

Research Article

The Effect of Seasonal Variation and Angle of Inclination on the Performances of Photovoltaic Panels in South Eastern Nigeria

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Abstract: The effects of seasonal variation and angle of inclination on the performances of photovoltaic panels in south eastern Nigeria are presented. Three photovoltaic panels, each with a rated capacity of 60 W, were used for the study in each of the locations considered. Three installation positions considered are: horizontal, an angle equal to the local latitude of location and an angle 5° greater than the local latitude of location. Power output from these panels was measured at fixed time interval from dawn to dusk for 12 months. Results obtained show an average performance of 25-30 W representing about 42-50% of the panels rated capacity. Furthermore, the horizontally installed panels, on the average, presented better performance than the others angles. Thus utilization of photovoltaic panels for power generation in the region considered should be limited to lighting applications and applications within the same power requirement range. Also for overall best performance, they should be installed in a horizontal position.

Keywords: Angle of inclination, photovoltaic panels, power generation, seasonal variation, solar

INTRODUCTION

Energy is an essential component of human existence. This is because a lot of our activities, both at home and outside the home depend on availability energy. At present, more than 90% of our energy needs derive from fossil fuel. This energy source apart from its exhaustible nature has a very high environmental problem attached to its use. For instance carbon dioxide, a product of combustion of the hydrocarbon fossil fuel, is one of the greatest culprits in the current global warming scourge. Furthermore, the ever increasing cost of fossil fuel and its irregular supply has added to its unattractive nature. Consequent on the above problems, there is increased and renewed search for renewable energy sources to serve as alternatives to fossil fuel. Solar energy is one of such renewable energy sources. It comes from the sun and as such it is free and nonpolluting. The only cost attached to the use of solar energy comes from the means of harnessing it.

There are currently two basic forms through which solar energy can be harnessed and used. The first is its direct conversion to heat for either solar heating applications like water heating and space heating or its usage for solar cooling applications. This form is often referred to as solar thermal applications. The second form is the conversion of solar energy into electrical energy in a device called the photovoltaic panel. The

resulting electrical energy produced is subsequently used to power electrical or electromechanical devices. Several studies have been carried out on the harnessing and use of solar energy. They include the works of Anyanwu and Ezekwe (2003), Lemmini and Errougani (2005) and Gonzalez and Rodriguez (2007) on solar refrigeration; Nieuwoudt and Mathews (2005), Esen and Esen (2005), Smyth *et al.* (2006) and Ogueke *et al.* (2009) on solar water heating; Dufo-López and Bernal-Agustín (2005), Fragaki and Markvart (2008), Whitaker *et al.* (2008) and Singh and Singh (2010) on solar electricity.

The general conclusion that can be drawn from these studies is that solar energy has the potential of providing a very high percentage of our energy demand. Unfortunately during day time when solar energy is available, its intensity varies; this implies that instantaneous energy available from the sun varies all through the day. Consequently an effective solar system design must put into consideration this variation pattern. For the solar thermal systems, appropriate use of the harnessing components' heat capacity will significantly balance out the effect of the fluctuating nature of solar energy on the overall system performance. For the photovoltaic systems however, this mitigating effect using thermal mass is not possible. Hence power generated from the PV panels varies from dawn to dusk. However power generated

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from the PV panels are often not used directly; they are converted to chemical energy and stored in batteries from where it is tapped for use through proper circuit arrangement.

The rating of PV panels used for power generation from solar energy are based on their DC power output under Standard Test Condition (STC) which is 1000 W/m² of sunlight intensity, a cell temperature of 25°C and an air mass of 1.5. There is also the Normal Operating Cell Temperature (NOCT) rating. This is done at 800 W/m² sunlight Irradiance, an average of 20°C air temperature, an average wind velocity of 1 m/s, with the back side of the solar panel open to that breeze. [AM Solar, Inc. (2012). Standard Test Conditions (STC) vs. Normal Operating Cell Temperature (NOCT). http://www.amsolar.com/home/amr/page_164]. When installed, PV panels operate below their STC or NOCT rating. The degree of deviation from the rated condition depends on geographic location and seasonal variation (Department of Energy, 1997). Therefore before considering the use of PV panels for power generation, it is important to fully understand the possible performance of PV panels in such location under the different season of the year. Some studies have been conducted in that regard. They include the works of Onyegebu (1989) on the performance of photovoltaic cells in an equatorial climate and Okeke and Anuforum (1990) on the effect of clearness index on the optimum performance of an array of silicon solar cells. These works however did not consider the power generated alongside the maximum rated power of such PV panels.

In Nigeria, a tropical country with three major seasons of rain, dry and harmattan, there is increased awareness on the possibility of power generation from solar using PV panels. At present, most of the installed PV powered facilities either fail completely or starts malfunctioning after less than one year of continuous operation. This should not be considering the cost of generating power from the sun using PV panels. Thus this study aims at determining the effect of seasonal variation and angle of inclination on the performance of PV panels in south eastern Nigeria.

METHODOLOGY

Three multicrystalline silicon cell PV panels of 0.45 m² cell area were used for this study in each of the locations considered. The panels have the following ratings: Maximum power, 60 W; Voltage at Maximum power (V_{mp}), 17.4 V; Current at maximum power (I_{mp}), 3.45 A; Short circuit current (I_{sc}), 3.90 A; and Open circuit voltage (V_{oc}), 21.6 V. Since all the locations in Nigeria are of Northern latitudes, they were mounted on a table and inclined at various angle ranging from



Fig.1: Picture of the experimental set-up

0° to (Latitude of location + 5)°, facing north. Figure 1 shows a photographic illustration of the experimental setup. A 5 ohms power resistor, which is intended to produce the maximum power from the PV panels, was connected across each of the terminals. The voltage across the power resistor was obtained using a digital multimeters from where current and power were obtained using Eq. (1) and (2), respectively:

$$I = \frac{V}{R} \quad (1)$$

$$P = IV \quad (2)$$

where, P, V and I are power (W), Voltage (V) and current (A), respectively.

Solar radiation was measured using a Daystar® hand held digital solar meter which uses a polycrystalline silicon DV cell as sensor. Its accuracy is $\leq 3\%$ within the measuring range of 0-1200 W/m² with a resolution of 1 W/m². Wind velocity and relative humidity were measured with an Omega® 4 in 1 digital hand held wind/humidity/light/temperature meter with an accuracy of 4%. Readings were taken at an interval of 1 h between 6 and 18 h local time. Three locations namely; Calabar, Owerri and Nsukka were used for the study. These locations were chosen to reasonably capture the solar map of south eastern Nigeria. Figure 2 shows the solar map of Nigeria. Nsukka is not clearly captured in the map; however it is a town between Enugu and Makurdi.

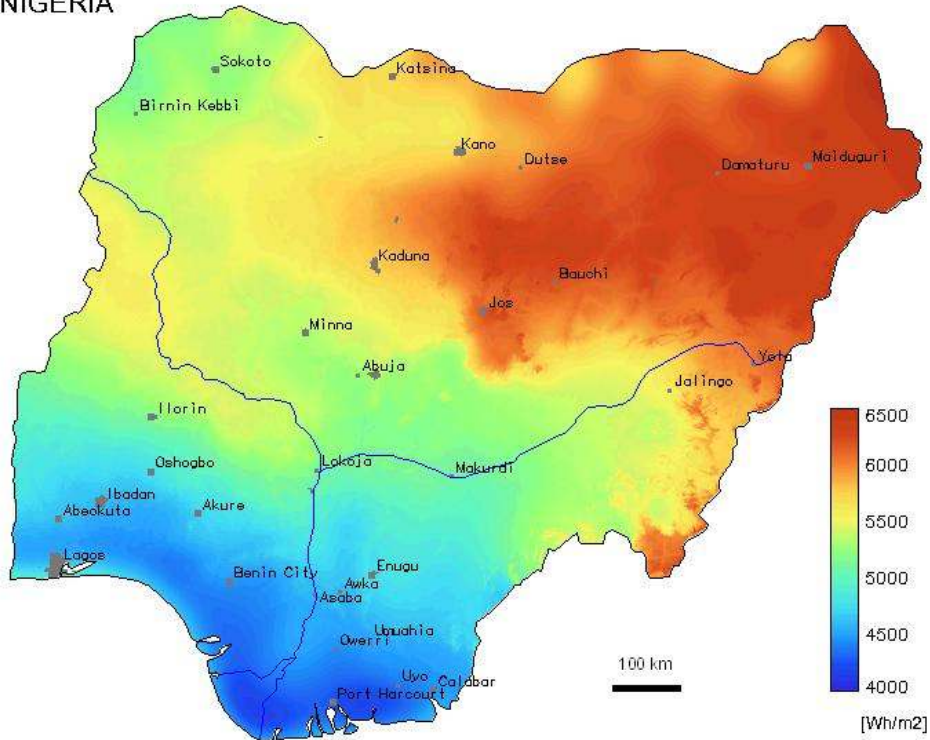
RESULTS AND DISCUSSION

Figures 3 to 5 show the power generation of the PV panels on typical clear, overcast and rainy days, respectively. These figures reveal a generally low power generation, compared to the rated maximum

Yearly average of daily sums of global horizontal irradiation (HelioClim-1/PVGIS data, period 1985-2004)



NIGERIA



PVGIS (c) European Communities 2002-2006
HelioClim-1 (c) Ecole des Mines de Paris/Armines 2001-2006

<http://re.jrc.ec.europa.eu/pvgis/>

Fig. 2: Solar map of Nigeria (<http://re.jrc.ec.europa.eu/pvgis/>)

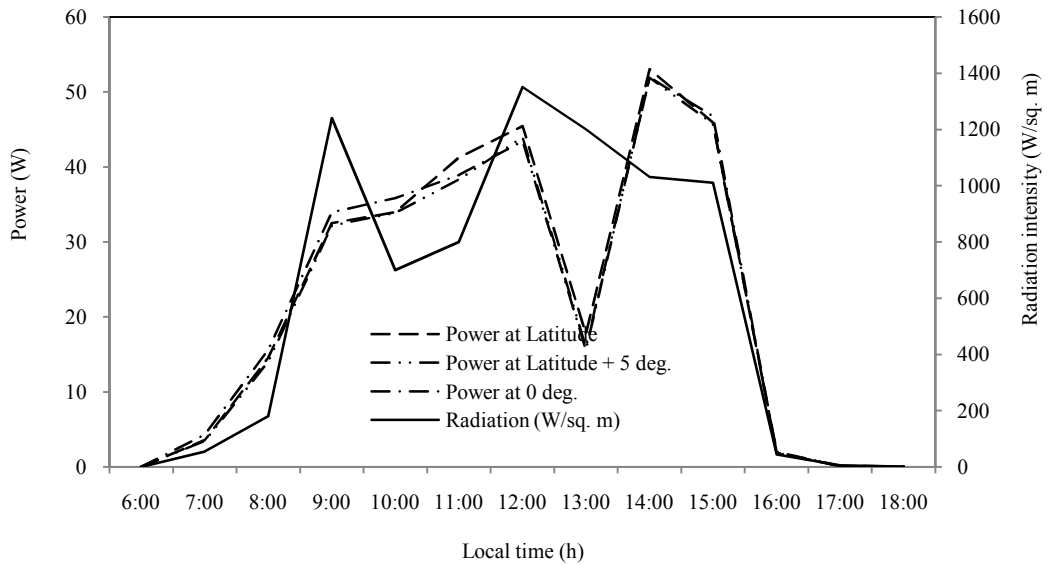


Fig.3: Performance of the PV panels on a clear day

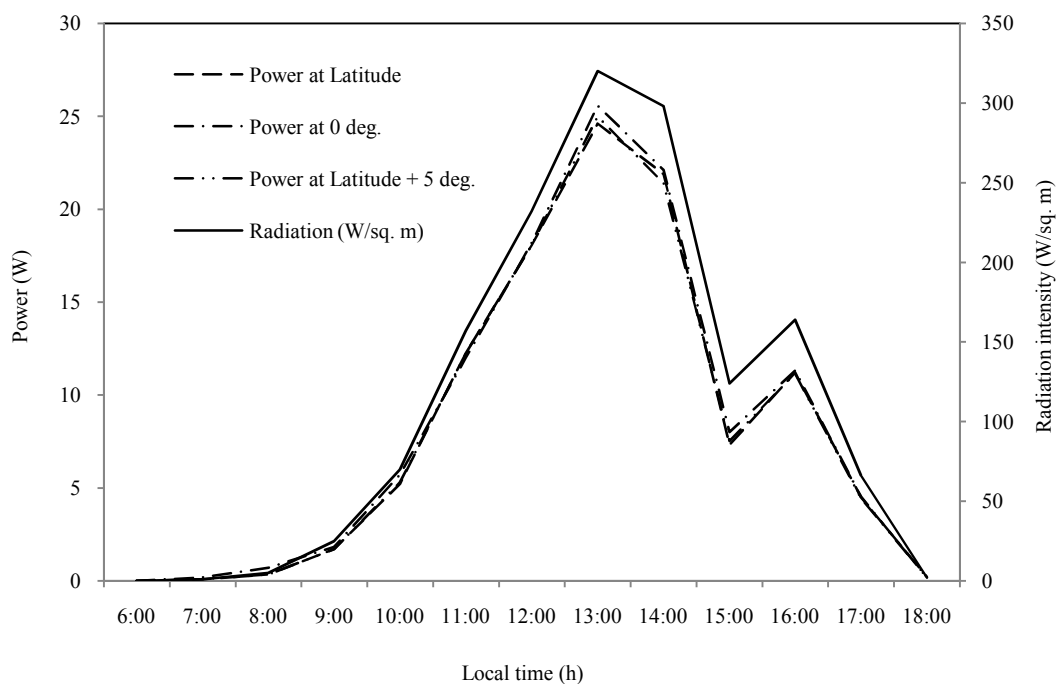


Fig. 4: Performance of the PV panels on an overcast day

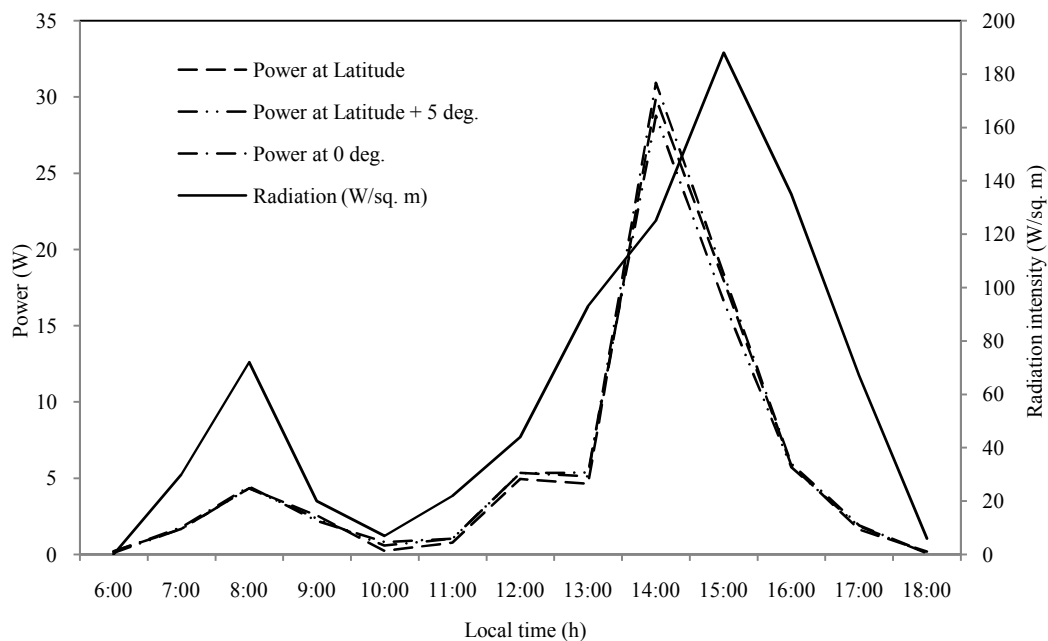


Fig. 5: Performance of the PV panels on a rainy day

power output of the panels. The range of under generation was 25-100% for a clear day in Calabar (Fig. 6). The same trend of under generation was

observed for the other locations considered. However, their percentages of under generation were different from that shown in Fig. 6. In Owerri, on a clear day, this

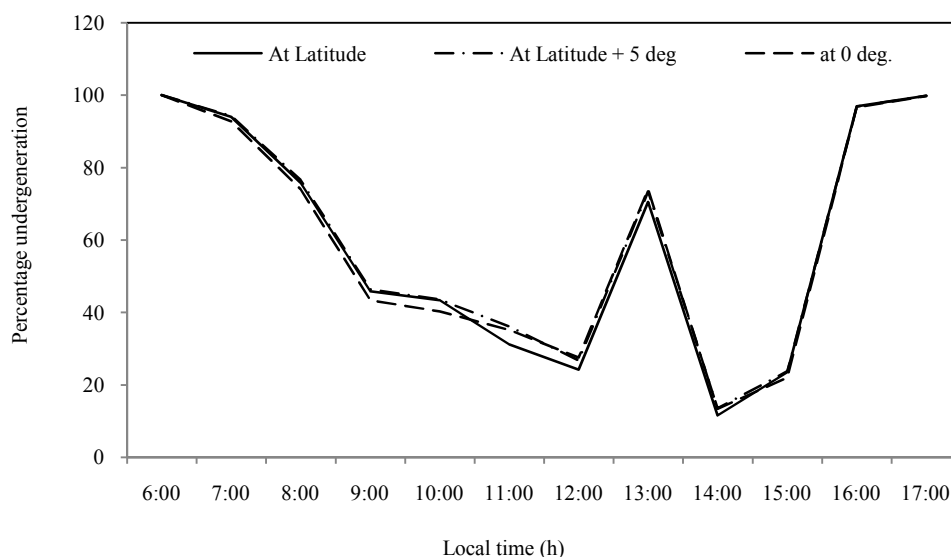


Fig. 6: Percentage to which the actual measured performances underpredicted the rated value

value was between 23-95% while for a similar day in Nsukka, it was between 19-96%. The trend shows that the performance closest to the rated PV panel's performances was obtained in Nsukka. This was followed by the performance recorded Owerri and then Calabar in that order. The recorded insolation intensity in these locations also follows the same trend, that is, highest in Nsukka, followed by Owerri while Calabar presented the lowest. However, these measured performances mostly fell below 50% of their rated value, even with the clearest sky, as seen from Fig. 3-5.

Figures 3 to 5 also show the effect of angle of inclination to the horizontal on the performance of the panels. Even though no clear trend could be established regarding the effect of this, the horizontally placed panel (i.e., 0°) presented very good results. In fact during the overcast days, its performance was on the average the best compared to that at the local latitude and the other angles. On clear days, its average performance was better than those at the local latitude and latitude +5°. The fact the horizontally placed panel recorded better performance on overcast days may be due to the predominantly diffuse nature of radiation during those periods. This is seen more clearly from Fig. 3, 4 which show the power output on clear and overcast days, respectively. A close look at Fig. 3 shows that during the morning hours when solar radiation is predominantly diffuse, the horizontally placed panel performed best. As it approached midday when radiation was more of direct, the performance of the panel inclined at the local latitude of location became best and subsequently dropped as dusk

approached, when again the radiation had become more diffuse. The maximum difference in power recorded for all the angles was about 2.9 W. The south eastern part of Nigeria is predominantly diffuse. This is seen from their average clearness index, K_T that is in the range 0.36-0.48 (Anyanwu and Oteh, 2003; Awachie and Okeke, 1985; Obiakor and Awachie, 1989). Furthermore out of the twelve months of the year, about seven fall within the rainy season. Consequently, PV panels' installations in such locations should be horizontally placed. At present, the practice is to mount them such that they are inclined at the local latitude of the location. For instance, in Owerri with latitude of 5.5°N, the panels are installed at an angle of 5.5° facing North.

The monthly average performance of the installed PV panels is shown in Fig. 7 for Owerri. The figure shows that the best performance was recorded during March-June. The next was during September-November. The lowest recorded performance for all the angles considered occurred during August, a month that recorded the highest level of rainfall and the least insolation during the test period. Between November-February, very high insolation level was recorded yet the output from the PV panels was lower than during the rainy season months (April-October) with much lower insolation. This is probably because of the very dusty nature of this period. Ending days of October often marks the outset of dry season which eventually dovetails into the harmattan season by the ending of November to early December. The dusty nature of this period causes layers of dust to settle on the surfaces of

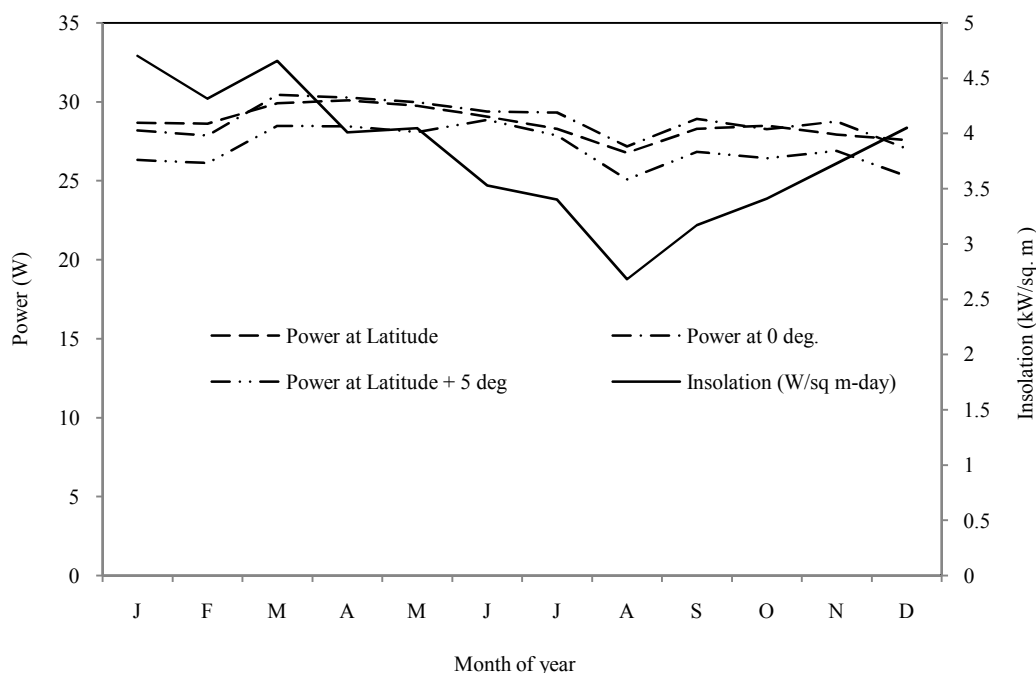


Fig. 7: Typical average performance of the installed PV panels

the panels thus reducing their solar energy conversion efficiency. Early rains usually start in March, thus washing off the dust layers. This coupled with the fact that rainy season has not fully commenced by then and as such insolation levels are still high is responsible for the rise in performance recorded. However, with increasing rains, performance begins to drop.

Figure 7 also shows an overall average best performance coming from the panel at 0°, with a best of about 30 W corresponding to about 50% of the rated capacity. This was followed by the one inclined at the local latitude and then latitude +5°. The same trend observed for Owerri was recorded for the other locations. However, the overall best performance was obtained from Nsukka (about 35 W or 58%) where the effect of dust was also found to be more pronounced and covered a longer period (four months, from November-February).

CONCLUSION

The effects of seasonal variation and angle of inclination on the performances of photovoltaic panels in south eastern Nigeria has been presented. Based on the results obtained, the following conclusions may be drawn:

- Solar panels perform at about 50% of their rated capacity in most cities in south eastern Nigeria.

Thus for a specified power generation using PV panels, at least two times the normal panel that should satisfy that requirement based on the power rating is required for a sustained power generation.

- Solar panel installation in the south east of Nigeria does not need to be at an angle equivalent to the local latitude which is the current practice. A horizontally mounted panel will perform better considering that solar radiation is predominantly diffuse in these locations. This is also the case for any location that experiences more diffuse than direct solar radiation.
- Considering the recorded output of about 50% of rated performance of PV panels and their cost, it is not advisable to deploy PV panels for large power generation purposes in those regions. Its use should be limited to such applications like lighting and others within that power requirement range.

ACKNOWLEDGMENT

We acknowledge with thanks the financial assistance of World Bank under its STEP-B research grant for renewable energy research at the Federal University of Technology, Owerri and also the financial assistance of the National Centre for Energy Research and Development, University of Nigeria, Nsukka.

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