Performance Efficiency of a Silicon Based Photovoltaic Cell Operating under Ambient Conditions in Benue State, Nigeria

[1*]Ikyo, B.A. [1]Sunday, D. [1x]Lyam, M.S. [1]Itodo, A.
[1]Department of Physics,
Benue State University Makurdi.
[x]Now with Martin Luther University Halle-Wittenburg Photovoltaics Group, Halle. Germany.

*Corresponding Author:aikyo@bsum.edu.ng

Abstract

The use of photovoltaic cells (solar cells) for generation of electricity is no longer uncommon in Nigeria; this is because solar energy is undoubtedly part of the solution to the problem of dwindling fossil-fuel reserves. Various technologies of photovoltaic systems are imported from different countries and are being used locally with little or no information of their appraisal and field performance. In this work the performance efficiency of a silicon based solar panel operating under ambient conditions has been determined in an experiment using an off the shelf PV module. Measurements were taken while varying the direction of the panel, the tilt angle and illuminance during the day. Results show that PV installations within Benue State and most areas within the north-Central geopolitical region will perform optimally when installed at 15^0 in the direction of the south. Apart from outlining the efficiency limiting factors, this work also provides an efficiency chart with data that can be used for solar installation.

Key word: Silicon Solar Cell, SolarIlluminance, Efficiency, Solar power,

Introduction

For decades now in Nigeria, power supply has been very epileptic, amidst several efforts by both government and investors to address the issue. The electrical energy problems in Nigeria range from inefficient and obsolete power generating plants and inadequate gas supply to the generating plants, poor maintenance culture and sabotage of pipelines. All these have resulted into inadequate power supply and low power quality which has led to the extensive substitution of poor public electricity supply with generating plants.

The energy problem has also been traced to other issues such as bad metering and lack of energy efficiency and conservation habits in Nigeria. These, couple with the enormous advantages of clean renewable energy sources has made the use of photovoltaic (PV) cells in private and public power generation within and outside Nigeria. Solar photovoltaic system and wind system have gained acceptance although their high prices pose a serious barrier to the middle and lower class.

Nigeria lies within a high sunshine belt, as such, has enormous solar energy potentials. The maximum solar radiation power reaching Nigeria's land surface (area; 924,000 km^2) is about 600MW per square kilometers (Abdulkarim, 2004). Given the prevailing efficiencies of commercial solar generators, if solar collectors or modules are installed on one-percent of Nigeria land area, it will be possible to generate 1850 Tera-Watt-hour (*TWh*) of solar electricity per year which is over one hundred times the current grid electricity consumption level in the country (Ajao, Oladosu, & Popoola, 2011).

Solar electricity from photovoltaic (PV) technology is achieved, by converting solar energy from sunlight (photons) into photoelectrons (electricity). PV devices (solar cells) are unique as they directly convert the incident solar radiation into electricity, with no noise, pollution or moving parts, making them robust, reliable and long lasting (Martí *et al.,* 2006). The power produced by a single cell is often not enough for commercial use, so cells are connected to form modules which are also connected to form array to supply a load in series (to get an increased voltage) or parallel (to get an increased current)(Martí *et al.,* 2006).

The performance efficiency of a photovoltaic cell depends on factors such as the type and quality of the material it is made of wafer preparation processes, carrier leakages and other optical losses (Esram & Chapman, 2007). Other factors that can affect the efficiency of the PV cell includes; the panel orientation, reflection of radiation, shading of the panel, the operating temperature the solar cell is subjected to, accumulation of dirt on the solar cells etc. There is ongoing research on the improvement of solar cell efficiency so as to obtain more power from the sun and to improve its quantum efficiency (Blankenship *et al*., 2011). One advantage of improved solar cell efficiency is that less space will be required to achieve the same power output especially in a situation where space is a constraint (Green, Emery, Hishikawa, Warta, & Dunlop, 2015).

The performance of a solar cell is estimated by the current density-voltage (J-V) characteristic, where active cell parameters such as short circuit current density (J_{sc}), open circuit voltage (V_{oc}), maximum current and voltage (J_{max}& V_{max}), can be measured. Once these parameters are measured, the cell maximum power, the fill factor (*FF*) and efficiency (η) can be calculated. Manufacturers report photovoltaic module poweroutput at *Standard Test Condition*s (STC) which correspond to solar irradiation of $1000Wm^{-2}$, temperature of 25^0C, Air Mass 1.5 and normal incidence. In real operating conditions however, the modules output is strongly affected by various environmental conditions. Consequently, the claimed manufacturers' efficiency may not necessarily be the practical efficiency because the impact of climatic factors on the energy produced by the PV modules varies according to the technology used (Esram & Chapman, 2007). The extensive usage of PV systems in Nigeria has resulted to an influx of various types of PV modules from different countries. It has become imperative to test the performance efficiency of those modules.

The aim of this study therefore, is to evaluate the effect of changes in the output power of a silicon based photovoltaic cell operating under ambient conditions due to variatioans in the angle of tilt and direction of the panel. This is necessary in order to make sure that the panel imported into this country meets the desired specification as prescribed on its rating. The results obtained here and the concept will be a great contribution to knowledge of PV systems in Nigeria. The results could consequently be used by Standards Organization of Nigeria (SON) for regulatory purposes. It will also serve as baseline information for PV installation Engineers and other relevant agencies.

Materials and Methods

The experiment was conducted at Benue State University Makurdi, (GPS coordinates

7.728694⁰N, 8.561113⁰E) Benue State, North Central Nigeria. The site was surveyed to avoid shadow casting from buildings and trees so as to maintain high efficiency. A compass was also used to get the true direction at which the panel was to be positioned per time.

The experimental set up comprised of a 4W polycrystalline silicon based solar panel (see table 1 for specifications)(Green, 2009), a solar meter (Philip Harris, sensor meter H27659), a compass (Prismatic compass), two multi-meters; ammeter (A830L) and a voltmeter (PG012), a variable resistor, a thermometer (Temptec 241A) and insulated wires with alligator clips.

Table 1: Detail specification of PV cell used in the experiment.

Item	Specification
Brand Name	Power Solution by Shenzhen Power- solution Ind. Co.
Brand Model	PS-K013 4W 9V polycrystalline Panel.
Optimum Operating Voltage (V)	7.81V
Optimum Operating Current (A)	0.52A
Maximum Power (W)	4W
Dimension	0.176m by 0.154m
Area	$0.0271m^2$

A wooden wedge supports of varying angle of inclination (15^0, 30^0, 45^0, 60^0, 90^0, and 180^0) were constructed with a stand (1.5meters above the ground) that supports the panel to be tilted at specific angle per time This construction was necessary to enable the panel to be placed at the needed angle of tilt of those specified and to provide safety and prevent the panel from falling off.

Before the experiment commenced a site free from shading from tree or building was identified. A GPS was used to identify the geographic North, South, West and East. The panel was then mounted on a 15^0tilt wedge support facing the south direction. The panel was clean and free from dirt. A digital solar sensor (Philip Harris Sensor Meter H27659) was used to measure the irradiation of the sun striking the panel surface. The solar panel was connected in series through connecting wires of diameter (5mm and approximate length of 5m) to an ammeter and a variable resistor. A voltmeter was then connected parallel to the panel to measure the panel voltage as shown in the circuit diagram in figure 1.

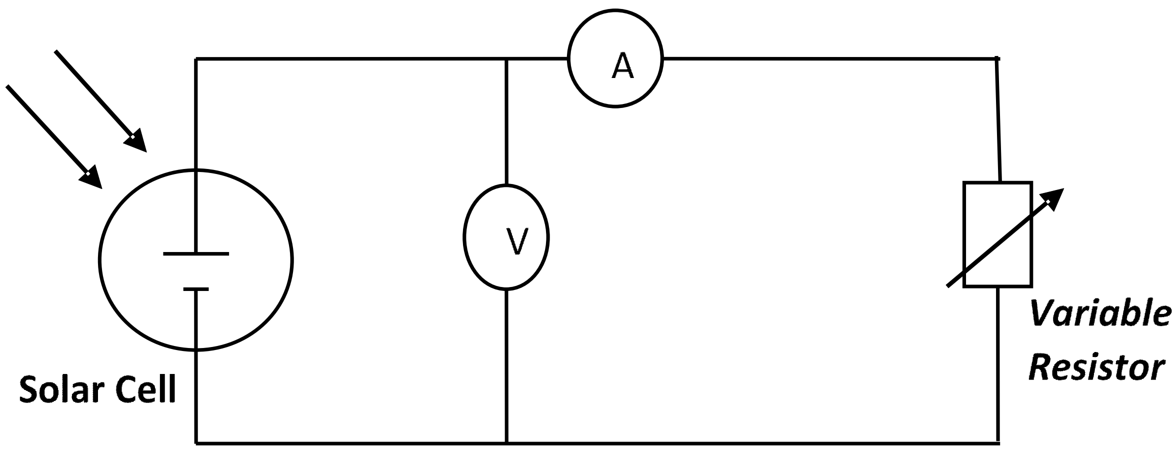

Fig 1. Circuit Diagram of the Experimental Setup

The variable resistor was used to enable the solar cell operate over a wide range of voltages and currents, this is because by varying the load resistance from zero (a short circuit) to infinity (an open circuit), the efficiency at which the cell delivers maximum power (P_{MAX}) can be determined. In this work the load was varied in order of; 0Ω, 1Ω, 4.7Ω, 10Ω, 22Ω, 32Ω, 47Ω, 51Ω, 82Ω, 100Ω, 220Ω, 540 Ω, 1kΩ and 3.2kΩ. The value of the voltage and current was recorded for each load. The operating condition such as the time, direction (North or South), ambient temperature and the solar radiation striking the surface of the panel was noted and the open-circuit voltage (V_{OC}), short-circuit current (I_{SC}), Maximum Power (P_{MAX}), current at P_{MAX} (I_{MAX}), and voltage at P_{MAX} (V_{MAX}) was determined.

The experiment was repeated at different directions, and angle of tilt (30^0, 45^0, 60^0, 90^0 and 180^0) of the solar panel at fairly constant ambient conditions. The results obtained were analyzed and graphs of I-V-P at all tilt angles well plotted.

The efficiency of the PV module is calculated using the equation

$$\eta = \frac{\text{Electrical power output}}{\text{Incident Solar Flux} \times \text{Area of Solar Panel}} \times 100\% \qquad 1$$

Where, electrical power output = $V_{OC} x\ Isc\ x\ FF$,

On a clear day at noon, the direct beam of radiation on the earth surface is approximately 1000Wm^{-2} (Abdulkarim, 2004). This value was used in calculating the efficiency of the photovoltaic module used in the experiment. The area of the sample panel is approximately 0.0271m^2.

Results and Discussion

The current-voltage (*I-V*) characteristics was determined for the geographic south and north respectively as shown in figure 2 and 3.

The calculated power was plotted against the voltage as shown in figure 4 and 5. The maximum power point on each of the P-V curves was measured.

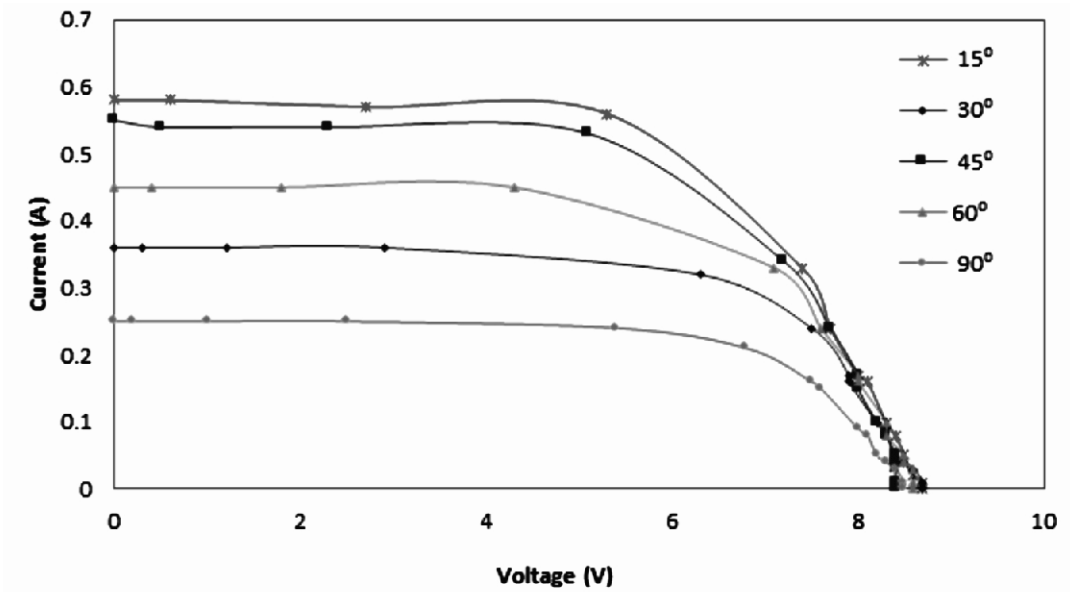

Figure2. I-V characteristics for the PV module, measured at Different Tilt Angle the Geographic South. Arrow indicates the *Vmp*

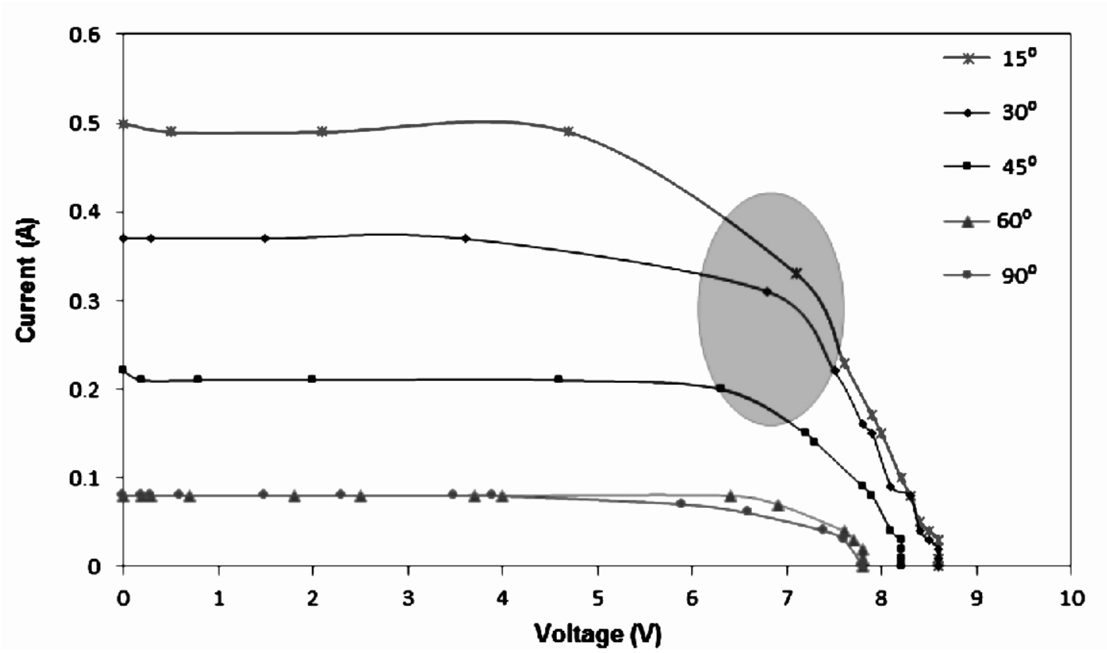

Figure 3. I-V Characteristics for the PV Module, Measured at Different Tilt Angles in the Geographic North. Arrow indicates *Vmp*

Generally, the *I -V* curve of a PV module describes its energy conversion capability at the existing conditions of photon excitation under a given condition. Figure 2 and 3 represent the *I-V* characteristics for the studied PV with angle of inclination varying from 15° to 90° in the south and north respectively. The curve represents the combinations of current and voltage at which the PV could be operated.

In both practical and ideal situations, the I-V curves are smooth, implying that the PV is not soiled, it is free of dust, there are no leakages of photocurrent, and the illuminance is uniform (Forrest, 2005). In figure, 2 and 3, the curves are smooth for angles of inclinations at 90°, 60° and 45°, while the curves measured at 30° and 15° are not smooth. This could be as a result of inhomogeneous photon excitation across the panel (Hussein, Ahmad, & El-Ghetany, 2004). The knee of the curves at 15⁰ South in figure 2 occurs at a voltage of 5.3V and current of 0.57A. This yields a power of 2.97W this also coincides with the position where the panel was most efficient. This result is in agreement with previous results as reported in (Green et al., 2015).

The observed steady state of the curve at voltages well below *Vmp*, is because the flow of photocurrent to the external load is relatively independent of output voltage (Hussein et al., 2004). As the voltage increase near the knee of the curve, the curve tends toward zero because, as the voltage increases further, an increasing percentage of the charges recombine within the solar cells and very little current reaches the load. At *Voc*, all of the charges recombine internally thus yielding zero current. The shaded area in figure 3 is to emphasize on the broadening of the knee points in the I-V curves. This is often as a result of temperature variation during the time of measurement (Anderson & Chai, 1976). Temperature causes band gap variation of crystalline material systems thereby causing additional recombination that are repeatable at specific temperatures.

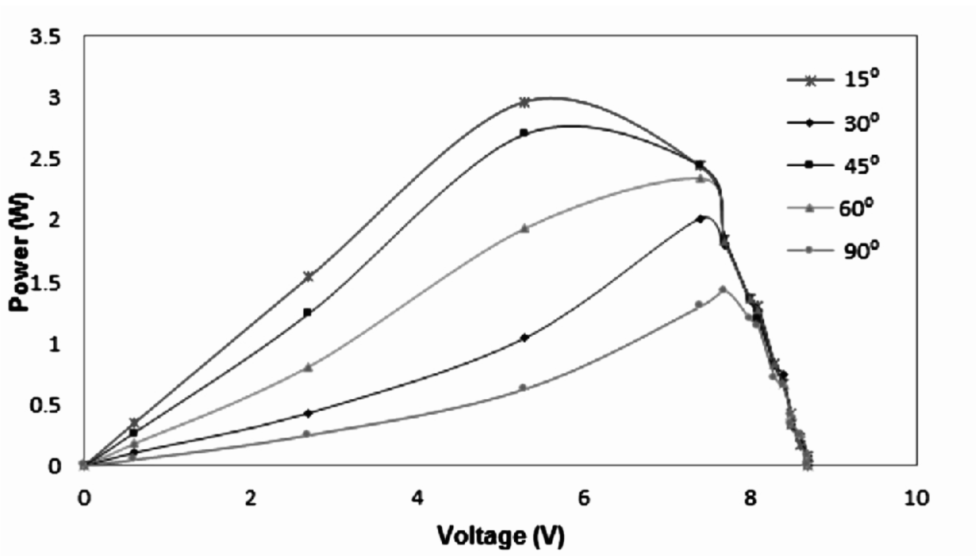

Figure 4. P-V Curve for the PV module Measured at Different Tilt Angle for South

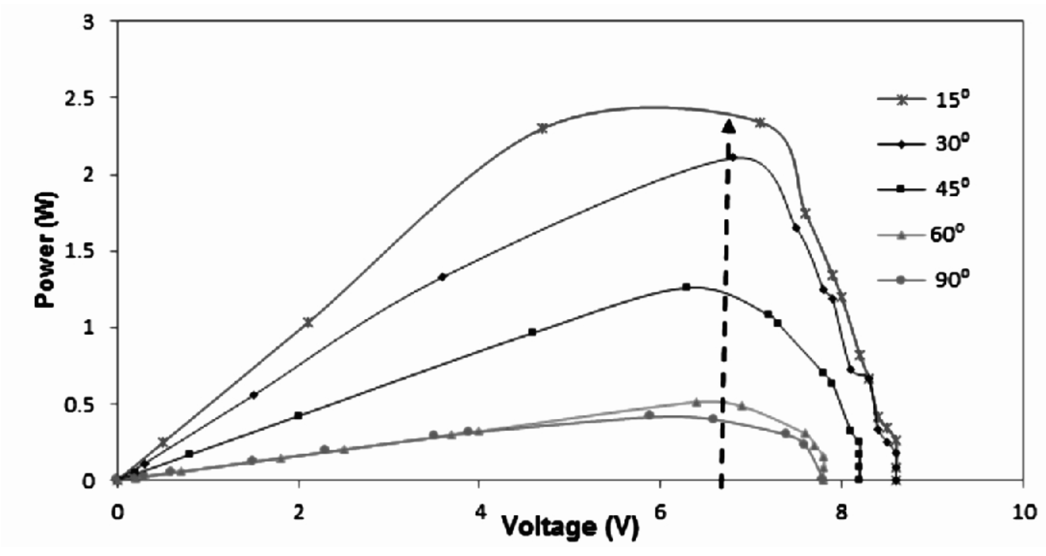

Figure 5. P-V curve for the PV module, measured at Different Tilt Angles for North. Arrow indicates the P_{max}

From the result obtained from the I-V characteristics, the power of the PV module was calculated and plotted for each tilt angle as presented in figure 4 and 5. The power produced by the cell in Watts is calculated along the I-V using the equation *P=IV,* as such, its *Imax* and *Vmp* will always coincides. Figures 4 and 5 which represents the power at tilt angles from 15° to 90°, the maximum power point to change with temperature and tilt angle. This is in agreements with previously reported work(Forrest, 2005),

From equation 1, the efficiency of the solar panel under investigation was calculated at the various tilt angles considered. It was observed that the efficiency is much higher when panel is at a tilt angle 15°. These clearly imply that at 15^0, at that tilt, the panel. Similar results were also obtained work carried out elsewhere(Green, 1987).

Figure 6, shows that efficiency of the solar panel varies as the angle of tilt changes from 15^0 to 180^0 split into north and south. It has been shown that the maximum efficiency of 11% of the panel under investigation was obtained when the panel was placed facing the geographic south at 15^0. The lowest efficiency 5.25% was obtained at 90^0. For the geographic north, the maximum efficiency of

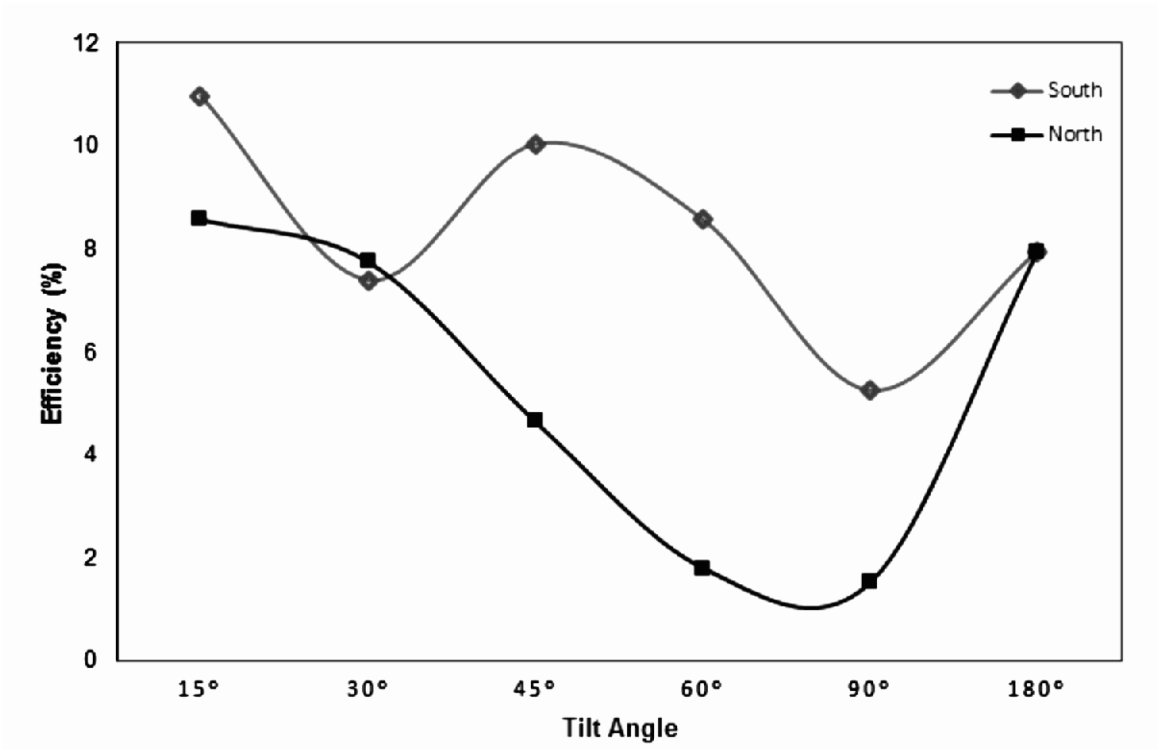

Figure 6. Graph of Efficiency (%)against Angle of Tilt (°)

Conclusion

From the result and analysis presented, it can be observed that under the prevailing weather and other atmospheric conditions, the efficiency and maximum power point of the panel varies with illuminance and tilt angle. Fixing the illuminance at constant level and assuming that the internal quantum efficiency is constant, we are able to determine an optimum position for installation of PV module with Benue state which can be generalized in areas with comparable weather conditions.

The highest efficiency of about 11% was recorded when the panel was south facing at 15^0, while the theoretical efficiency of the solar panel used was approximately 15%. This is because solar panel is tested under standard test conditions (STC) in the factory. These conditions are not always practically the same which suggest the pertinence for ambient testing of all PV products before they are certified for use in Nigeria. This work has shown that the practical efficiency of the photovoltaic module is considerably lower than the theoretically efficiency stated by the manufacturers. Solar panel installed in Makurdi and environs should be south facing tilt at 15^0 to maximize efficiency.

Reference

Ajao, K., Oladosu, O., & Popoola, O. (2011). Using HOMER power optimization software for cost benefit analysis of hybrid-solar power generation relative to utility cost in Nigeria. International Journal of Research and Reviews in Applied Sciences, 7(1), 14

Akinyele, D., Rayudu, R., & Nair, N. (2015). Global progress in photovoltaic technologies and the scenario of development of solar panel plant and module performance estimation− Application in Nigeria. Renewable and Sustainable Energy Reviews, 48, 112-139.

Anderson, W., & Chai, Y. (1976). Becquerel effect solar cell. Energy Conversion, 15(3), 85-94.

Blankenship, R. E., Tiede, D. M., Barber, J., Brudvig, G. W., Fleming, G., Ghirardi, M., . . . Melis, A. (2011). Comparing photosynthetic and photovoltaic efficiencies and recognizing the potential for improvement. science, 332(6031), 805-809.

Esram, T., & Chapman, P. L. (2007). Comparison of photovoltaic array maximum power point tracking techniques. IEEE Transactions on Energy Conversion EC, 22(2),439.

Forrest, S. R. (2005). The limits to organic photovoltaic cell efficiency. MRS bulletin, 30(01), 28-32

Green, M. A. (1987). High efficiency silicon solar cells. Paper presented at the Seventh EC Photovoltaic Solar Energy Conference.

Green, M. A. (2009). The path to 25% silicon solar cell efficiency: History of silicon cell evolution. Progress in photovoltaics: research and applications, 17(3), 183-189.

Green, M. A., Emery, K., Hishikawa, Y., Warta, W., & Dunlop, E. D. (2015). Solar cell efficiency tables (Version 45). Progress in photovoltaics: research and applications, 23(1), 1-9.

Hussein, H., Ahmad, G., & El-Ghetany, H. (2004). Performance evaluation of photovoltaic modules at different tilt angles and orientations. Energy conversion and management, 45(15), 2441-2452.

King, D. L., Kratochvil, J. A., & Boyson, W. E. (1997). Measuring solar spectral and angle-of-incidence effects on photovoltaic modules and solar irradiance sensors. Paper presented at the Photovoltaic Specialists Conference, 1997., Conference Record of the Twenty-Sixth IEEE.

Martí, A., Antolín, E., Stanley, C., Farmer, C., López, N., Díaz, P., . . . Luque, A. (2006). Production of photocurrent due to intermediate-to-conduction-band transitions: a demonstration of a key operating principle of the intermediate-band solar cell. Physical Review Letters, 97(24), 247701.