Nigerian Journal of Solar Energy
(October, 2025), 35 (1&2): 1 – 11

ISSN: 0794-9537

Full Length Research Article

Outdoor Performance Evaluation and Modelling of Polycrystalline Photovoltaic Module in Minna, Nigeria

[1]Ezenwora J A,* [2]Oyedum O D and [3]Ugwuoke P E
[1, 2]Department of Physics, Federal University of Technology, P.M.B. 65 Minna, Nigeria.
[3]National Centre for Energy Research and Development, University of Nigeria, Nsukka.
***Corresponding Author:** joelezen@futminna.edu.ng **Phone:** +2348053331748

ABSTRACT

Outdoor characterisation and performance evaluation of Photovoltaic (PV) modules is needed for effective PV power system. The performance response of polycrystalline silicon PV module to atmospheric parameters of solar irradiance, temperature, wind speed and relative humidity was investigated in Minna, North Central Nigeria, using Campbell Scientific CR1000 software-based data acquisition system. The PV module under test and meteorological sensors were installed on a metal support structure at the same test plane. The data monitoring was from 08.00 to 18.00 hours each day continuously for a period of one year. Maximum value of module efficiency of 10.91 % for the module was recorded at irradiance of 375 W/m2. At 1000 W/m2 the efficiency reduced to 6.20 %, as against manufacturer's specification of 48 % for the module. The maximum power output achieved for the module at irradiance of 1000 W/m2 was 1.323 W representing 13.23 % of the manufacturer's power specification for the module. Accordingly, Module Performance Ratio (MPR) for the PV module is 0.13. The rate of variation of module response variables with irradiance and temperature was determined using a linear statistical model given as Y= a + bHg + c Tmod. The coefficient of determination for the fits for the performance variables are: 69.1 %, 93.1 %, 62.4 % and 88.9 % for the open-circuit voltage, short-circuit current, power and maximum power respectively. The overall lack of fit tests for these performance variables is significant at probability, P value of 0.000, signifying good fits.

Keywords: Ambient; Module; Photovoltaic; Polycrystalline; Statistical-model

1.0 INTRODUCTION

The need to characterise and evaluate the performance of photovoltaic modules in order to ensure optimal performance and technical quality in photovoltaic power systems has been pointed out (Almonacid *et al.*, 2009). Standard Test Condition (STC) hardly occur outdoors, therefore the effect of deviation of meteorological parameters from STC together with the fact that PV modules with actual power smaller than the nominal value can still be found in the market lend credence to this. Essentially, PV power system design involves electrically-matching power components and ultimately, the power supply to the load. STC are easily recreated in a factory, and allow for consistent comparisons of products, but need to be modified to estimate output under common outdoor operating conditions. Module output power reduces as module temperature increases (Ezenwora *et al.*, 2018). The rate of decrease of output power with temperature for a particular locality ought to be understood and the loss factor for each module type in every location established. These loss factors need to be documented and applied in order to effectively estimate system output and sizing before installation. This will lead to the design and installation of efficient PV power system that is reliable, dependable and durable. In developed world such as the United States of America (USA) which is a lead actor in PV research, there have been efforts to conduct outdoor tests of modules and array performance since 1976 through the Sandia National Laboratory (Ezenwora *et al.*, 2018). The US has effectively established and documented loss factors for all losses affecting PV power systems for all PV module types and for every location.

Realistic outdoor performance analysis of various types of modules is needed in developing countries such as Nigeria, in order to be able to effectively design and size arrays for different applications and sites. It is no longer news that Nigeria is an energy resource rich country, blessed with both fossil fuel reserves such as crude oil, natural gas, coal, and renewable energy resources like solar, wind, biomass, biogas and hydropower resources. It is also true that despite the abundance of these energy resources in Nigeria, the country is in short supply of electrical power. There is supply-demand gap particularly in view of the growing energy demand in the domestic, commercial and industrial sectors of the economy, and the reason for this is not farfetched. Nigeria's electricity supply is characterized by significant challenges and a reliance on natural gas for power generation. Nigeria has twenty-three (23) power-generating plants connected to the national grid with the capacity to generate 11,165.4 MW of electricity, but actual generated capacity is well below this. As at May, 2018, for example, the available capacity was 8,034 MW with an average daily generation of 3,827 MW. While thermal and hydropower sources contribute to the electricity mix, actual supply often lags behind demand, leaving a large portion of the population without access, and as a result a significant portion of Nigerians rely on expensive diesel generators to supplement the inadequate grid supply. Currently, Natural gas dominates electricity generation, accounting for 86% of the country's power production. Nigeria has significant potential for renewable energy sources like solar and hydropower, which are increasingly being explored. Investing in renewable energy projects will help diversify the energy mix and reduce reliance on fossil fuels. The government is investing in renewable energy projects to diversify the electricity mix and improve access. Addressing the gap between generation capacity and demand is crucial for improving access and reliability (Wikipedia, 2025). While the initial capital investment may be higher, PV power system provides electrical power at less cost than electricity from generator, based on life-cycle cost. Because it has an added advantage of requiring little maintenance, low running costs and being environmentally friendly. PV power is the most reliable source of electricity ever invented and it is portable, easily installed, and virtually maintenance-free (Ezenwora *et al*., 2018). Therefore, this study was carried out with the-state-of-the-art Data Acquisition System (DAS) to determine the realistic outdoor performance of polycrystalline silicon PV module in Minna and its environs for effective design and sizing of PV power system.

2.0 MATERIALS AND METHOD

2.1 Monitoring Stage

The performance response of polycrystalline silicon PV module to ambient weather parameters; solar irradiance, temperature, wind speed and relative humidity, was monitored in Minna environment, using CR1000 software-based data logging system with computer interface. The PV module under test, and meteorological sensors, were installed on support structure at the same test plane, at about three metres of height, so as to ensure adequate exposure to insolation and enough wind speed, since wind speed is proportional to height (Ugwuoke, 2005). The elevation equally ensures that the system is free from any shading from shrubs and also protected from damage or interference by intruders. Also, the whole experimental set up was secured in an area of about four metres in diameter. The modules were tilted at approximately 10^{o} (since Minna is on latitude $09^{o}37'$ N) to horizontal and south-facing to ensure maximum insolation (Ezenwora *et al*., 2018).

The data monitoring was from 08.00 to 18.00 hours local time, each day continuously for a period of one year, spanning from December 2014 to November 2015, so as to cover the two distinct and well-defined climate seasons of the area. The experiment was carried out near Physics Department, Federal University of Technology, Minna (latitude 09°37' N, longitude 06°32' E and 249 metres above sea level). The sensors were connected directly to the CR1000 Campbell Scientific data logger, while the module was connected to the logger via electronic load specifically designed for the module. The logger was programmed to scan the load current from 0 to 1 A at intervals of 50 mA every 5 minutes, and average values of short-circuit current, I_{sc}, open-circuit voltage, V_{oc}, current at maximum power, I_{max}, voltage at maximum power, V_{max}, power and maximum power point obtained from the module together with the ambient parameters are recorded and logged. Data download at the data acquisition site was performed every 7 days to ensure effective and close monitoring of the DAS. At the end of each month and where necessary, hourly, daily and monthly averages of each of the parameters - solar (global) irradiance, solar insolation, wind speed, relative humidity, ambient and module temperatures, and the output response variables (open-circuit voltage, V_{oc}, short-circuit current, I_{sc}, voltage at maximum power point, V_{max} , current at maximum power point, I_{max}, efficiency, Eff and fill factor, FF) of the photovoltaic module was obtained. The global solar radiation was monitored using Li-200SA M200 Pyranometer, manufactured by LI-COR Inc. USA, with calibration of 94.62 microamperes per 1000 W/m^2. The ambient temperature and relative humidity were monitored using HC2S3-L Rotronic HygroClip2 Temperature/Relative Humidity probe, manufactured in Switzerland. Wind speed was monitored using 03002-L RM Young Wind Sentry Set. And module temperature was monitored using 110PV-L Surface-Mount Temperature probe. All sensors are installed in the CR1000 Campbell Scientific data logger with measurement and control module. Table 1 shows the manufacturer's specifications at STC of the module investigated while Plate I shows the data acquisition set up.

Table 1: Manufacturer's specification at STC and measured dimensions of the module

Cell Technology	No of Cells per Module	Max. Rated Power (W)	Max. Rated Voltage (V)	Max. Rated Current (A)	Open-Circuit Voltage (V)	Short-Circuit Current (A)	Module Dimensions (m x m)	Cell Dimensions (m x m)	Total Surface Area of Cells (m²)	Model /Make	Eff (%)
Poly-crystalline Module	36 Cells of 4 Parallel and 9 series string	10	17.4	0.59	21.6	0.67	0.30 x 0.20	0.037 x 0.016	0.0213	SLP 10-12 /China	48*

*Module efficiency was calculated with Equation 2 because it was not included in the manufacturer's specifications

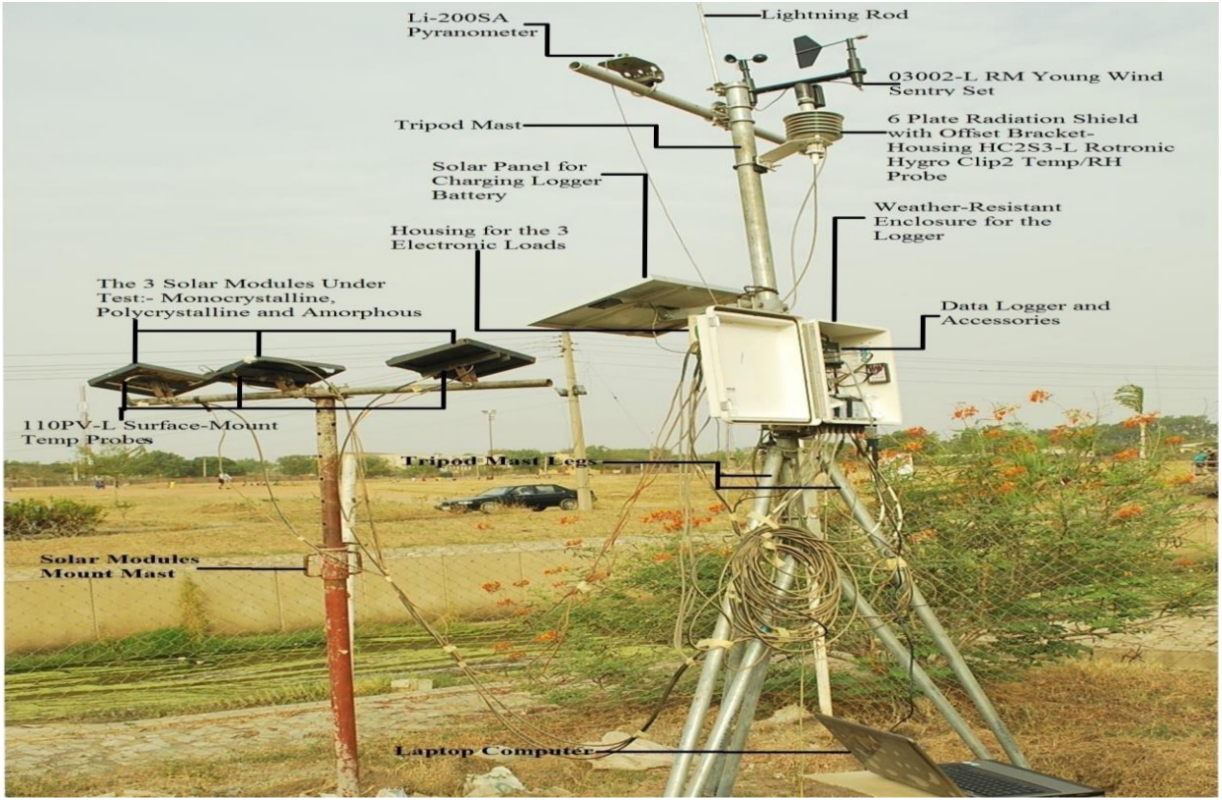

Plate I: The Experimental set up (Near Physics Department, FUT Minna)

2.2 DATA ANALYSIS

Performance response of the module to ambient weather parameters was investigated in terms of open-circuit voltage, V_{oc}, short-circuit current, I_{sc}, voltage at maximum power point, V_{max}, current at maximum power point, I_{max}, efficiency, Eff and fill factor, FF. Fill Factor, FF, Efficiency, Eff, and Module Performance Ratio (MPR) were evaluated using the following expressions:

$$Fill\ Factor, FF = \frac{I_{max}V_{max}}{I_{sc}V_{oc}} \quad (1)$$

$$Efficiency, Eff = \frac{I_{max}V_{max}}{P_{in}} = \frac{I_{sc}V_{oc}FF}{P_{in}} = \frac{I_{sc}V_{oc}\,FF}{AE_e} \quad (2)$$

$$Module\ Performance\ Ratio\ (MPR) = \frac{Effective\ Efficiency}{Efficiency\ at\ STC} \quad (3)$$

$where\ A = module\ surface\ area\ and\ E_e = solar\ intensity$

Statistical analysis was carried out with the aid of statistical package; Minitab 17 to determine the rate of variation of module response variables with irradiance and temperature, and linear statistical models for prediction of performance variables are presented. Multiple regression models, analysis of variance (ANOVA) and correlation between the variables were considered with the aim of establishing the statistically significant relationship between the variables and the goodness of fit of the models for the research study. The regression equation is;

$$Y = a + bH_g + cT_{mod} \quad (4)$$

where Y is the output response parameter being predicted, H_g is global radiation (solar irradiance) and T_{mod} is module temperature. The coefficients b and c are the rates of variation of output variables with respect to irradiance and module temperature, respectively while a is intercept on the Y axis.

The I-V curves were produced by plotting current against voltage produced by the logger in scanning the electronic load current from 0 to 1 A at intervals of 50 mA. The maximum power point, P_{max}, which is the operating point of the module, was equally recorded by the logger.

3.0 RESULTS AND DISCUSSION

The output characteristics of the polycrystalline silicon PV module as a function of global irradiance are shown in Figure 1. This output characteristics is expressed in the form of I-V curves.

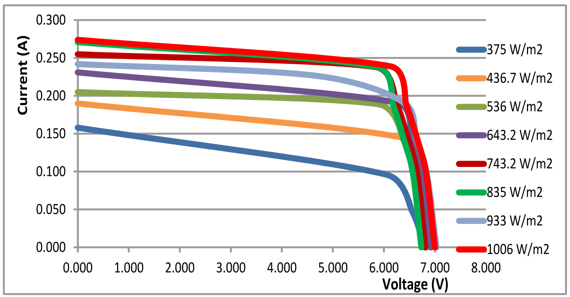

Figure 1: I-V Characteristics for the polycrystalline silicon module as a function of global irradiance.

Open-circuit voltage, V_{oc}, is seen to increase reluctantly with increase irradiance. Its increase is not commensurate with increase in irradiance and this explains the bunching of the I-V characteristics curves along voltage axis compared to relative regular spacing along the current axis. This is due to high temperature associated with increase in irradiance which has adverse effect on the open-circuit voltage. On the contrast, the short-circuit current increased generally with irradiance. This contrast in open-circuit voltage and short-circuit current is more glaring in Figures 2 and 3 where these performance variables are compared with module temperature at various irradiance levels.

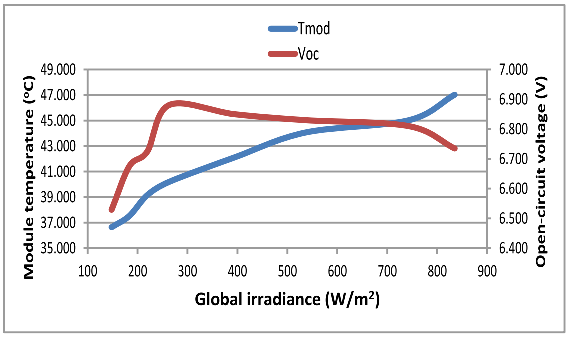

Figure 2: Variation of open-circuit voltage and module temperature as a function of global irradiance for the polycrystalline module.

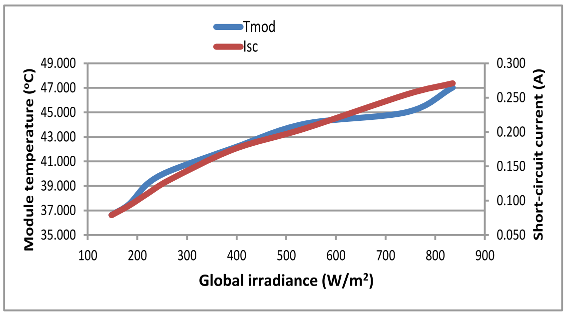

Figure 3: Variation of short-circuit current and module temperature as a function of global irradiance for the polycrystalline module.

It is clear then that the open-circuit voltage does not have linear relationship with module temperature and solar irradiance as against short-circuit current that increased linearly. This result is in agreement with Ugwuoke and Okeke (2012) and Ezenwora *et al.* (2018).

The relationship of maximum power point (MPP) and efficiency to temperature variations was investigated and shown in Figures 4 and 5 respectively.

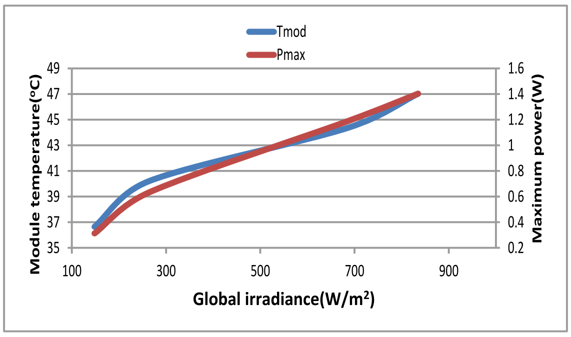

Figure 4: Variation of Maximum Power Point (MPP) and module temperature at different levels of irradiance for the polycrystalline module

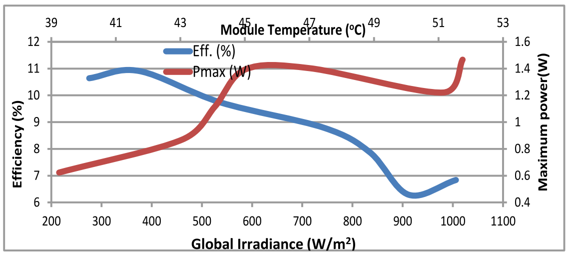

Figure 5: Variation of efficiency and maximum power point as a function of global irradiance and module temperature for the polycrystalline module

It was observed that the maximum power, like the short-circuit current, increased steadily with increased solar irradiance and module temperature for the module, suggesting that maximum power is more correlated to current than voltage for the measured range of solar irradiance. As shown in these Figures the maximum power point increases with increase in solar irradiance of about 800 W/m^2. This explains the inclusion of Maximum Power Point Tracker (MPPT) in some photovoltaic power system components. Maximum power point and efficiency show symmetrical structure at irradiance of about 550 W/m^2. This is in agreement with some earlier works (Bajpai and Gupta, 1986; Ugwuoke, 2005).

Monthly hourly averages of open-circuit voltage, short-circuit current, power output and maximum power point were investigated and the plots for a typical dry season month (January) and a typical rainy season month (August) are shown in Figures 6 to 9.

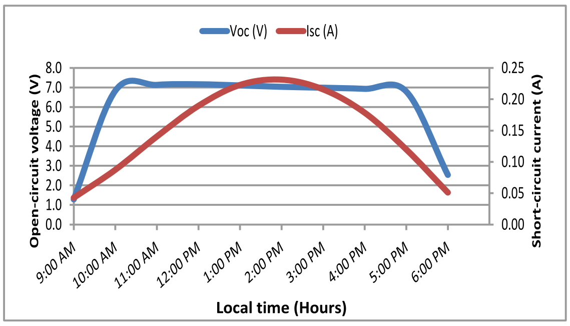

Figure 6: Hourly average variation of open-circuit voltage and short-circuit current of polycrystalline silicon module as a function of time for the month of January 2015

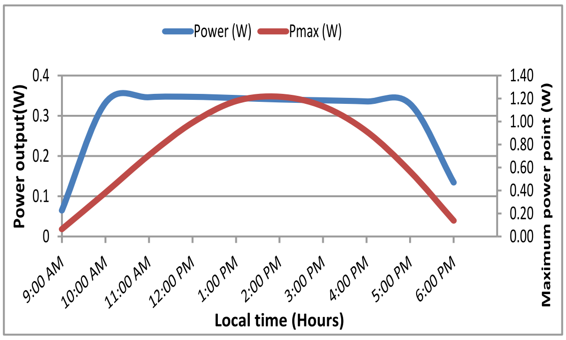

Figure 7: Hourly average variation of power and maximum power of polycrystalline silicon module as a function of time for the month of January 2015

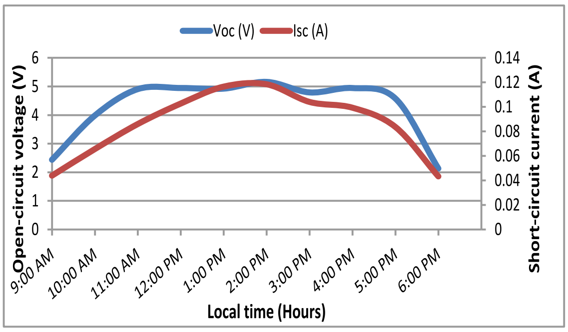

Figure8: Hourly average variation of open-circuit voltage and short-circuit current of polycrystalline silicon module as a function of time for the month of August 2015

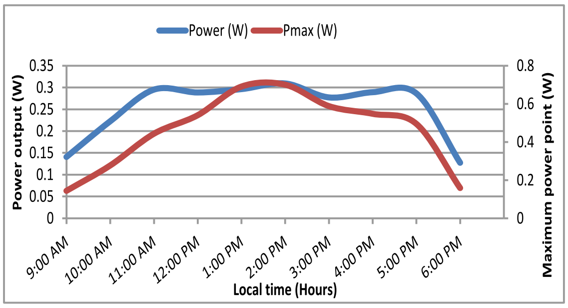

Figure 9: Hourly average variation of power and maximum power point of polycrystalline silicon module as a function of time for the month of August 2015

It was observed that open-circuit voltage peaks earlier in the day than short-circuit current for the module. The open-circuit voltage peaks at 11.00 am local time for the typical dry season month of January and then for the typical rainy season month of August, open-circuit voltage peaks at 2:00 pm local time. On the other hand the short-circuit current maintains a steady peak time of 2:00 pm local time for the two seasons. This is in the afternoon time when the module temperature is high, confirming that short-circuit current has a linear relationship with module temperature and solar irradiance. It is equally observed that power output peak time coincides with open-circuit voltage peak time and maximum power point peak time coincides with short-circuit current peak time for the polycrystalline silicon module. Thus, confirming earlier suggestion that current is more correlated to maximum power point than voltage and the well-known fact that output voltage and power of crystalline silicon photovoltaic modules decreases at high temperatures as their module temperature increases. This is further alluded to by the shape of the curves of these performance variables as seen in the Figures.

Hourly average values of the module performance variables and ambient parameters for the one year duration of this study are shown in Tables 2.

Table 2: Annual hourly averages of ambient parameters and performance variables for the polycrystalline silicon module

T (Hours)	H_g (W/m^2)	T_a (°C)	T_{mod} (°C)	V_{oc} (V)	I_{sc} (A)	Power (W)	P_{max} (W)	RH (%)	WS (m/s)
9:00 AM	258	26.5	27.6	3.30	0.056	0.169	0.186	65.3	1.99
10:00 AM	427	27.8	30.6	6.12	0.099	0.306	0.461	61.8	2.18
11:00 AM	569	29.1	33.5	6.52	0.143	0.324	0.724	54.5	2.17
12:00 PM	666	30.3	36.3	6.61	0.178	0.327	0.920	53.2	2.08
1:00 PM	708	31.3	38.4	6.66	0.202	0.331	1.064	51.5	2.02
2:00 PM	696	32.2	39.9	6.62	0.208	0.330	1.089	48.8	1.93
3:00 PM	608	32.7	40.0	6.46	0.190	0.324	0.990	47.3	1.87
4:00 PM	482	33.0	39.3	6.43	0.161	0.321	0.827	45.7	1.82
5:00 PM	309	32.9	37.4	5.98	0.110	0.301	0.536	44.9	1.71
6:00 PM	139	31.9	33.8	2.83	0.052	0.154	0.170	46.2	1.59

The monthly average values of solar irradiance, wind speed and relative humidity together with open-circuit voltage, short-circuit current, maximum power point and module temperature for the polycrystalline module is presented in Table 3.

Table 3: Monthly average values of ambient parameters with the performance variables

Month	H_g (W/m^2)	WS (m/s)	RH (%)	V_{oc} (V)	I_{sc} (A)	P_{max} (W)	T_{mod} (°C)
Dec 14	509.5	1.68	32.08	5.880	0.146	0.699	35.14
Jan 15	529.8	1.99	25.97	5.919	0.147	0.721	33.63
Feb 15	529.6	1.59	32.06	5.693	0.139	0.656	39.22
Mar 15	537.6	1.88	33.14	5.761	0.140	0.670	39.49
Apr 15	569.0	1.70	31.99	6.211	0.157	0.779	40.54
May 15	509.9	1.81	55.87	6.301	0.151	0.747	37.71

Jun 15	424.3	1.74	71.40	5.596	0.125	0.587	33.03
Jul 15	415.7	1.68	73.14	5.555	0.124	0.573	32.52
Aug 15	326.4	1.45	81.08	4.292	0.086	0.379	30.42
Sep 15	415.8	1.47	74.15	5.174	0.128	0.627	33.21
Oct 15	479.9	1.39	70.175	6.071	0.153	0.761	35.75
Nov 15	557.9	1.41	35.3364	6.250	0.176	0.893	38.00

Table 4: Summary of performance response for the module at different irradiance levels

Irradiance (W/m^2)	V_{oc} (V)	I_{sc} (A)	P_{max} (W)	V_{max} (V)	I_{max} (A)	FF	Eff (%)
276	6.83	0.131	0.624	6.439	0.097	0.698	10.64
375	6.81	0.158	0.869	6.052	0.144	0.810	10.91
437	6.90	0.190	0.921	6.354	0.145	0.703	9.90
537	6.83	0.205	1.113	5.892	0.189	0.795	9.74
643	6.93	0.231	1.196	6.263	0.191	0.748	8.73
743	6.81	0.255	1.394	5.847	0.238	0.801	8.79
835	6.74	0.271	1.402	5.882	0.238	0.767	7.87
912	6.77	0.249	1.221	5.224	0.234	0.726	6.29
933	7.03	0.242	1.222	6.374	0.192	0.719	6.16
1000	7.00	0.255	1.323	5.646	0.234	0.741	6.20

$T_{mod} = 41.7^oC$

MPR = 0.13

Pmax (%) = 13.23%

It was observed here that wind speed peaked in the month of January, during the dry season of the study area, normally characterised by strong North-East trade wind and favours open-circuit voltage more than short-circuit current (amidst other factors). Also, it is observed that module temperature recorded relatively low value, vis-a-vis their irradiance levels during this month. This is because high wind speed leads to increased rate of heat transfer from the module to the ambient resulting in the low module temperature. Relative humidity peaked in the month of August, which is the peak of rainy season of the study area and leads to lowest insolation level also witnessed in this month because increased water content in the atmosphere gives rise to cloudy weather which results in the absorption and scattering of sun's rays. Other factors being equal, high relative humidity brings about low module temperature which would normally favour open-circuit voltage more than short-circuit current. However, with such high value of relative humidity as recorded in August, its effect becomes domineering and results in very low insolation level that dictates the results of other parameters as is shown in the Table. This explains the lowest recorded values of all the performance variables for the module.

The performance of the polycrystalline photovoltaic module at different levels of solar irradiance (global irradiance) for the period studied were summarised in Table 4. Fill factor and efficiency at different levels of irradiance for the module were also computed and inserted.

For comparison between outdoor module performance and STC specifications, module performance ratio (MPR), module temperature and maximum power at 1000 W/m^2 are equally presented. The maximum power output achieved for the module at 1000 W/m^2 was 1.323 W representing 13.23 % of the manufacturer's power specifications for the polycrystalline photovoltaic module. Module efficiency recorded maximum value of 10.91 % at irradiance of 375 W/m^2. This maximum value then decreased steadily with increased irradiance and at 1000 W/m^2 the efficiency reduced to 6.20 % as against manufacturer's specification of 46 %. Open-circuit voltage at 1000 W/m^2 was 7.00 V as against manufacturer's specification of 21.6 V, while the short-circuit current was 0.255 A as against manufacturer's specification of 0.67 A. Maximum current, I_{max} recorded 0.234 A, as against STC value of 0.59 A. Therefore, module performance ratio for the PV module under investigation is 0.13 and it was equally observed here that the module did not record module temperature of 25 °C at 1000 W/m^2 solar irradiance as usually assumed for STC condition, rather, as seen in Table 4, the module temperature is well beyond 25 °C in the local environment. It is then quite clear and obvious, given the enormous margin of deviation of the outdoor characterised values from the manufacturer's STC specifications, that STC data is suspect; it is only handy in making comparison among solar modules. Designing with manufacturer's STC data will produce an unreliable and defective PV power system. In addition, over specified modules are flooding our local market.

3.1 RESULTS OF STATISTICAL ANALYSIS AND MODELS

Models for V_{oc}, I_{sc}, P and P_{max} were analysed in this section. The prediction models at different levels of irradiance and module temperature for the performance variables resulting from this work are all good, judging by statistical index, and are as follows:

$$V_{oc} = 1.11 + 0.00564H_g + 0.0523T_{mod} \quad (5)$$

$$I_{sc} = -0.0759 + 0.000219H_g + 0.00298T_{mod} \quad (6)$$

$$P = 0.106 + 0.000258H_g + 0.00156T_{mod} \quad (7)$$

$$P_{max} = -0.49019 + 0.00130H_g + 0.0151T_{mod} \quad (8)$$

3.2 Comparison between Measured and Predicted Performance Variables

The predicted performance variables at different levels of irradiance and module temperature were plotted with the measured variables for the polycrystalline silicon module and presented in Figures 10 – 13. Here it is seen that the predicted short-circuit current shows exact profile with the measured short-circuit current. This again confirms that output current of the PV module has linear relationship with solar irradiance and module temperature while output voltage and power have non-linear relationship with these ambient parameters.

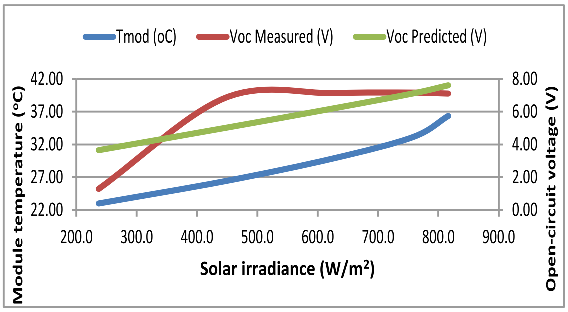

Figure 10: Measured and predicted open-circuit voltage with module temperature as a function of solar irradiance for the polycrystalline module

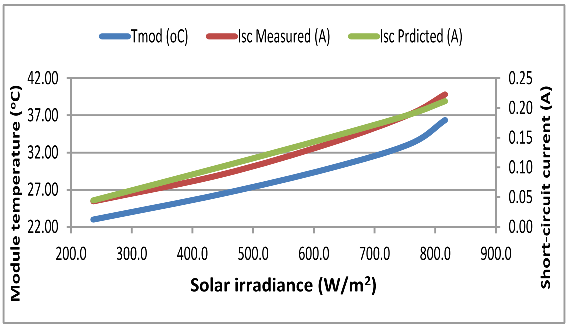

Figure 11: Measured and predicted short-circuit current with module temperature as a function of solar irradiance for the polycrystalline module

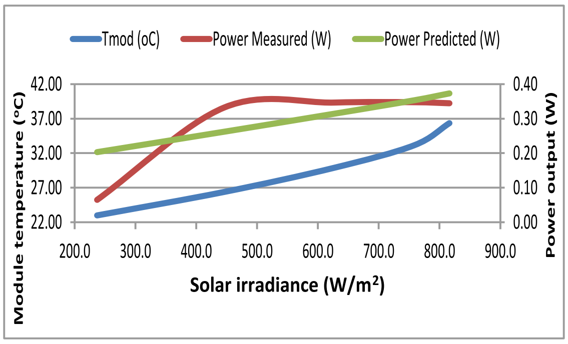

Figure 12: Measured and predicted power output with module temperature as a function of solar irradiance for the polycrystalline module

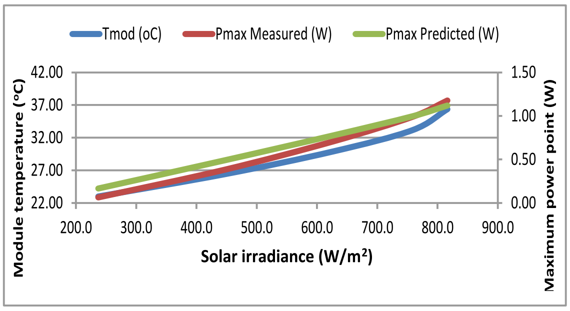

Figure 13: Measured and predicted maximum power with module temperature as a function of solar irradiance for the polycrystalline module

4.0 CONCLUSION

The outdoor characterisation and performance evaluation of the polycrystalline photovoltaic module in Minna local environment reveals that actual values of performance variables of the module differ greatly from the manufacturer's specifications. The magnitude of the difference between STC specification and the realistic outdoor performance, in this particular study, points to the fact that over rated modules are entering our local market. The maximum power output achieved for the module at irradiance of 1000 W/m^2 was 1.323 W representing 13.23 % of the manufacturer's maximum power specification. While maximum efficiency peaked at irradiance of 375 W/m^2 with efficiency value of 10.91 %. This maximum value then dropped steadily with increase in irradiance and, at 1000 W/m^2, reduced to 6.20 % as against manufacturer's specifications of 48 %. Similarly, it was observed that the module did not record 25°C module temperature at irradiance of 1000 W/m^2 as used in STC specifications by the manufacturer. Module temperature was therefore observed to have significant influence on the general performance of the module.

It is recommended that outdoor characterisation and performance evaluation of all commercially available PV modules be carried out in every location of developing countries where this is lacking. Results should be collated, adopted and installers of PV power systems made to abide by the regulations thereof to ensure technical quality. Also, government should put adequate mechanism in place to checkmate over rated PV modules and dumping.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Contributors: This article is an excerpt from PhD work of the corresponding author supervised by the co-authors and all contributors oblige its publication.

Conflicts of interest: None

REFERENCES

Almonacid, F., Rus, C., Hontoria, L., Fuentes, M. and Nofuentes, G., (2009). Characterisation of Si-Crystalline PV Modules by Artificial Neural Networks, *JOURNAL OF RENEWABLE ENERGY*, 34 (4) 941-949; www.elsevier.com/locate/renene

Electricity sector in Nigeria (2025). https://en.wikipedia.org (Accessed on 27.04.2025).

Bajpai, S.C. & Gupta, R.C. (1986). Effects of Temperature Variations on the Performance of Monocrystalline Solar Cells. *NIGERIAN JOURNAL OF SOLAR ENERGY*, 5, 35-41.

Ezenwora, J.A., Oyedum, O.D. and Ugwuoke, P.E. (2018); Comparative Study on Different Types of Photovoltaic Modules Under Outdoor Operating Conditions in Minna, Nigeria, in *International Journal of Physical Research, Vol. 6 (1), pp 35-48.*

Midwest Renewable Energy Association Fact Sheet: Off Grid PV Systems (2013). www.doe.erec@nciinc.com, (accessed 13.05.13).

Ugwuoke, P.E. & Okeke, C.E., 2012. Performance Assessment of Three Different PV Modules as a Function of Solar Insolation in South Eastern Nigeria, *INTERNATIONAL JOURNAL OF APPLIED SCIENCE AND TECHNOLOGY*, 2 (3), 319-327; www.ijastnet.com

Ugwuoke, P.E., (2005). Characterisation and Performance Evaluation of Crystalline and Amorphous Photovoltaic Modules in Nsukka Under Field Conditions. PhD Thesis, Department of Physics and Astronomy, University of Nigeria, Nsukka.

Ugwuoke, P.E., Ezema F.I. & Okeke C.E. (2005). Performance Response of Monocrystalline PV Modules to Some Meteorological Parameters at Nsukka, *NIGERIAN JOURNAL OF SPACE RESEARCH*, 3 (2), 63-69.