International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 6 Issue 7 Ver. I ǁ 2018 ǁ PP. 01-13

Analysis of PV Modules Performance in Nigeria: A Guide for Suitable System Design and Module Specifications Selection

Nduka O. Arinze[1], & Mohamed Emad Farrag[2],
[1]*National Agency for Science and Engineering Infrastructure (NASENI) Solar Energy Limited, Nigeria.*
[2]*School of Engineering and Built Environment, Glasgow Caledonian University, Glasgow UK. Email:*
Corresponding Author: Nduka O. Arinze

Abstract: *Photovoltaic (PV) cells and modules are used to generate electricity directly from the sun (solar energy). These cells and modules are tested by their manufacturers typically at 1000W/m^2 solar radiation, 25^{o}C PV-module temperature and about 1m/s wind speed (air mass of 1.5) as the Standard Test Conditions (STCs). However, the outdoor operating conditions for an installed PV module is not controlled and therefore, vary with the above standard conditions. The climatic factors influencing the performance of a PV module are mainly ambient conditions (available solar radiation at the selected location) and the location based PV-module temperature. Thus, this work uses the daily meteorological data (ambient temperature, solar radiation and wind speed) of eight Nigerian cities to calculate city-based PV-module temperature, which in-turn is used with the solar radiation data to simulate the electrical outputs and efficiencies of the three commercially available PV Module types in Nigeria. The simulated open circuit voltage V_{oc}, short circuit current I_{sc}, actual/real power output and efficiency of monocrystalline, polycrystalline and amorphous silicon PV modules, 100W each, are presented in this work. The city based results have been analysed in each month of the year. The analysis showed that PV-module temperature has less impact on amorphous silicon PV module's actual power output, but the most impact is on that of polycrystalline silicon module. Also, months and locations with high module temperature, recorded low efficiency and V_{oc}, however, high efficiency and V_{oc} were recorded for months and locations with low module temperature. On the other hand, months and locations with high solar radiation, recorded better real power and I_{sc}. Thus, decisions on PV specifications and PV array design suitable for any of the locations studied in this work should be guided by the above facts; in consideration of the negative and positive impacts due to the variations between the STCs and actual operation conditions.*

Key words: *Photovoltaic Cells, module temperature, STCs, climate data.*

Date of Submission: 20-07-2018 Date of acceptance: 03-08-2018

I. INTRODUCTION

Nigeria is blessed with reasonable amount of sun shine, both during the dry and rainy seasons. Nigeria has average daily sunshine hours of 6.25 hours anually; 9.0 hours in the far northern region and 3.5 hours in the coastal areas (Bala *et al*, 2000). Solar PV technology converts solar energy directly to electricity through PV Cells (connected together to form a PV module). PV modules are exposed to capture the energy from the sun (solar energy) by installing them outdoor where they can receive every available sun ray. The capturing of solar radiation by the PV cells/modules results into electric power output.

The performance of a PV module strongly depends on ambient conditions such as available solar radiation at the selected location and the location based PV-module temperature (Zhou *et al*, 2007). According to Bücher (1997), the Standard Test Conditions (STCs) used in the rating of PV-modules are mainly 1000W/m^2 irradiation and 25^{o}C PV-module temperature. Obviously, the STCs vary with the real outdoor conditions of locations, days, and months in Nigeria. It is very needful to have a reliable knowledge and understanding of the PV-module performance under the actual climatic conditions for correct product selection criteria and accurate prediction of their energy performance (Zhou *et al*, 2007).

Different approaches have been used by researchers to predict the performance and estimate the efficiency and actual electrical output of PV module types under the outdoor operating conditions. This has been going on for more than 35 years (Sarhaddi *et al*, 2010). Software such as SunSim, RETScreen, PVForm and many others are used to estimate the electrical outputs and system size of PV systems. Thermal models such as the ones developed by SNL (King *et al*, 2004) and NREL (TamizhMani *et al*, 2003) have been used in predicting PV-module temperature of any module type at any location in the world. Also, investigations such as the ones conducted by Nordmann and Clavadescher (2003); Nishioka *et al* (2003); Hamrouni et al (2008); Zdravkovic *et al* (2009); Abdelkader *et al* (2010); Buday (2011); Ugwuoke *et al* (2006) had been carried out on the influence of climatic parameters on the performance of PV modules. Kozak *et al* (2009); Kurtz *et al* (2009) had used Meteorological data from database of weather stations to analyze the influence of climatic conditions on PV modules performance.

According to Skoplaki and Palyvos (2009), among all the thermal models, the empirical thermal model developed by King et al (2004) is simpler and more adaptable and it provides ±5°C accuracy in the prediction of the PV module's operating temperature. With this model, Kurtz *et al* (2009) used Typical Meteorological Year (TMY3) data sets to investigate the thermal exposure of PV modules. Hence, this work presents the analysis of PV modules performance at eight (8) selected Nigerian cities with the use of the empirical thermal model developed by King et al (2004) to calculate the city-based Module-Temperature.

II. PHOTOVOLTAIC CELLS/MODULES: THEORITICAL BACKGROUND

The performance of PV cells/modules are assessed based on their electrical outputs, temperature, efficiency and durability. This is usually represented in current-voltage (I-V) curves. According to Hankins (1995), I-V curves are used to compare PV cells/modules, and also to determine their performance at various climatic conditions. The conditions used by manufacturers to plot I-V curves of PV cells/modules of any type are solar irradiance of 1000W/m^2 and module temperature of 25°C. Figure 1 shows a typical I-V curves for a PV cell/module at different solar radiations and temperatures.

——————— : Solar Radiation at 1000W/m^2 and different Temperatures

- - - - - - - - - - : Cell/Module at 25°C and different Radiations

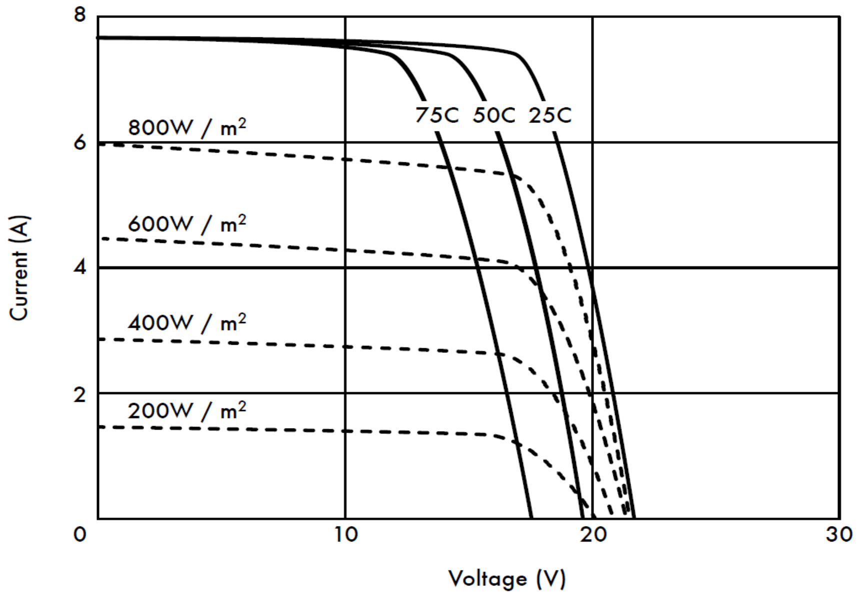

Fig 1: typical I-V curve for current at different solar radiations and voltage at different cell/module temperatures. **Source:** *wndw.net/pdf/wndw2-en/ch07-solar.pdf*

The PV-module temperature is commonly calculated using:

$$T_m = T_{amb} + \frac{\text{NOCT-20}}{800} * G(W/m^2) \qquad (1)$$

Where T_m = PV-module temperature

T_{amb} = ambient temperature

NOCT = Normal Operating Cell Temperature of the PV module

G = Solar irradiance (in W/m^2)

NOCT is defined as the mean solar cell junction temperature within an open-rack mounted PV module in Standard Reference Environment (SRE) which include tilt angle at normal incidence to the direct solar beam at local solar noon, total irradiance of 800 W/m^2, ambient temperature of 20°C and wind speed of 1 m/s at no electrical load (Garcia *et al*, 2004). It is usually included in PV module data sheets by manufacturers. Obviously, the conditions used to calculate NOCT vary with the outdoor condition where the PV modules are installed. Thus, researchers have made efforts to develop models for calculating the PV-module temperature through actual field measurements and thermal modelling.

The model that seems more acceptable was developed by King *et al*, (2004) at Sandia National Laboratory (SNL), USA; as testified by Skoplaki and Palyvos (2009).

$$Tm = E * \exp(a + b * WS) + Ta \qquad \textbf{(2)}$$

Where:
T_m = Back-surface module temperature, (°C).
T_a = Ambient air temperature, (°C)
E = Solar irradiance incident on module surface, (W/m^2)
WS = Wind speed measured at standard 10-m height, (m/s)
a and b are constants which depend on mount type.

For open-rack mount, equation **(2)** is given by:

$$T_m = T_a + E * e^{(-3.473 - 0.0594*WS)} \qquad \textbf{(3)}$$

Electric power (active), is the product of electric current flowing into and the voltage across the PV terminals. PV modules are described based on their rated maximum power and the peak power outputs without any losses (usually theoretical). The rated maximum power is given by:

$$Pm = Im * Vm \qquad \textbf{(4)}$$

Where;
I_m = rated maximum power current,
V_m = rated maximum power voltage

Whereas the theoretical peak power output of a PV module is given by:

$$P = Isc * Voc \qquad \textbf{(5)}$$

Where;
I_{sc} = short circuit current,
V_{oc} = open circuit voltage.

However, given the solar irradiance of a location (G, in W/m^2), the estimated outdoor/site maximum power output of a PV panel with area (A, in m^2) and efficiency (η, in %) is given by:

$$P = G * A * \eta \qquad \textbf{(6)}$$

The open circuit voltage (V_{oc}) in equation **(5)** at any given climatic/outdoor condition, is given by:

$$V_{oc}(\text{at } T_m) = V_{oc}(\text{STC}) - K * (T_m - 25) \qquad \textbf{(7)}$$

Where;
V_{oc}(STC) = rated open circuit voltage at 25^{o}C,
T_m = module temperature, and
K= Temp coeff (i.e. the rate of decrease in voltage per ^{o}C rise in temperature).

The short circuit current of PV module in equation **(5)** at any condition is given by:

$$I_{sc}\ (\text{at G}) = I_{sc}\ (\text{STC}) * \frac{G}{1000} \qquad \textbf{(8)}$$

Where;
I_{sc}(STC) = the rated short circuit current at irradiance of 1000W/m^2
G = the actual recorded solar irradiance (in W/m^2) at a particular time and location.

The maximum power a PV module can produce under the actual outdoor operating conditions is given by: $Pmp = Isc(\text{at G}) * Voc(\text{at } Tm) * FF$ **(9)**
Where;
I_{sc}(at G) = the short circuit current at the actual solar irrediance G(W/m^2),
V_{oc}(at T_m) = the open circuit voltage at the actual PV-module temperature and
FF = fill factor of the PV module .

Maximum Power (P_{mp}) output of a PV module is the point on its Current-Voltage (I-V) curve under the actual climatic conditions, where the product of output current and output voltage is maximum. This is indicated at the sharp bend point on the I-V curve in Figure 2.

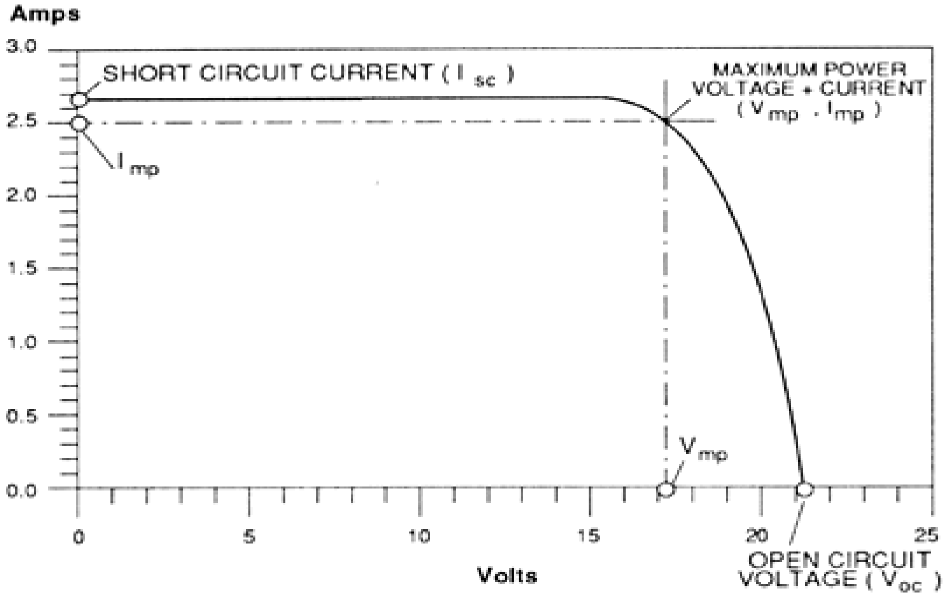

Fig 2: The I-V curve showing the maximum power point.
Source: *http://www.daviddarling.info/encyclopedia/I/AE_I-V_curve.*

PV Module Fill Factor (FF) is the ratio of the rated maximum power to the theoretical peack power. FF is dimensionless and is given by:

$$FF = \frac{I * V}{I_{sc} * V_{oc}} \quad \textbf{(10)}$$

The efficiency of the PV module is a measure of the percentage of solar power (it receives on a given area) that it can convert to electric power under the operating conditions. It is given by:

$$\eta = \frac{P_{out} * 100\%}{P_{in}} \quad \textbf{(11)}$$

Where;
P_{out} is the output electric power and
P_{in} (irradiance*PV module Area) is the available solar power per m^2 received by the PV module.

III. CASE STUDY

The eight cities selected for this work are Abuja, Akure, Awka, Enugu, Kano, Maiduguri, Minna and Sokoto. These cities are selected based on the peculiarity of their climates and their significance in the popularization of solar electricity in Nigeria. Among these cities, Abuja, Kano, Maiduguri, Minna and Sokoto are located in the Northern region while Akure, Awka and Enugu are located in the Southern region of the country. Table 1 shows average daily city based sunrise (at 7am), sunset (at 6pm) and maximum (at mid-day for ambient temperature and solar radiation and at sunrise/sunset for wind speed) values of the years 2009 and 2010 climate data. As represented Figures 3, 4 and 5, the 2009 and 2010 average annual climate data are: ambient temperature (28.16 – 33.04 ^{o}C), solar radiation (206.24 – 272.55 W/m^2) and wind speed (1.73 – 4.73 m/s).

Table 1: City Based Sunrise, Sunset and Maximum Climate Data

City	Sunrise Temp	Sunset Temp	Max Temp	Sunrise Solar Rad	Sunset Solar Rad	Max Solar Rad	Sunrise Wind Speed	Sunset Wind Speed	Max Wind Speed
Abuja	21°C	25°C	33°C	109W/m^2	102W/m^2	570 W/m^2	6m/s	5.5m/s	6m/s
Akure	19 °C	21°C	29°C	107W/m^2	103W/m^2	577 W/m^2	4.1 m/s	4.7 m/s	4.7m/s
Awka	19 °C	22°C	28°C	108W/m^2	105W/m^2	520 W/m^2	3.6 m/s	3.7 m/s	3.7m/s
Enugu	21 °C	22°C	31°C	107W/m^2	107W/m^2	525 W/m^2	4.87 m/s	5.88m/s	5.88m/s
Kano	20 °C	21°C	36°C	114W/m^2	111W/m^2	642 W/m^2	7.5 m/s	6.7 m/s	7.5m/s
Minna	24°C	23°C	38°C	109W/m^2	108W/m^2	595 W/m^2	4.1 m/s	4.4 m/s	4.4m/s
Maiduguri	20°C	22°C	39°C	120W/m^2	117W/m^2	786 W/m^2	5.03 m/s	6.31m/s	6.31m/s
Sokoto	21°C	21°C	37°C	117W/m^2	114W/m^2	727 W/m^2	5.67m/s	5.87m/s	5.87m/s

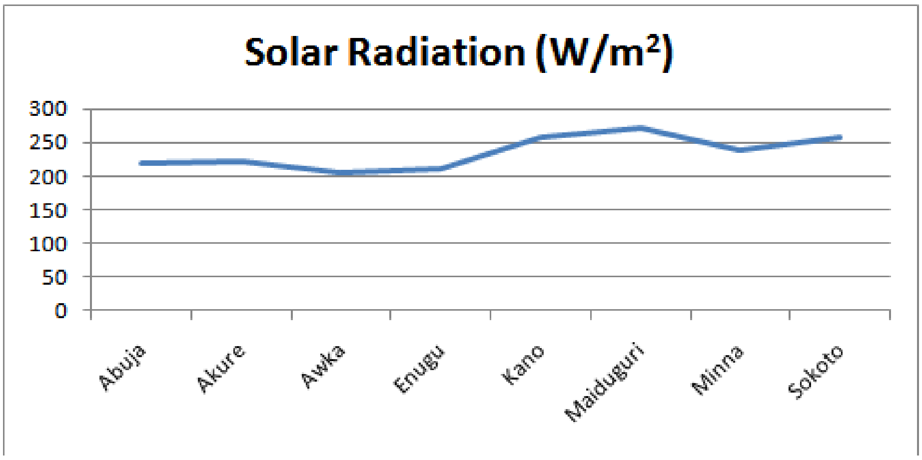

Fig 3: The annul city based solar radiation

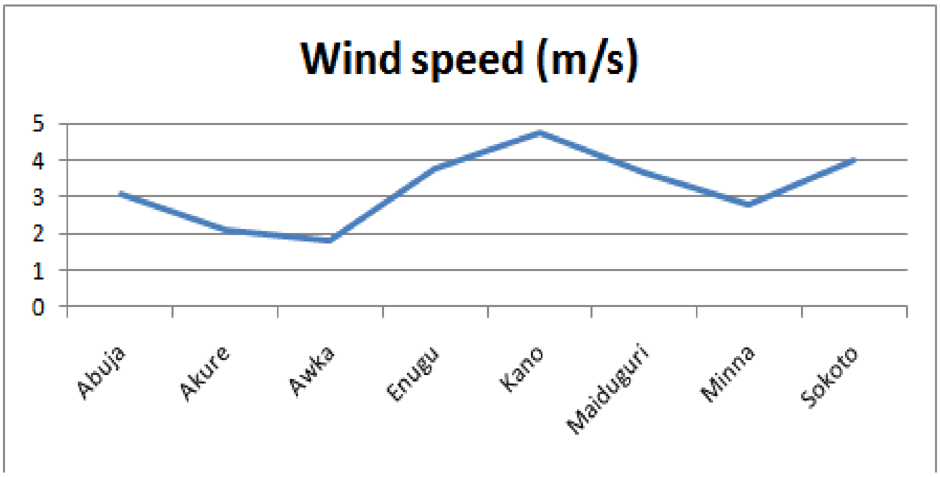

Fig 4: The annual city based wind speed

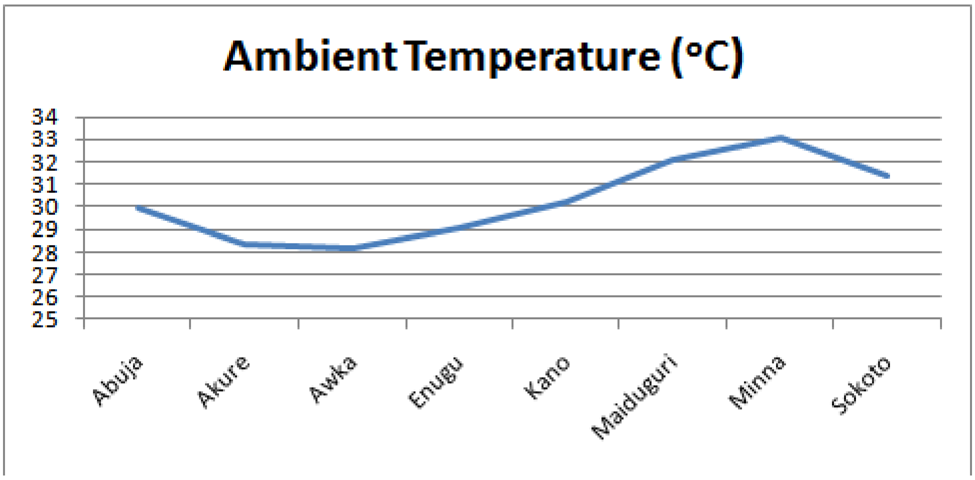

Fig 5: The annual city based ambient temperature

3.1 Procedure

Secondary data (climate data) analysis method is adopted in this work. This method is adopted based on the fact that the widely accepted equations **(2)** and **(3)** by King et al (2004) can be used for any location in the world. Hence, secondary data had been used to implement these equations.

The methodologies adopted are as follows:

i. Years 2009 and 2010 climate data (ambient temperature, solar radiation/insolation and wind speed) of eight selected cities of Nigeria were collected from the NIgerian METeorological Agency (NIMET).
ii. Microsoft Excel Spreadsheet was used to simulate city based PV-module temperature (T_m), open circuit voltage (V_{oc}), short circuit current (I_{sc}), real/actual power and efficiency of three PV module types (mono-crystalline, poly-crystalline and amorphous silicon), using equations **(3), (7), (8), (9)** and **(11)** respectively, based on the NIMET data.
iii. The results obtained were used to analyze the performance of each PV module type at each city and in each month of the year.

The climate data used; are the average day-time (7am to 6pm; typical sunrise to sunset period) ambient temperature, solar radiation and the corresponding wind speed. Solar radiation data from NIMET were initially given in MJ/m^2/day and were converted to W/m^2 using a conversion factor of 11.5741 (note: 1kWh/m^2/day = 3.6 MJ/m^2/day, therefore; 1 MJ/m^2/day = 11.5741 W/m^2). The wind speed data were given in knots and were converted to m/s by dividing the value by a factor of 2.

The manufacturer's specified characterizations for each PV modules are stated in Table 2.

Table 2: Data Sheet Information for The Three PV Module Technologies

Characterisation	**Mono-crystalline Silicon Module**	**Polycr-ystalline Silicon Module**	**Amorphous Silicon Module**
P_{max}	100W	100W	100W
Efficiency	18%	17%	10%
V_{max}	19.0V	17.2V	77.0V
I_{max}	5.26	5.8A	1.293A
V_{oc}	22.8V	21.6V	99.0V
I_{sc}	5.68	6.46A	1.65A
Temp Coefficient of P_{max}	-0.44%/^{o}C	-(0.5+/-0.05)%/^{o}C	-0.33%/^{o}C
Temp Coefficient of V_{oc}	-0.36%/^{o}C	-(80+/-10)mV/^{o}C	-0.2%/^{o}C
Area	0.6465m^2	0.77787m^2	1.5752m^2

IV. PV MODULE PERFORMANCE ANALYSES

The average of 2009 and 2010 meteorological data of each of the selected cities was used to ascertain the level of city based climatic impacts on the outputs of each type of PV module. As a result, analysis on which climatic parameter(s) influenced the PV module(s) performance most, the PV technology whose outputs have been influenced most, and the month(s) of the year and location that produced the best and worst performances in terms of maximum real power and efficiency were carried out. **Figures 6 to 19** are the graphical representation of the analyses results.

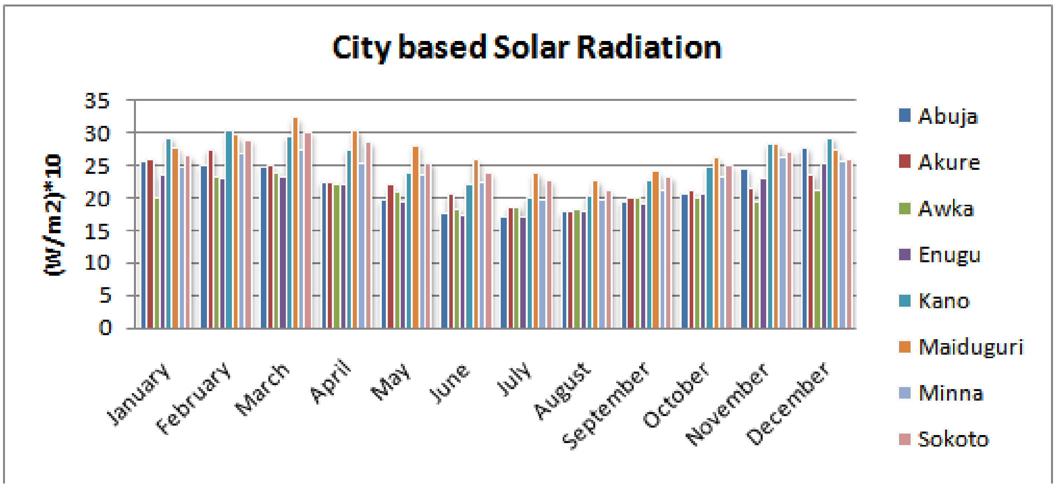

Fig 6: Graph of the average monthly solar radiation

Figure 6 above shows the average solar radiation in W/m^2 received at each city. It further indicates what month of the year the cities received what magnitude of solar radiation. This figure indicates that Maiduguri (in March) recorded the highest solar radiation of about $320W/m^2$, while Enugu (in July) recorded the lowest solar radiation of about $170W/m^2$.

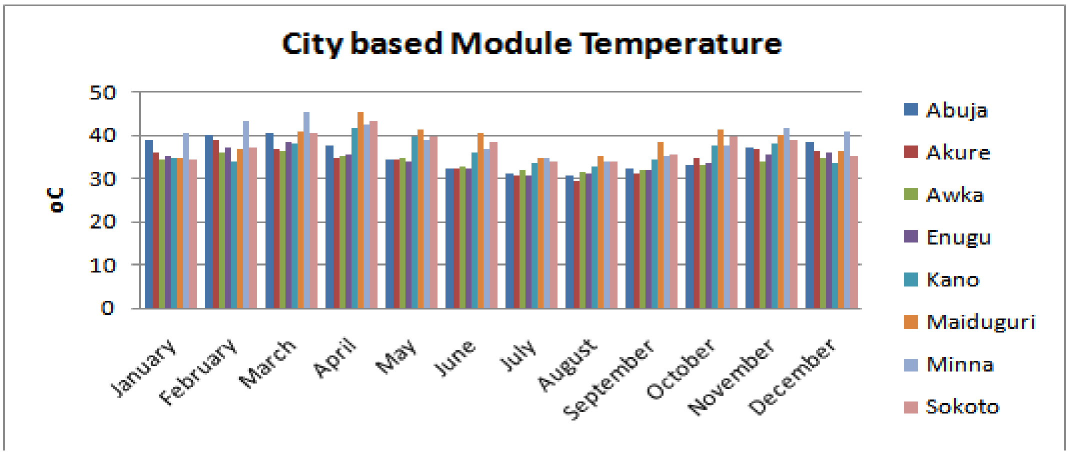

Fig 7: Graph of the average monthly PV module temperature

Figure 7 shows the PV-module temperature calculated for each city using **Equation 3**:

$$T_m = T_a + E * e^{(-3.473 - 0.0594*WS)}$$

This figure indicates that Maiduguri (in April) and Minna (in March) recorded the highest module-temperature (T_m) of above 45°C while Akure (in August) recorded the lowest T_m.

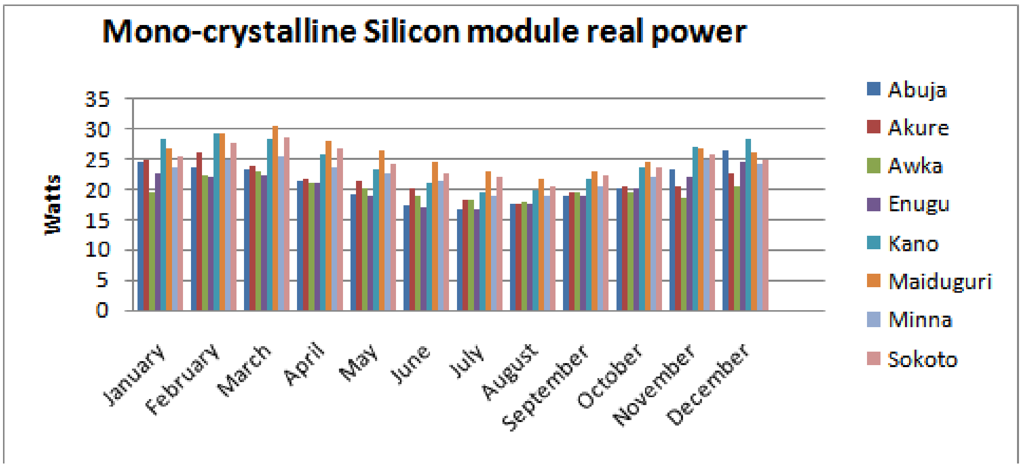

Fig 8: Graph of the mono-cystalline silicon module real power average monthly output

Figure 8 above shows the mono-crystalline silicon module real power recorded at each city in every month of the year. This figure indicates that mono-crystalline silicon module recorded the highest real power output of about 31W in March at Maiduguri, but its lowest output of about 17W was recorded in July at the cities of Abuja and Enugu.

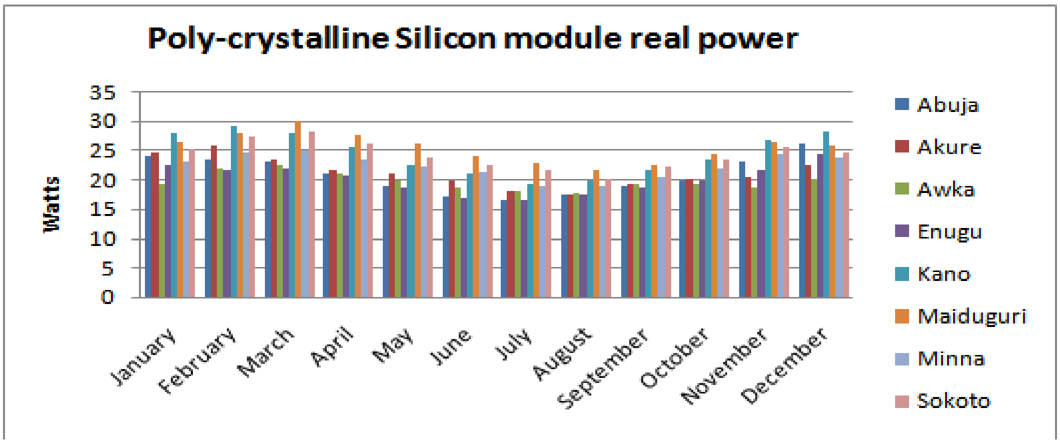

Fig 9: Graph of the poly-crystalline silicon module real power average monthly output

Figure 9 above shows the poly-crystalline silicon module real power recorded at each city in every month of the year. This figure indicates that poly-crystalline silicon module recorded real power output of 30W as the highest output in March at Maiduguri, but the lowest output of about 16W was recorded in July at Abuja.

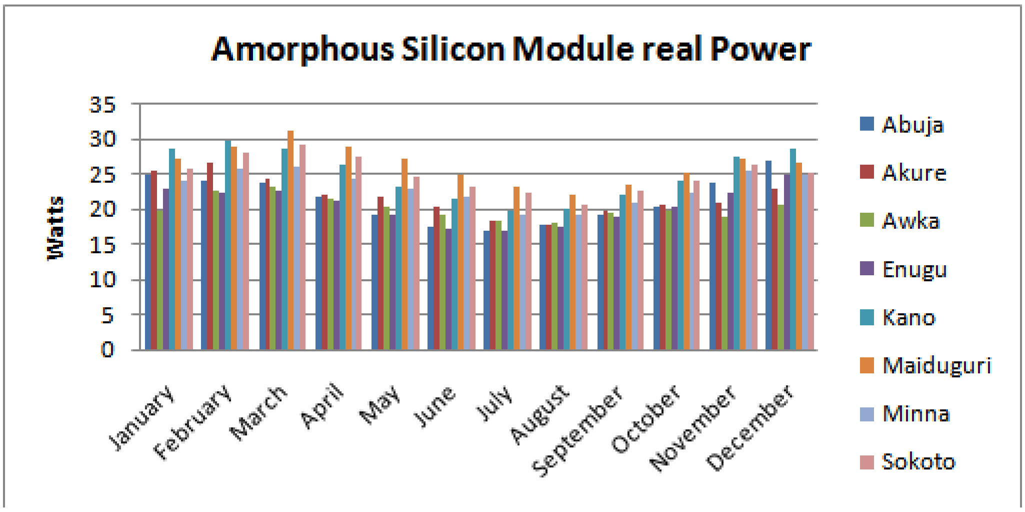

Fig 10: Graph of the amorphous silicon module real power average monthly output

Figure 10 shows the amorphous silicon module real power recorded at each city in every month of the year. This module recorded the highest real power of about 31W in March at Maiduguri and lowest of about 16W in July at Enugu city.

All the real power values recorded for each PV modules (for the three technologies) were calculated using **Equation 9**: $P_{mp} = I_{sc}(\text{at } G) * V_{oc}(\text{at } T_m) * FF$

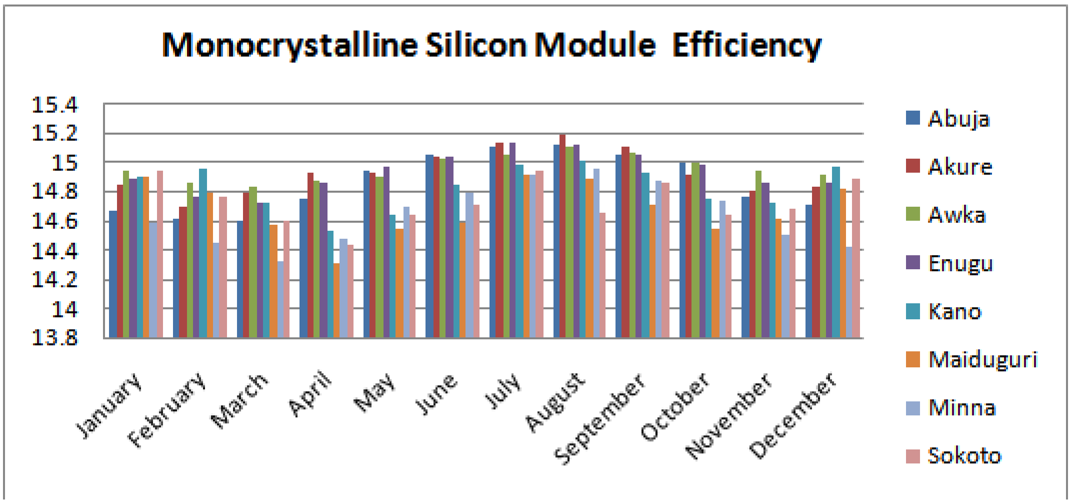

Fig 11: Graph of the monocrystalline silicon module average monthly efficiencies

Figure 11 above shows the mono-crystalline silicon module recorded efficiency at each city in every month of the year. The mono-crystalline module recorded its highest efficiency of about 15.2% in August at Akure, but its lowest efficiency of about 14.3% was recorded in March (at Minna) and April (at Maiduguri).

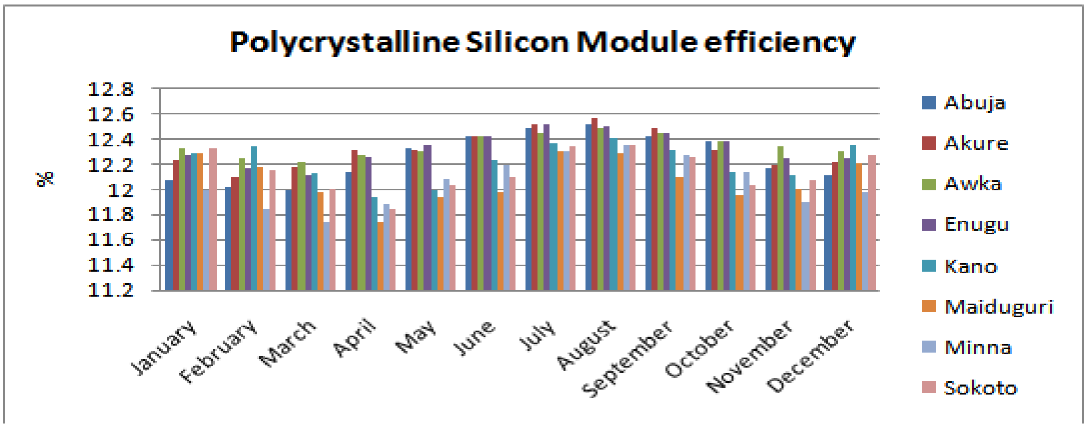

Fig 12: Graph of the polycrystalline silicon module average monthly efficiency

Figure 12 above shows the poly-crystalline silicon module recorded efficiency at each city in every month of the year. This module recorded its highest efficiency of about 12.5% in August at Akure, but its lowest efficiency of about 11.7% was recorded in March (at Minna) and April (at Maiduguri).

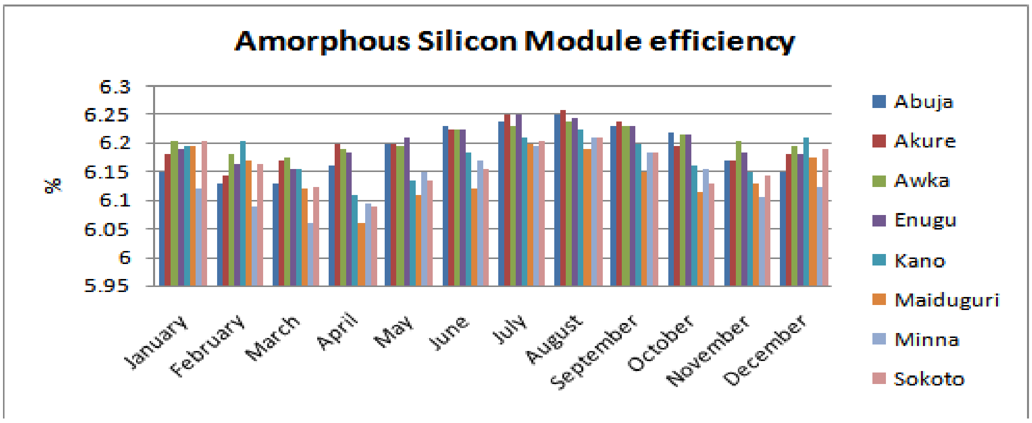

Fig 13: Graph of the amorphous silicon module average monthly efficiency

Figure 13 above shows the amorphous silicon module recorded efficiency at each city in every month of the year. For this module, the highest efficiency of above 6.25% was recorded in August at Akure, while the lowest efficiency of above 6.05% was recorded in March (at Minna) and April (at Maiduguri). All efficiencies recorded for each PV modules (for the three technologies) were calculated using **Equation 11**: $\eta = \frac{P_{out} * 100\%}{P_{in}}$

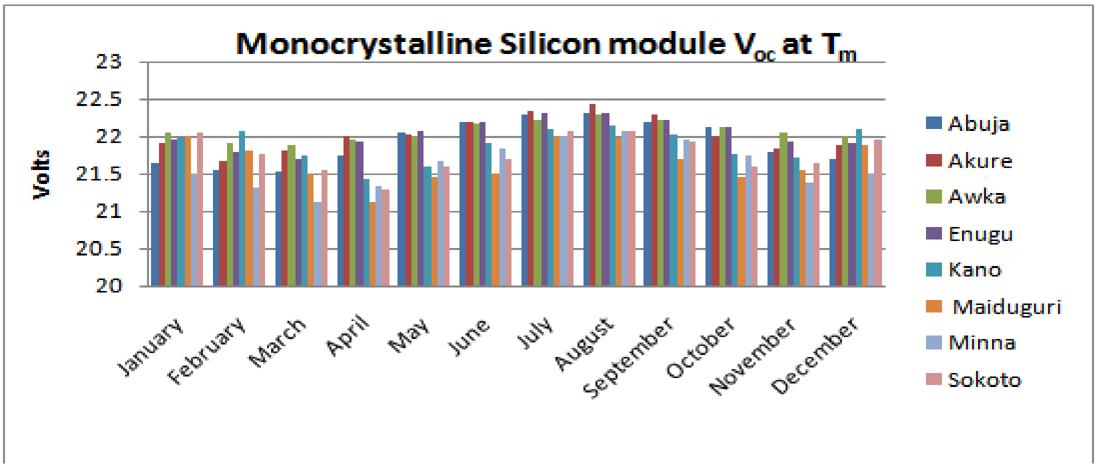

Fig 14: Graph of average Monthly V_{oc} of the mono-crystalline Silicon

Figure 14 above shows the open circuit (V_{oc})Voltage of mono-crystalline silicon module based on the module-temperature recorded at each city in every month of the year. The highest V_{oc} of 22.4V was recorded in August at Akure, while the lowest V_{oc} of about 21.2V was recorded in March (Minna) and April (Maiduguri).

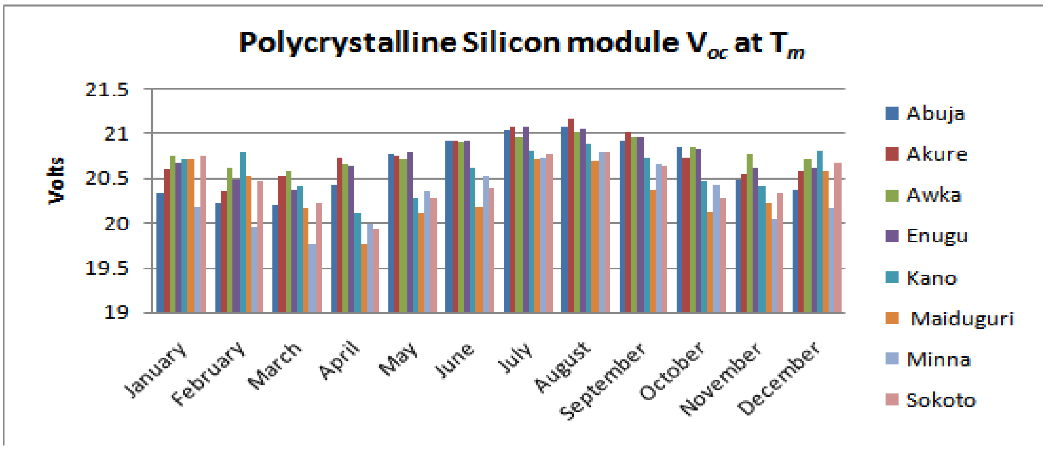

Fig 15: Graph of average monthly V_{oc} of the polycrystalline Silicon Module

Figure 15 above shows the open circuit (V_{oc}) Voltage of polycrystalline silicon module at the module-temperature recorded at each city in every month of the year. This module recorded a highest V_{oc} of about 21.2V in August at Akure, while its lowest V_{oc} of about 19.75V was recorded in March (at Minna) and April (at Maiduguri).

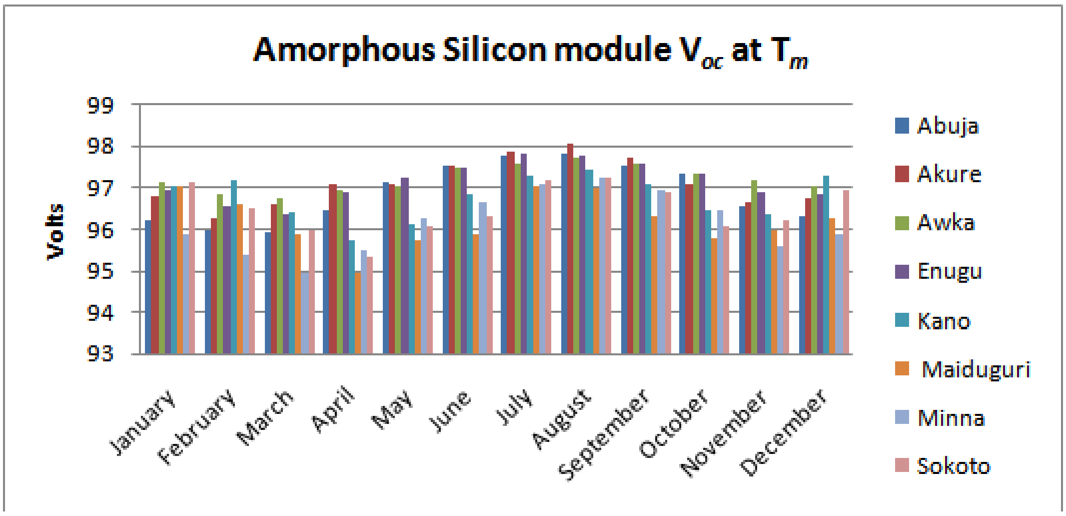

Fig 16: Graph of average monthly V_{oc} of the amorphous Silicon Module

Figure 16 above shows the open circuit (V_{oc}) Voltage of amorphous silicon module at the module-temperature recorded at each city in every month of the year. This module recorded its highest V_{oc} of about 98.1V in August at Akure, while its lowest V_{oc} of 95V was recorded in March (at Minna) and April (at Maiduguri). All open circuit (V_{oc}) values recorded for each PV modules (for the three technologies) were calculated using **Equation 7**: $V_{oc}(\text{at } T_m) = V_{oc}(\text{STC}) - K * (T_m - 25)$

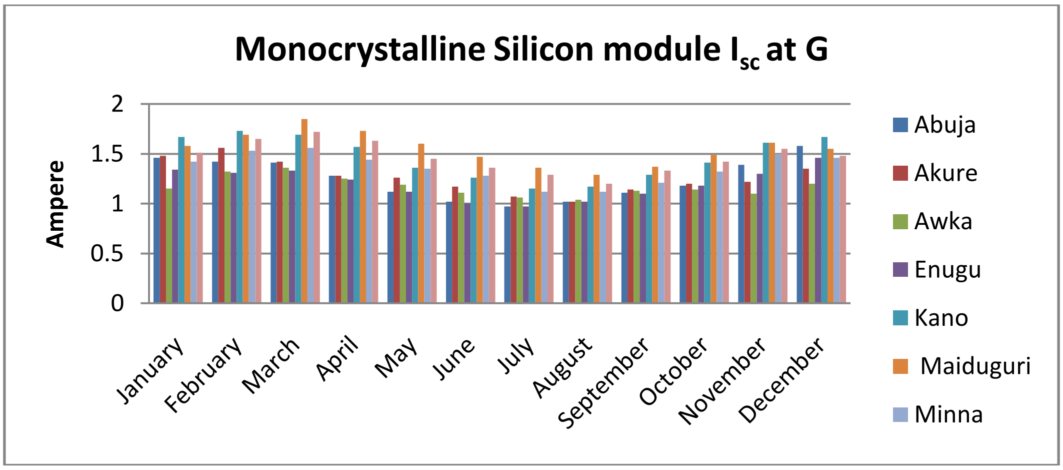

Fig 17: Graph of average Monthly Is_c of the mono-crystalline Silicon Module

Figure 17 above shows the short circuit current (Is_c) of the mono-crystalline silicon module, based on the average monthly solar radiation recorded at each city. This module recorded the highest monthly average of about 1.8A at Maiduguri in March, while the lowest value of about 0.9A was recorded in July at Abuja and Enugu.

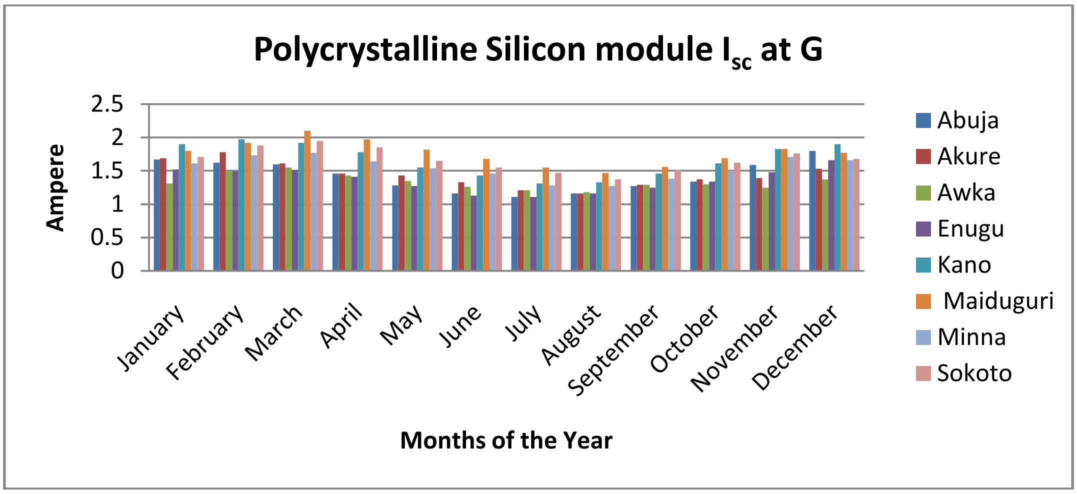

Fig 18: Graph of average Monthly Is_c of the poly-crystalline Silicon Module

Figure 18 above shows the short circuit current (Is_c) of polycrystalline silicon module based on the average monthly solar radiation recorded at each city. The highest value recorded by this module is about 2.2A in March at Maiduguri, while its lowest is about 1.2A in July at Enugu and Abuja.

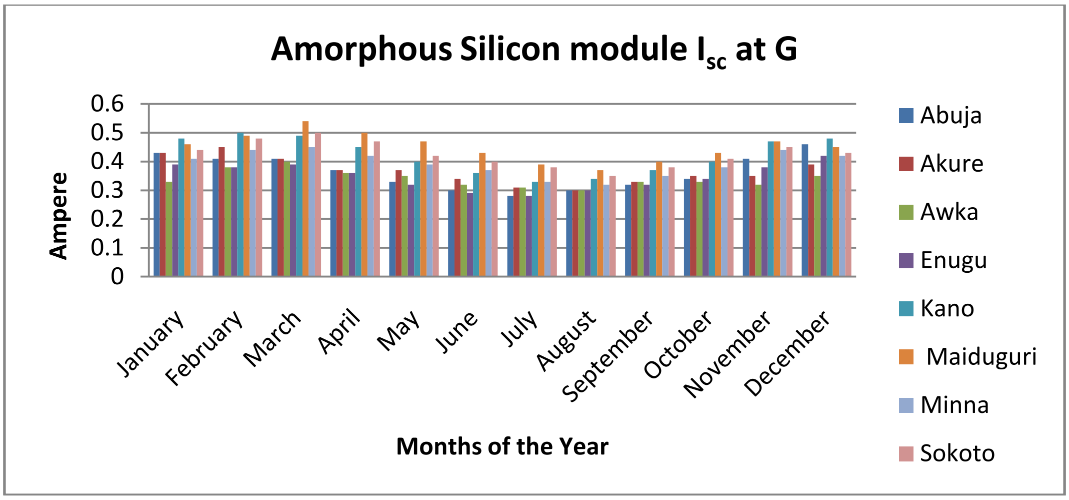

Fig 19: Graph of average Monthly Is_c of the amorphous Silicon Module

Figure 19 above shows the short circuit current (Is_c) of amorphous silicon module based on the solar average monthly solar radiation recorded at each city. The highest value recorded is about 0.55A in March at Maiduguri; while the lowest is about 0.29A at Abuja and Enugu in July. All short circuit current (Is_c) values recorded for each PV modules (for the three technologies) were calculated using **Equation 8**:

$$I_{sc}\ (\text{at G}) = I_{sc}\ (\text{STC}) * \frac{G}{1000}$$

4.1 Discussions and Results

The analyses in **Figures 6 – 13** show that the three PV module types produced higher electric power in locations and months of the year with higher solar radiation. However, the reverse is the case about their efficiencies, especially at locations and months with high PV module temperatures. Also, the above Figures have shown that whenever any two months with almost the same solar radiation (G) or one of them is a little lower than the other, the month that has lower module temperature T_m produces higher maximum real power. However, the above observation was not always the case with the amorphous silicon module, especially when the difference in their module temperature between them is very little. Some of the instances are summarized in Table 3 below.

Table 3: Comparison of the impact of Monthly Module Temperature Difference on the Modules

City and Year	Months	Month with higer T_m & G	Month with Better output	Remarks
Abuja	May & September	May	September	Only for monocrytalline modules
Minna	July & August	July	August	For the 2 crystalline silicon modules
Kano	March & December	March	December	For the 2 crystalline silicon modules

From **Table 3**, it means that if module temperature is kept constant and lower, and the solar radiation is increased, a PV module would perform very well. This also shows that module temperature does not affect amorphous silicon modules as much as it does to crystalline silicon modules (both mono and poly).

Matching **Figures 6 and 7, and Figures 14–16 and 17-19**, indicates that most of the cities where the PV modules recorded high short circuit current I_{sc}, have more availability of solar radiation, and are most times where they produce low open circuit voltage V_{oc} due to high PV-module temperature.

Therefore, in designing a PV array for cities with high ambient temperature and solar radiation, particular attention has to be paid to the maximum output voltage of the PV module that will form the array so that the number of PV modules connected in series should be more than those in parallel. Monocrystalline and Amorphous silicon PV module (connected more in series) appear more suitable for such locations (since they are known to have high maximum power voltage rating). On the other hand, array designs in the cities with low ambient temperature and low solar radiation, should have more modules connected in parallel to achieve more current output since the drop in voltage impact will be very little. PV modules (especially Poly-crystalline modules) usually with high maximum current output, should be considered for such locations.

V. CONCLUSION

There is always difference between outdoor conditions and the PV module manufacturer's Standard Test Conditions (STCs). Also, climatic conditions differ from location to location and from one month of the year to the other. As evident in this work, the three commercially available PV modules would perform differently at different locations in Nigeria.

The relationship between PV-module temperature and the climatic parameters such as ambient temperature and solar radiation is direct and linear; however, the PV-module temperature has a linear-inverse relationship with wind speed. Cities (mostly in the northern Nigeria) with the potential of high PV-module temperature will produce lower open circuit voltage and lower PV-module conversion efficiencies. Those with higher solar radiation produced better short circuit current and yielded better actual power at low module temperature. However, the impact of module temperature on the actual power output of the amorphous silicon module is more minimal. This resulted to its higher real/actual power output. The northern cities in Nigeria can be said to need array design that has more modules connected in series (for better voltage output), while the southern cities would need array design with more parallel connected modules (for better current output). Hence, the PV module to be installed in the northern Nigeria should have high maximum power voltage V_m specification to cushion the negative impact from high PV-module temperature T_m likely to be experienced there, while the once for the southern and coastal parts of the country should have high maximum power current I_m specification due to the expected low solar radiation.

The results presented in this paper would be able to guide someone to decide on the suitable PV array design (in terms of series and parallel connections) and PV module specifications (in terms of the rated electrical outputs) for every location in Nigeria.

REFERENCES

[1]. Abdelkader M. R., Al-Salaymeh A., Al-Hamamre Z., and Sharaf F. (2010), A comparative Analysis of the Performance of Monocrystalline and Multiycrystalline PV Cells in Semi Arid Climate Conditions: the Case of Jordan. Jordan Journal of Mechanical and Industrial Engineering. Volume 4, Number 5, November 2010. ISSN 1995-6665, Pages 543- 552.

[2]. Bala, E.J., Ojosu, J.O. and Umar, I. H. (2000). Government Policies and Programmes on the Development of Solar-PV Sub-sector in Nigeria. Nigerian Journal of Renewable Energy, Vol. 8, No. 1&2, pp. 1-6.

[3]. Bekker B. (2007), Irradiation and PV Array Energy Output, Cost, and Optimal Positioning Estimation for South Africa. Journal of Energy in Southern Africa. Vol 18 Number 2, May 2007.

[4]. Bücher .K . (1997), Site Dependence of the energy collection of PV Modules. Journal of Solar Energy materials and Solar Cells 47(1997)85-94. Elsevier

[5]. Buday M. S. (2011), Measuring Irradiance, Temperature and Angle of Incidence Effects on Photovoltaic Modules in Auburn Hills, Michigan. A project submitted in partial fulfillment of requirements the degree of Master of Science (Natural Resources and Environment), University of Michigan, USA. August 19, 2011.

[6]. Garcı´a M.C. A. & Balenzategui J.L. (2004), Estimation of Photovoltaic Module Yearly Temperature and Pperformance based on Nominal Operation Cell Temperature Calculations. Journal of Renewable Energy 29 (2004) 1997–2010. Elsevier

[7]. Hankins M. (1995), Solar Electric Systems for Africa: A Guide for Planning and Installing Solar Electric Systems in Rurral Africa. Published by AGROTEC Harare and Commonwealth Science Council London.
[8]. King D.L., Boyson W.E., and Kratochvil J.A. (2004), Photovoltaic Array Performance Model. Sandia National Laboratories, SAND2004-3535, (2004).
[9]. Kozak T. et al (2009), Influence of Ambient Temperature on the Amount of Electric Energy Produced by Solar Modules. MIXDES 2009, 16th International Conference "Mixed Design of Integrated Circuits and Systems", June 25-27, 2009, Ód, Poland.
[10]. Kurtz S. et al (2009), Evaluation of High-Temperature Exposure of Photovoltaic Modules. Paper presented at the 34th IEEE Photovoltaic Specialists Conference Philadelphia, Pennsylvania. June 7-12, 2009.
[11]. Menicucci, D. F. (1985), PVFORM – A New Approach to Photovoltaic System Performance Modeling. 18th IEEE PVSC, Las Vegas, NV, October 21-25, 1985.
[12]. NIMET (2010), Nigeria Climate Review Bulletin 2010.
[13]. Nishioka K., Hatayama T., Uraoka Y., Fuyuki T., Hagihara R. And Watanabe M. (2003), Field Test Analysis of PV System Output Characteristics Focusing on Module Temperature. Journal of Solar Energy Materials and Solar Cells 2003;75:665–71. Elsevier
[14]. Sarhaddi F., Farahat S., Ajam H. and Behzadmehr A. (2010), Exergetic Performance Evaluation of a Solar Photovoltaic (PV) Array. Australian Journal of Basic and Applied Sciences, 4(3): 502-519, 2010 ISSN 1991-8178.
[15]. Skoplaki E., and Palyvos J.A. (2009), On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations.Journal of Solar Energy 83 (2009) 614–624, Elsevier
[16]. TamizhMani G. et al (2003), Photovoltaic Module Thermal/Wind Performance: Long -Term Monitoring and Model Development For Energy Rating. Solar Program Review Meeting 2003 NREL/CD-520-33586 Page 936.
[17]. Ugwuoke P.E., Oparaku O.U. and Okeke C.E. (2006), The Effect of Global and Diffuse Insolation on The Performance of Photovoltaic Modules Deployed at Fixed Angle Tilt in Nsukka. Nigerian Journal of Solar Energy, Vol. 1 (2006), pp. 254 -257.
[18]. Zdravkovic´ M. et al (2009), Temperature Effects on Photovoltaic Components Characteristics. Scientific Publications of The State University of Novi Pazar Ser. A: Appl. Math. Inform. and Mech. vol. 1, 1 (2009), 29-36.
[19]. Zhou W., Yang H., Fang Z. (2007), A novel model for photovoltaic array performance prediction. Journal of Applied Energy 84 (2007) 1187–1198. Elsevier

Nduka O. Arinze "Analysis of PV Modules Performance in Nigeria: A Guide for Suitable System Design and Module specifications Selection" International Journal of Research in Engineering and Science (IJRES), vol. 06, no. 07, 2018, pp. 01-14.