment of 2°. The tilt angle the solar panel produced maximum average power output of 38.02W was 22°, according to the results of the experiment. As a result, the power produced by a solar panel is determined by the angle at which it is inclined, the weather conditions, and the solar panel's orientation. Improper solar panel orientation will ultimately result in power loss and a poor gain on investment. Solar panels should be kept at the best tilt angle for highest energy gain, and seasonal alteration of the panel can result in a significant increase in solar energy power.

Mohammad H. [7] gave a simple numerical model for optimizing solar panel tilt angle for a given panel azimuth angle, which is based on a spreadsheet. His method is based on the ASHRAE solar irradiation model, which is a systematic model for measuring solar irradiation based on direct, reflected, diffuse, and dispersed components. The tilt angle to generate optimal annual solar irradiation per square area of panel is then calculated. The result shows that at tilt angle 45° the maximum annual solar radiation is observed.

Hussein et al [8] conducted an experiment to assess the competence of photovoltaic modules at several tilt angles and directions. A computer Fortran program based on the study and linked to the TRNSYS simulation program was used to forecast annual results. From their work, the best tilt angle and orientation for PV modules in Cairo (Egypt) are 20° to 30° and south facing. Furthermore, with a constant change from the south, the annual extreme output energy of PV modules at a constant surface tilt angle shifted westward is more than that of PV modules shifted eastward.

By analyzing solar radiation data assessed from hours of sunshine and ambient temperature to foresee PV energy production at the site, Udoakah [9] hope to determine the optimal tilt angle for maximum solar insolation for pv systems in Enugu. The greatest tilt angle for PV energy output is 6° if the module is set, but if changed monthly, the best tilt angles for each month are 30°, 24°, and 6° for (January to March), 0° for (April to September), 18°, 30°, and 36° for (October to December). The energy gotten was found to be 192.70 W/m^2 when the tilt angle of the module is changed monthly to its finest tilt. As compared to the 186.86 W/m^2 gotten when the tilt angle was set, this value represents a 3% rise.

3. MATERIAL AND METHOD

The outdoor experiment was conducted between October to December 2019. Two regions were covered in Uyo city are Ikpa (latitude 5.04°N & longitude 7.92°E) and Nwaniba (latitude 5.02°N & longitude 7.93°E) in Uyo city. The ravine in the north-eastern is the most prominent characteristic of the city's physical landscape. Small perennial streams run through the ravine. These are outlets of the river ikpa, the largest watercourse in the city's vicinity. Since Uyo is sited in the Niger Delta, it has a damp climate with plenty of rain, hot temperatures, and relatively high humidity. [10].

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Fig 2. Ikpa Location

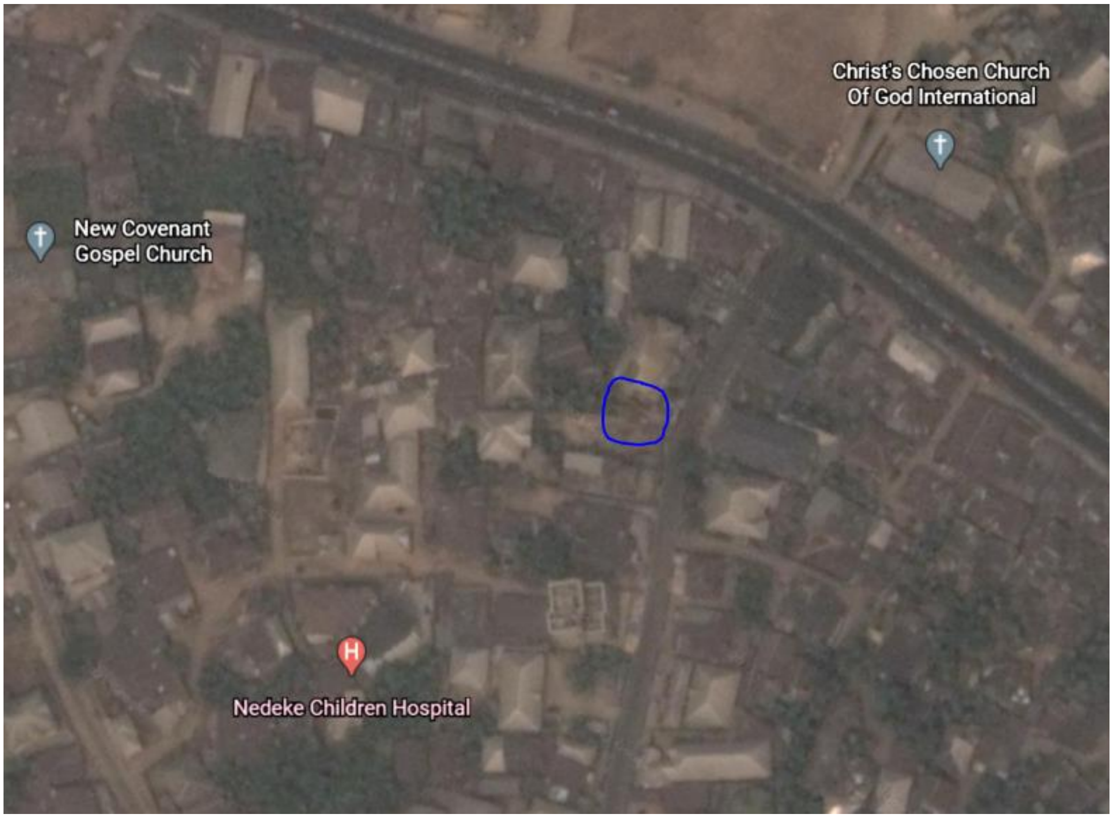

Fig 3. Nwaniba Location

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3.1. Experimental Setup

The setup for the experiment consisted of monocrystalline solar panel, compass, DT-830D digital multimeter.

Fig 4. DT-830D Digital Multimeter and Compass Reader

Table 1. Solar Panel Specifications

PRIME SOLAR: PS-SP-160			
Rated Max Power	160W	Open Circuit Voltage	21.8V
Rated Voltage	18.4V	Short Circuit Current	9.35A
Rated Current	8.70A	Max System Voltage	1000V
Max Series Fuse	15A	STC Am 1.5, 1000W/m^2	

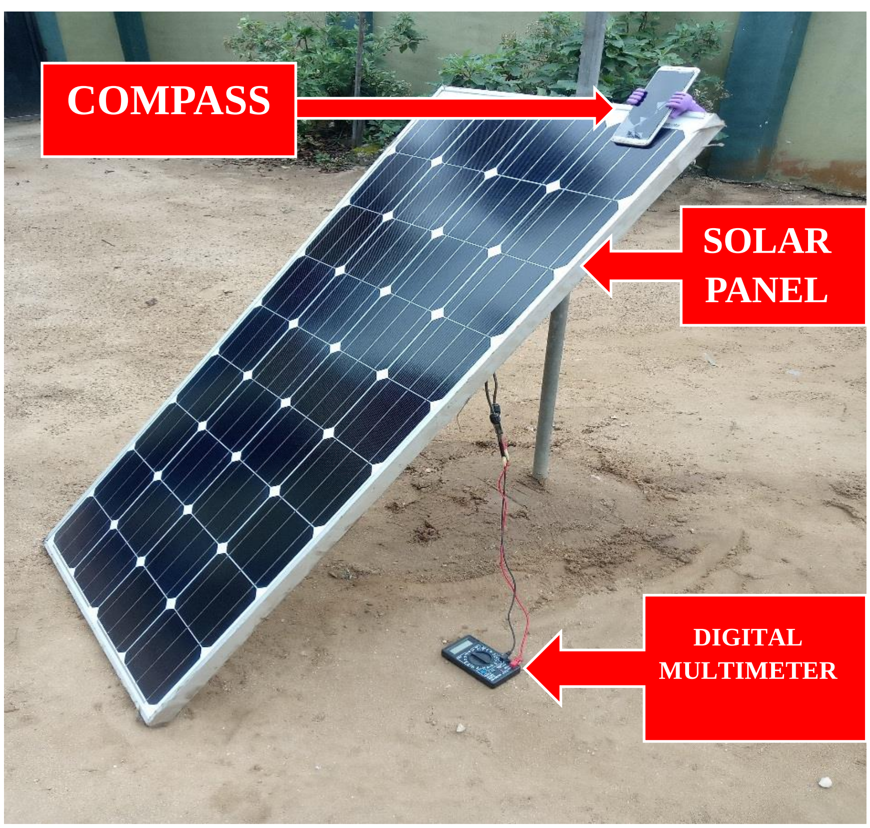

Fig 5. Experimental Setup

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It was setup using a 160W rated solar panel, a digital multimeter to measure voltage and current outputs from the panel, compass used to show the direction to the geographical cardinal points. The solar panel was mounted in an open space and in such a way that it can be tilted from 0° to 90° to the horizontal. A digital multimeter was connected to the outputs wires from the panel which measures the output voltage (V_{oc}) and current (I_{sc}), digital clock was used for timing the measurements (hourly). The solar panel was first mounted at 0° to the horizontal facing North and the readings were taken for voltage and current and then adjusted in an increment of 5° till it gets to 90° and all readings for the different tilt angles were recorded. The same procedure was repeated for South, East and West geographical cardinal positions. The measurements for each geographical cardinal position and tilt angles was done at an hourly interval (from 7:00AM to 6:00PM). Data measured was analyzed and used to establish the most efficient tilt angle and geographical cardinal position of solar panel in Uyo city for efficient performance.

Fig 7. Solar Panel At 0°, 45°, 90° Tilt Angle

Simulation of the solar panel was done on PSIM software to observe the current, voltage and power characteristics of the panel.

3.2. Solar Panel Parameters

Standard Testing Condition (STC)

This is a lab setting in which solar PV panels are checked to evaluate module performance, or the quantity of the available solar energy that can be transmuted into electricity. STC is an industry standard that specifies the performance of PV modules using a cell temperature of 25°C and an irradiance of 1000 W/m^2 with an air mass 1.5 (AM 1.5) set.

Fill Factor

The fill-factor of a PV cell is the ratio of the maximum power to the product of I_{sc} and V_{oc}.

$$Fill\ Factor = \frac{V_{mpp} \times I_{mpp}}{V_{oc} \times I_{sc}} \quad (3.1)$$

Open Circuit Voltage (V_{oc})

The open circuit voltage for a solar panel is the voltage it generates when no load is connected to it. You can read V_{oc} by simply measuring with a voltmeter. There is no load on the solar panel because it is not attached to anything, and it produces no current.

$$V_{oc} = V_t \ln \frac{I_{ph}}{I_{sat}} \quad (3.2)$$

Where Vt = thermal voltage

$$V_t = \frac{nKT}{q} \quad (3.3)$$

Short Circuit Current (I_{sc})

Short circuit current of panels is when the panels are not attached to a load but the plus and minus wires of the panels are connected, current is the number of amps (i.e. current) they produce. You can measure Isc by simply using an ammeter. Under normal test conditions, this is the maximum current that the solar panels can generate.

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$$I_{sc} = I_{ph} \quad (3.4)$$

Maximum Power Point Voltage (V_{mpp})

The V_{mpp} is the voltage at which the optimum power output is reached when connected to MPPT solar equipment under normal test conditions.

Maximum Power Point Current (I_{mpp})

When the power output is at its peak, the I_{mpp} is the current (amps) when connected to MPPT solar equipment under normal test conditions.

3.3. Performance Parameter

Vishakha B. [14] highlights the following performance parameters;

- ***Total Energy Generated*:** is the total energy (Wh) generated by the module in a day while charging and is represented by:

$$E = \sum E_t \quad (3.5)$$

Where Et is energy generated in each hour t= time (1 to 7).

- ***Efficiency*:** is the ratio of output energy to the input power.

$$Efficiency(\%) = \frac{Output\ Energy(W_h)}{Insolation \times Area} \times 100 \quad (3.6)$$

- ***Solar Operational Efficiency***: Is the ratio of practical output to the rated output of the module.

$$Solar\ Operational\ Efficiency\ (\%) = \frac{Output\ Power(Wh)}{Rated\ Power(Wh)} \times 100 \quad (3.8)$$

4. RESULT AND DISCUSSION

4.1. Tilt Angle Determination

From the data gotten from the experiments, the average power from 7:00am to 6:00pm tilt angles with corresponding time for south cardinal point which has been established to be the best cardinal position for optimum performance based on the outdoor experiment is given below.

Table 2. Average Power and Tilt Angle

TILT ANGLE (°)	0	5	10	15	20	25	30	35	40	45	50
AVERAGE POWER(W)	49.86	50.70	51.99	54.45	53.77	53.50	53.17	51.64	50.28	49.39	47.37

TILT ANGLE (°)	55	60	65	70	75	80	85	90
AVERAGE POWER(W)	44.50	42.45	39.63	35.09	32.61	29.48	26.65	24.09

From table 2, the lowest average power was 24.09W at tilt angle of 90° and the highest was obtained and the highest average power was obtained at 15° with 54.45W.

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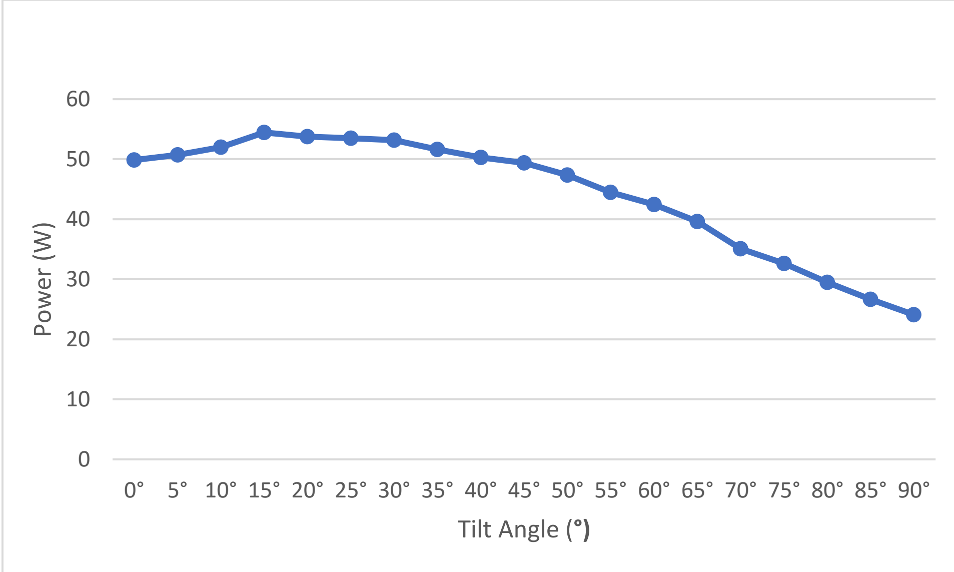

Fig 8. A Graph of Average Power Against Tilt Angles

Figure 9, there is a rise in average power from 0° to 15° and then it drops till it gets to 90° tilt angle. The maximum power of 54.45W is observed at an angle of 15° while the lowest was 90° which produced 24.09W. It can therefore be concluded that 15° is the tilt angle with the most efficient performance.

4.2. Cardinal Positioning/ Direction

From result obtained, the tilt angle of 15° been established as the best tilt angle, it is thus used to determine the cardinal position with the most efficient performance of the solar panel.

Table 3. Cardinal Direction Average Power Values with Time

TIME (AM/PM)	NORTH (W)	SOUTH (W)	EAST (W)	WEST (W)
7:00	0.91	1.72	1.75	0.75
8:00	7.48	10.20	10.36	6.58
9:00	26.18	36.10	41.81	29.14
10:00	50.80	72.62	74.62	43.20
11:00	66.58	94.80	91.84	72.47
12:00	93.63	115.91	104.43	95.54
1:00	97.60	115.50	101.20	108.07
2:00	82.78	102.31	78.60	101.97
3:00	36.83	68.47	34.32	71.15
4:00	20.26	26.32	16.04	40.59
5:00	4.62	5.61	3.65	7.32
6:00	0.17	4.20	0.08	4.41
AVERAGE (W)	**40.80**	**54.48**	**47.13**	**48.43**

From table 3, from 7:00am to 1:00pm there is an observable rise in average power and from 2:00pm to 6:00pm there is a drop in average power for all cardinal positions. For north position, the lowest power reading of 0.17W at 6:00pm and highest power reading of 97.60 at 1:00pm, for south position, the lowest power reading of 1.72W at 7:00am and highest power reading of 115.91W at 12:00pm, for east position, the lowest power reading of 0.08W at 6:00pm and highest power reading of 104.43W at 12:00pm, for west position, the lowest power reading of 0.75W at 7:00am and highest power reading of 108.07W at 1:00pm. The north position has an average power of 40.80W, 54.48W for south position, 47.13W for east cardinal position and 48.43W for west cardinal position. Since the solar panel is to be fixed in a particular direction and not moved with change in the sun direction as the sun travels from

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the east to west path, the south cardinal position is the best cardinal position/direction for the solar panel to be placed for the efficient performance.

4.3. Simulation Result

Simulation Of Panel on PSIMT Software

The simulation of the "prime solar" solar panel was done on PSIM software.

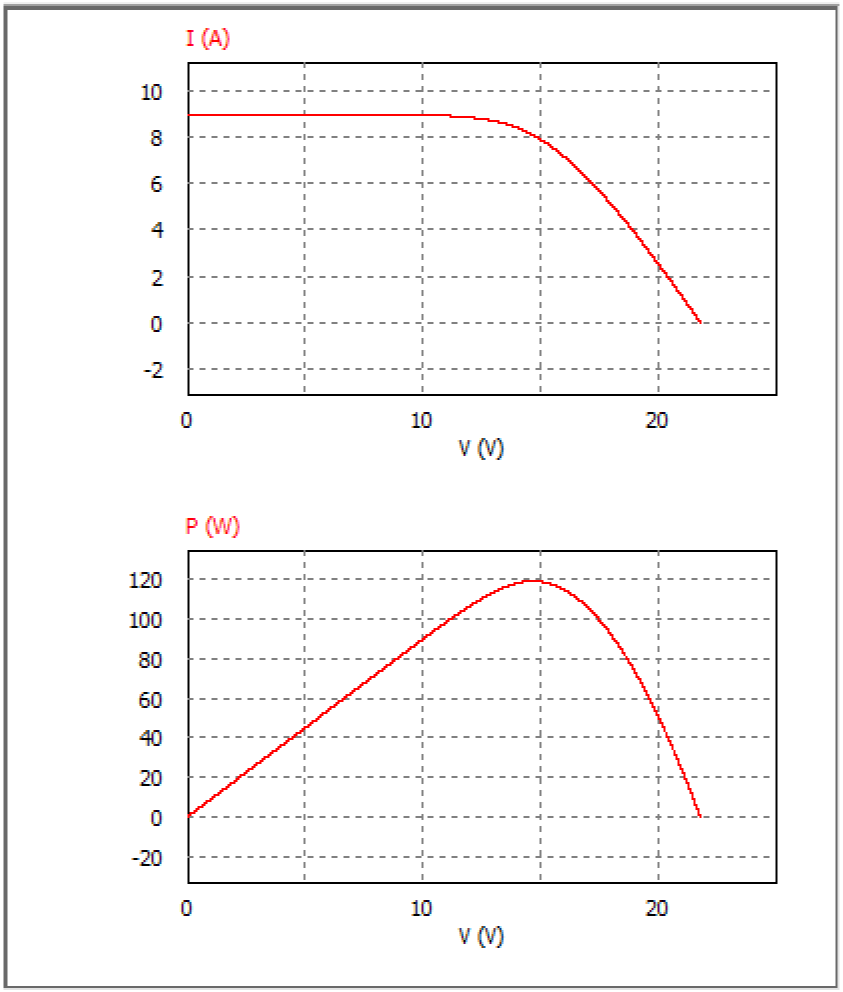

Fig 10 I-V and P-V Characteristics of Solar Panel

From figure 10, the i-v and p-v curve shows the relationship between the current, voltage and power. The i-v curve shows that current values takes a steady reading until it attends peak and then drops to 0A, while the p-v curve shows that the power rise from 0W until it gets to the peak and then drops to 0W. From the software, the simulation peak values of the panel are 8.40A for peak current, 14.70V for peak voltage and 119.23W for peak power (MPP). The peak values of the solar panel at outdoor experiments was observed to be 5.71A for peak current, 20.3V for peak voltage and 115.91W for peak power value (MPP). The MPP values for simulation was 119.23W and outdoor experiment was 115.91W which is close and shows the simulation result and outdoor experiment are in order.

5. CONCLUSION

Outdoor experiment was performed on solar panel to investigate the efficient performance of the panel using Uyo, Akwa Ibom, Nigeria. Tilt angle is the angle of solar panel to the horizontal surface and the results of the experiment shows that at 15° of tilt angle facing South cardinal position, the maximum average power was obtained to be 54.48W compared to the North, East and West values of 40.80W, 47.13W, 48.43W thus making the tilt angle and south cardinal position the best for solar panel installation in Uyo . Therefore, from the study it is seen that for solar panels to perform efficiently at its peak, it has to be kept in the right tilt angle and cardinal position. This work is applicable to Uyo city in Akwa Ibom state, Nigeria for solar panel installation for efficient

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performance. However, further studies can be conducted for other regions as the result of this outdoor experiment may be applicable to Uyo and may differ for other region in Nigeria, as well as the world at large.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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