INDIAN JOURNAL OF
ENGINEERING

18(50), 2021

To Cite:
Chidubem EA, Big-Alabo RUA, Omorogiuwa E. Impact of ambient temperature on the power output of a photovoltaic module in Kaduna state, Nigeria. *Indian Journal of Engineering*, 2021, 18(50), 294-303

Author Affiliation:
Department of Electrical and Electronics Engineering, University of Port Harcourt, River state, Nigeria

Peer-Review History
Received: 27 June 2021
Reviewed & Revised: 30/June/2021 to 03/August/2021
Accepted: 05 August 2021
Published: August 2021

Peer-Review Model
External peer-review was done through double-blind method.

DISCOVERY
SCIENTIFIC SOCIETY

Impact of ambient temperature on the power output of a photovoltaic module in Kaduna state, Nigeria

Egbugha Anselem Chidubem, Roland Uhunmwangho Ameze Big-Alabo, Eseosa Omorogiuwa

ABSTRACT

This paper aim to study the impact of temperature on the power output of photovoltaic modules in Kaduna State, Nigeria. Initially, a PVsyst simulation software was used to analyze the output performance of the PV panel at varying temperature. Secondly, an outdoor experiment was also conducted to observe the performance in real time. In the experiment, two digital multi-meters were used to measure the output parameters of a 120Watts mono-crystalline and polycrystalline panel, while a temperature sensor (thermostat) was attached at the back surface of the photovoltaic panel, which is closer to the cell, in order to measure the PV panel temperature. The experiment The measurement of all data was carried out daily for three (3) months which captures three seasons; August, January and April, between 7:00AM and 6:00PM for an interval of 30mins. The result of simulation and outdoor experiment clearly shows that increase in temperature consequently increases the current output but decreases the voltage and power output of the PV panel. It was also observed that the PV panel is supposed to attain its peak point between 11:00AM and 2:30PM due to the angle of incident ray from the sun, high solar irradiance and temperature, but the heat generated by the PV panel in that region, as a result of the prolonged stay of the panel under the sun, negatively affect the output voltage and power generation.

Keywords: pv panel, photovoltaic panel, polycrystalline, mono-crystalline, temperature sensor, solar irradiance.

1. INTRODUCTION

The need for renewable energy is on a continuous rise due to the inefficiency of power supply in Nigeria and some other developing countries of the world. There is a global concern over the concentration of atmospheric increase of carbon dioxide from environmental safety of energy production techniques, greenhouse gas emissions, volatile energy prices to name a few [1-2]. The resources of renewable energy are replenishing, readily available and are environmentally friendly. This resource includes; hydro, solar energy, geothermal, wind and biomass. Renewable energy which is considered as a remedy to the difficult nature of exhaustion of fossil fuels and the damaging (to both the inhabitants and soil) issuance and outflow accompanied with their utilization of fossil fuels.

In Nigeria, many communities do not have access to the national electricity grid. As at 1996, only about 40% of the national populations had been linked and these are largely in the urban areas [3]. Consequence to the shortage in energy supply, it has become necessary to complement the conventional hydropower, gas and fossil fuel generation in the country by harnessing from the abundance of the sun and other sources of energy supply. An Estimations of local, regional, and national, monthly, seasonal, and annual solar irradiation in Nigeria abound [4][5][6][7][8].

It is well known that the efficiency and output power of the solar cells changes with temperature and solar irradiance level [9][10][11]. Due to the abundance of the sun, solar energy technology has become one of the most needed alternative sources of energy, and the best potential for solar PV power plants in Nigeria lies in the northern part of the country.

[12] Studied to determine the impact of environmental temperature on the performance of a standalone photovoltaic solar system in Awka, Nigeria. The work revealed that an indirect proportionality exists between the ambient temperature of a locality and the output power produced by the PV system. The average temperature of Kaduna State is most times higher than the optimum operating temperature of the PV panel at STC, therefore may result in a significant reduction in PV power generation. This study will help solar system designers, installers, manufacturers and government agency for works and housing to take into account, the ambient temperature when designing and predicting the performance of the photovoltaic system in Chukun Local government area of Kaduna State, Nigeria.

Mechanism of Photovoltaic p-n junctions

The mechanism of a photovoltaic p-n junction involves a light beam which comes in contact with the p-n junction of a photovoltaic cell; the N-Type silicon dislodges an electron, creating a free electron and a hole. The free electron and hole has sufficient energy to jump out of the depletion zone. Heat is generated as a result of the recombination of the newly created electric charge carriers which are mostly recombined. This charge carriers may be electron–hole pairs in a solid semiconducting material or electron–ion pairs in a liquid electrolyte [13]. The creation of the photovoltaic phenomenon is conditioned by separating these pairs before recombination. This is done with the presence of an internal electric field due to spatial cargo. The movement of electrons in this electric field is moved from p-type to n-type semiconductors and holes are moved from the n-type semiconductor to p-type, which result in the separation of generated electron hole pairs as shown in figure 1.1. The Separated minority carriers on one side of the connector are becoming majority carriers with limitless lifetime on the other side, thus they create current (Isc) and voltage (Vsc) of a solar cell [14]**.** The resistance of the circuit multiplied by the square of the current is the power converted into electricity. The temperature of the cell is elevated by the remaining power of the photon and dissipates into the atmosphere [15]. The Current-voltage characteristics of the cell are a graph of the output current of the PV generator as a function of voltage at a given temperature and irradiance.

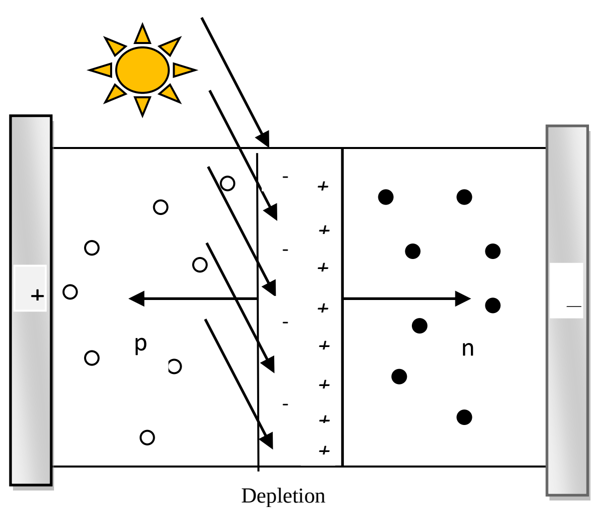

Figure 1.1: Basic p-n junction of photovoltaic cell and charge transport phenomena.

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS

Standard Test Condition (STC) For Photovoltaic Modules

The Standard test conditions (STCs) for a PV module performance are 25°C cell temperature, standard spectral distribution characteristic of a 1.5 air mass (AM) and an incident normal irradiance of 1000W/m^2 [16]. Figure 1.2 shows a typical I-V characteristics curve of a PV module [17].

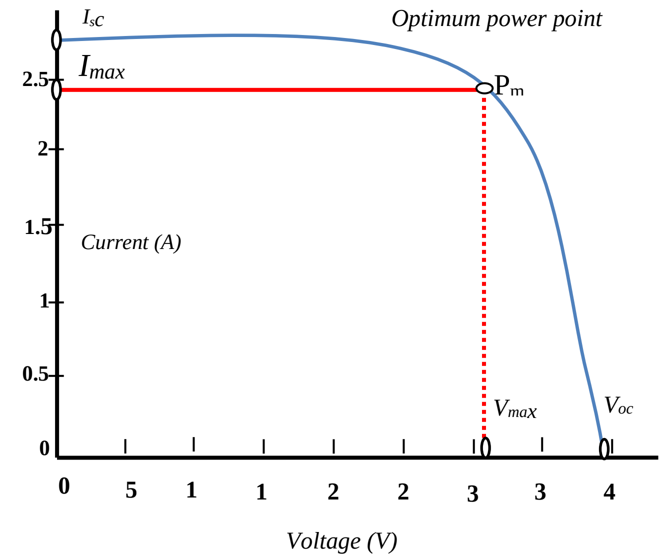

Figure 1.2: Typical I-V characteristic curve of a PV module (Abdul et al, 2014)

The power (*P*) is the product of current (*I*) and voltage (*V*) [18]. The fundamental equation which relates the parameters as a result of the effect of temperature on the electrical efficiency of a PV cell can be expressed as [19]:

$$P_m = I_m V_m = (FF) I_{sc} V_{oc} \quad (1)$$

Where, Isc is short circuit current, Voc is open circuit voltage, FF is fill factor, Vmp is the maximum power voltage and Imp is the maximum power current at the maximum power point in the modules I-V curve.

2. MATERIALS AND METHODS

Initially, PVsyst simulation software was used to analyze the output performance of the PV panel at varying temperature. The determination of data used was done under standard test conditions (STC) with Irradiance of 1000 W/m^2, Temperature of 25^{0}C and Air mass of 1.5 [16]. The aim of this simulation is to observe the influence of temperature on the output performance of a PV panel. The available data for the PV panel used for outdoor were explore by the software as shown in Figure 2.1.

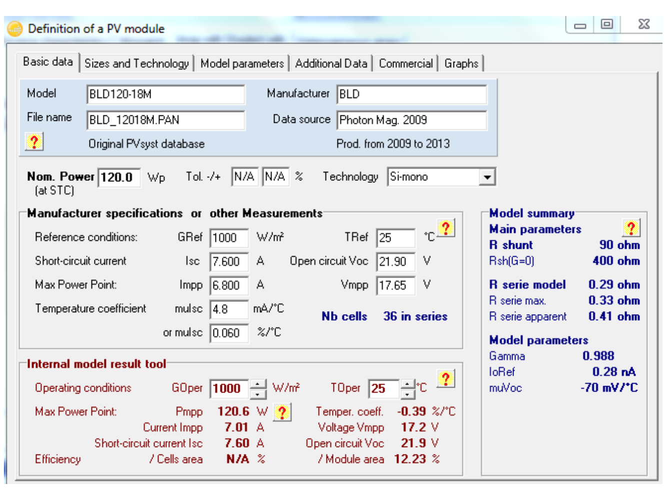

Figure 2.1: Data page for definition of PV panel

In this study, the performance of the PV panel was also ascertained in an outdoor experimental. A 120Wp Mono-crystalline and Polycrystalline PV panel under study were placed side-by-side, on a vertically (Portrait) plain surface facing south. The characteristics of PV was tested at the premises of Rana World Tech Engineering Limited, Narayi, Kaduna, which is located in Kaduna South, Nigeria and lies on 10.4549°N latitude and 7.4057°E longitude. The measurement of all data was carried out daily for three (3) months which captures three seasons; August, January and April, between 7:00 AM and 6:00 PM for an interval of 30mins. Two MASTECH (MY64) Multi-meters were used; one had a temperature sensor (thermostat) attached at the back surface of the photovoltaic panel which was used to measure the PV panel temperature, while the other was used to measure the ambient temperature and electrical parameters of the PV panel. A summarized picture of the experimental set-up is shown in Figure 2.2. The power generated by the PV panel was estimated using the equation [20]:

$$P_{max} = Isc^* Voc \qquad (2)$$

Where P_{max} = Power output of the photovoltaic module

I_{sc} = short circuit current

V_{oc} = Open circuit voltage

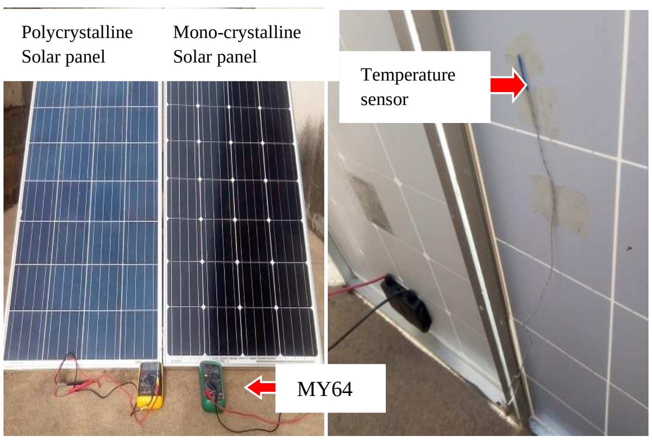

Figure 2.2: Photographic view for outdoor experiment

3. RESULTS AND DISCUSSION

Output Performance of PV panel based on PVsyst Software

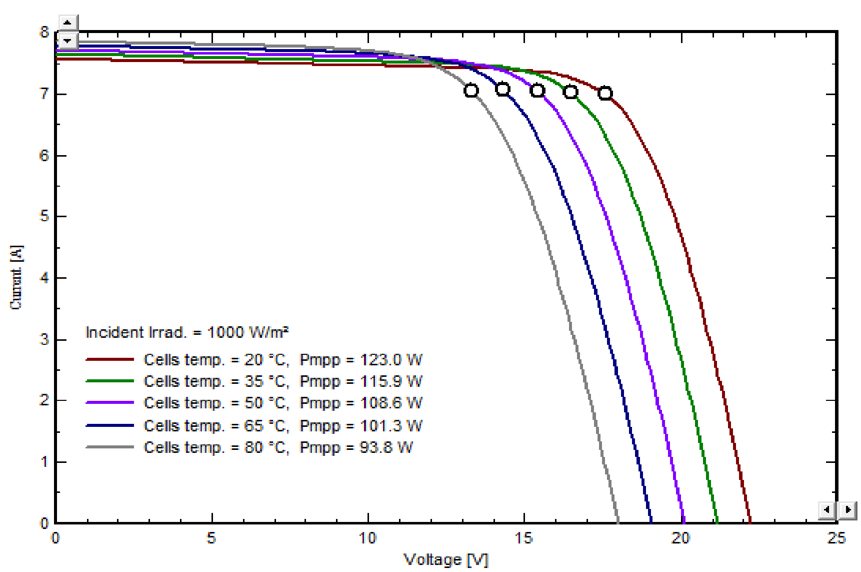

Figure 3.1: I-V characteristics of PV panel at constant 1000W/m² irradiance and varying temperature

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS

The PV panel which considered as a crucial component in a PV system is expected to perform at its best during high solar irradiance, but contrary, the performance is deterred due to the heat generated by PV panel. Figure 3.1 shows distributive temperatures of PV panel and the resultant power output of the PV panel at constant irradiance. Base on the variations of panel temperature, these figures also shows the curves for power voltage (P-V) and current-voltage (I-V) characteristics.

Initially when temperature was 20°C at constant irradiance, the voltage recorded was 22.2V while the current was 7.6A, but as the temperature rise to 35°C, the voltage drop to 21.1V while the current increased slightly to 7.7A. As the temperature continues to rise to a point of 80°C, the voltage drop was recorded at 18V while the current increased to about 7.9A. The effect of temperature also applies to the power output of PV module; as power decreases with increase in temperature as shown in figure 3.1. By analyzing the behavior of the figures, as the temperature of the PV panel increase, it causes a gradual decrease in voltage output and slight increase in the current output of the PV panel. It is observed from the figure that the PV panel loses about 5% (5Watts) power for every 10°C its temperature. By analysis, the PV panel at temperature of 80°C recorded a minimum power output of 93.8Watts, whereas the maximum output power at 20°C was recorded as 123Watts (see figure 3.2).

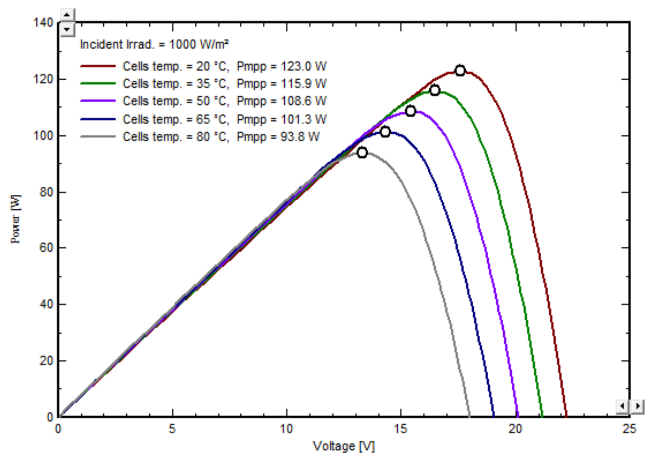

Figure 3.2: P-V characteristics of PV panel at constant 1000W/m² irradiance and varying temperature

Output Performance of PV panel under outdoor condition

Normally, as the solar irradiance continue to intensify, the ambient temperature increases and thereby increasing the temperature of the PV panel. The heat generated by the panel was due to a prolonged exposure of the PV panel to the sun. Table 1 and 2 shows the behavior of the PV modules Electrical parameters during the outdoor experiment at different temperature and intensity of solar irradiance. The average temperature at twilight was at 22°C, but as time went by, the sun surface and the irradiance of the sun started increasing. The maximum ambient temperature was recorded between 11:00 noon and 3:00PM at an average of 32°C. The PV panel recorded a maximum average temperature of 44°C while the minimum average temperature recorded was 22°C at the lowest solar irradiance.

Table 1: Average value for 120Wp Monocrystalline

TIME	AMBIENT TEMERARE (°C)	PHOTOVOLAIC TEMERARE (°C)	Voc (V)	Isc (A)	Power (Watts)
7:00AM	21	21	14.16	0.52	7.3632
7:30AM	22	22	15.89	0.89	14.14
8:00AM	22	25	18.76	1.45	27.20
8:30AM	26	28	20.36	1.72	35.02
9:00AM	29	31	20.78	2.98	61.92
9:30AM	31	34	20.86	3.28	68.42
10:00AM	30	34	20.96	4.3	90.13
10:30AM	32	36	20.88	4.48	93.54
11:00AM	32	37	20.48	4.66	95.44
11:30AM	32	39	19.68	4.75	93.48
12:00PM	33	40	19.44	4.79	93.12

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS

12:30PM	32	41	18.96	4.9	92.904
1:00PM	32	42	18.48	5.02	92.77
1:30PM	31	43	18.08	5.11	92.39
2:00PM	32	44	17.68	5.19	91.76
2:30PM	30	44	17.67	5.2	91.88
3:00PM	29	43	18.07	3.46	62.52
3:30PM	28	42	18.89	2.5	47.23
4:00PM	26	37	18.97	2.05	38.89
4:30PM	26	33	18.45	1.69	31.18
5:00PM	21	31	16.79	1.51	25.35
5:30PM	22	28	16.9	1.45	24.51
6:00PM	22	25	14.22	1.24	17.63

Table 2: Average value for 120Wp Polycrystalline

TIME	AMBIENT TEMERARE (^{0}C)	PHOTOVOLAIC TEMERARE (^{0}C)	Voc (V)	Isc (A)	Power (Watts)
7:00AM	21	21	14.18	0.51	7.2318
7:30AM	22	22	15.91	0.88	14.00
8:00AM	22	25	18.78	1.44	27.043
8:30AM	26	28	20.38	1.71	34.85
9:00AM	29	31	20.8	2.97	61.78
9:30AM	31	34	20.88	3.27	68.28
10:00AM	30	34	20.98	4.29	90.00
10:30AM	32	36	20.9	4.47	93.42
11:00AM	32	37	20.5	4.65	95.33
11:30AM	32	39	19.7	4.74	93.38
12:00PM	33	40	19.3	4.81	92.83
12:30PM	32	41	18.9	4.85	91.67
1:00PM	32	42	18.5	4.91	90.84
1:30PM	31	43	17.98	5.02	90.26
2:00PM	32	44	17.76	5.08	90.22
2:30PM	30	44	17.69	5.1	90.21
3:00PM	29	43	18.45	3.45	63.65
3:30PM	28	42	18.91	2.49	47.09
4:00PM	26	37	18.99	2.04	38.74
4:30PM	26	33	18.47	1.68	31.03
5:00PM	21	31	16.81	1.5	25.22
5:30PM	22	28	16.92	1.44	24.36
6:00PM	22	25	14.24	1.23	17.52

Temperature Vs Voltage Characteristics

From the experiment it was observed that the maximum voltage was recorded between 9:00AM and 11:30AM, but as the ambient temperature intensifies and the PV panel temperature began to increase between 11:00AM and 3:00PM, during this peak hours of solar radiation, it was observed that the voltage of the two crystalline module started experiencing a slight reduction in voltage. The temperature of the PV module was observed to be more than the ambient temperature as shown in table 1 and 2. From the experiment, it is clear that voltage of a PV modules decrease as the cell temperature rises; this negative effect is common to both mono-crystalline and polycrystalline modules. Figure 3.3a and 3.3b presents a graphical representation of the Influence of temperature on the voltage of both mono-crystalline and polycrystalline module.

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS

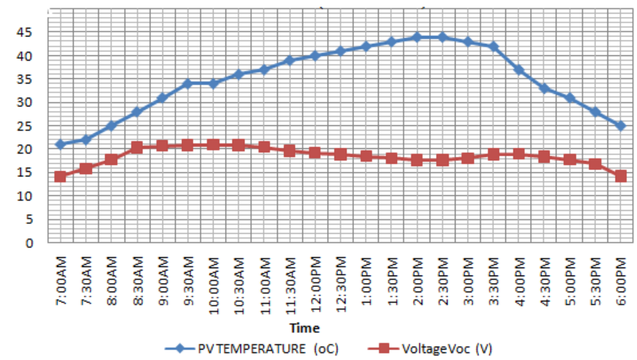

Figure 3.3a mono-crystalline panel

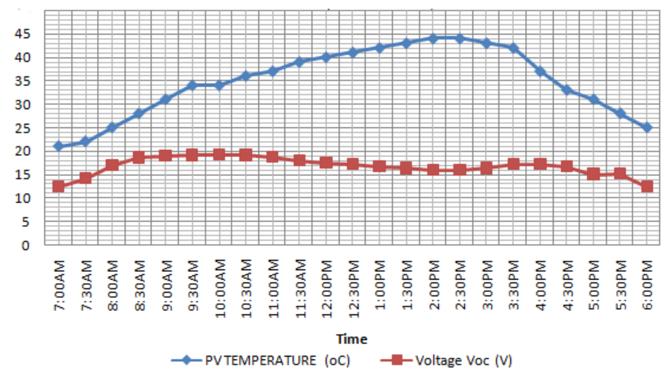

Figure 3.3b Polycrystalline panel

Figure 3.3: Influence of temperature on the open circuit voltage (V_{oc}) of a PV module

Temperature Vs current Characteristics

Fig.3.4 describes the overall average behavior of current throughout the experiment. It was observed that the PV panel output current increases as the intensity of the sun and the PV panel temperature increases. This current increase was observed at a peak solar irradiance from 11:30A.M to 3:00P.M. At 2:00P.M, the average temperature recorded was 37^{0}C and the maximum output current produced was 5.1A, but at PV temperature of 22^{0}C, only 0.52A was produced. The average maximum open circuit current recorded was between the hours of peak solar radiation and high temperature as shown in table 1 and 2. It was observed that at a low radiation and minimum PV temperature, the PV output current is low. Thus, the PV panel output current is directly proportional to solar irradiance. Figure 3.4a and 3.4b presents a graphical representation of the Influence of temperature on the current on both mono-crystalline and polycrystalline module.

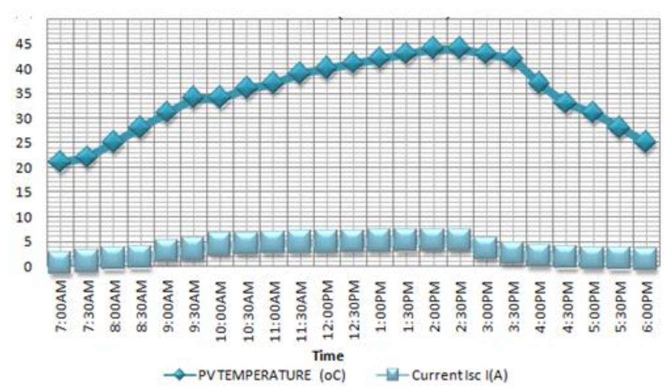

Fig. 3.4a mono-crystalline panel

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS

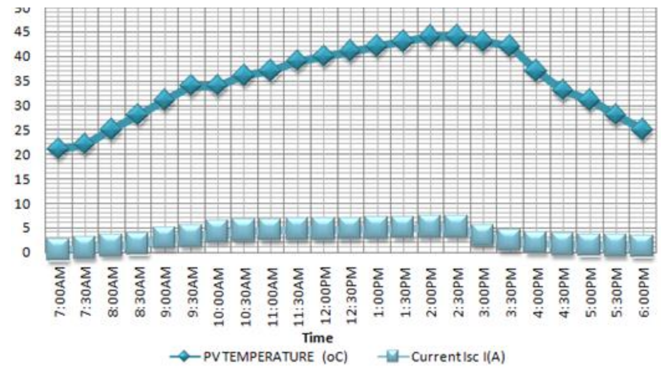

Fig. 3.4b Polycrystalline panel

Figure 3.4: Influence of temperature on the short circuit current (I_{sc}) of a PV module

Temperature Vs power output Characteristics

The voltage and current of the PV panels was measure in other to obtain the power produced by the panel. The power outputs of the PV panel at every point in time were calculated by using equation 2. Table 1 and 2 presents the average output power generated by the PV panel during the outdoor experiment. The output power which is supposed to significant rise to its peak between 11:00am and 3:00pm was observed to reduce gradually as the temperature of the PV panel continue to rise above the STC. The decrease was as a result of the negative effect of high temperature on panel open circuit voltage. The major productions of solar energy were recorded between 8:00AM and 11:00PM. During peak hour of solar radiation, the maximum power (95.44W) was recorded at PV temperature of 37 ^{O}C, whereas the minimum (91.88W) was recorded at 44^{0}C. Figure 3.5a and 3.5b presents a graphical representation of the Influence of temperature on the current on both mono-crystalline and polycrystalline module.

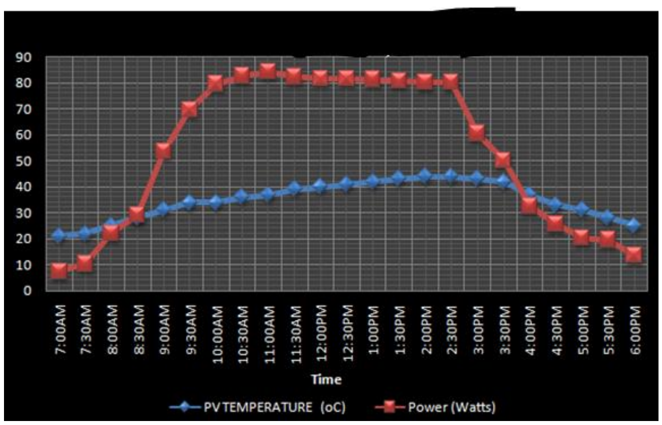

Fig. 3.5a mono-crystalline panel

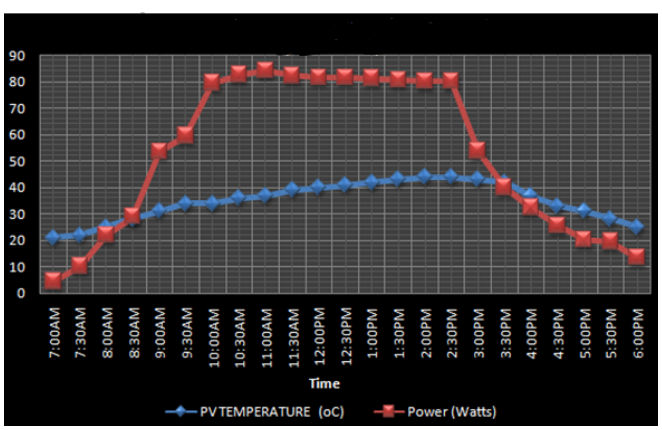

Fig. 3.5b Polycrystalline panel

Figure 3.5: Influence of temperature on the power output of a PV module.

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS

4. CONCLUSION

The impact of ambient temperature on the parameters of Photovoltaic module in Kaduna state, Nigeria was investigated. The report of this experiment was carried out via PVsyst software simulation and an outdoor experiment. The result of the experiment shows that the heat generated by the PV panel between the periods was as a result of the prolonged stay of the panel under the sun, which negatively affects the output voltage, thereby affecting the power generated by the PV panel. This explains the relationship that exists between the ambient temperature and power output of the photovoltaic module in that locality. This experiment goes to show that the ambient temperature is a factor that must be considered when predicting and designing the behavior of mono-crystalline and polycrystalline solar panel in that locality.

Funding

This study has not received any external funding.

Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

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

REFERENCES AND NOTES

1. Nguyen H, and J. Pearce (2010). Estimating potential photovoltaic yield with r.sun and the open source geographic resources analysis support system. Solar Energy 84: 831-843.
2. Choi Y. J., Rayl, C., Tammineedi, and Brownson J. (2011). PV Analysis: Coupling ArcGIS with TRNSYS to assess distributed photovoltaic potential in urban areas. Solar Energy 85: 2924-293.
3. Umar I.H. Research and Development and Energy Crisis in Nigeria Paper presented at the 1999 Technology Submit Abuja Nigeria.1999.
4. Ojosu, J. (1988). "Solar radiation distribution maps of Nigeria."NBRRI Rep. No. 11, Nigerian Building and Road Research Institute, Lagos, Nigeria.
5. Fadare, D. (2009). "Modelling of solar energy potential in Nigeria using an artificial neural network model." Appl. Energy, 86(9), 1410–1422.
6. Ezekwe, C., and Ezeilo, C. (1981). "Measured radiation in a Nigerian environment compared with predicted data." Sol. Energy, 26(2), 181–186.
7. Chineke, T. (2008). "Equations for estimating global solar radiation in data sparse regions." Renew. Energy, 33(4), 827–831.
8. Chineke, T., and Okoro, U. (2010). "Application of Sayigh "universal formula" for global solar radiation estimation in the Niger delta region of Nigeria." Renew. Energy, 35(3), 734–739.
9. Carr A. J., Pryor TL. A comparison of the performance of different PV module types in high ambient temperature. ISES 2001, Solar World Congress; 2001
10. Shaari S, Kassim MN, Ahmad A. Performance characteristics of an amorphousbase solar photovoltaic system in Malaysia field condition. In: Second national seminar on energy in buildings, UiTM Shah Alam; March 2005.
11. The German Solar Energy Society (DGS LV Berlin BRB). Planning and installing photovoltaic systems. James & James/Earthscan; 2005. p. 23.
12. Ike, C. U., 2013, "the Effect of Temperature on the Performance of A Photovoltaic Solar System in Eastern Nigeria," International Journal of Engineering and Science, Vol.3, Issue 12, Pp. 10-14.
13. Nabulsi, A. A., & Dhaouadi, R. (2012). Efficiency optimization of a DSP-based standalone PV system using fuzzy logic and dual-MPPT control. *IEEE Transactions on Industrial Electronics,* 8(23), 573-584.
14. Green M. A. (1981), Solar Cells: Operating Principles, Technology, and System Applications, Prentice-Hall series, Australia.
15. Vongkoon, P., & Liutanakul, P. (2012). Digital R-S-T Controller for Current Loop Control of DC/DC Buck Converter: A Photovoltaic (PV) Array Simulator under Partial Shading Condition. *IEE Proc-Electrical Power Application* (37), 712-723.
16. Mustapha I, Dikwa M.K, Musa B.U and Abbagana M., "Performance evaluation of polycrystalline solar photovoltaic module in weather conditions of Maiduguri, Nigeria," Arid Zone Journal of Engineering, Technology and Environment. August, Vol. 9, 69-81, 2013.

17. Abdul Q. Jakhrani, Saleem R. Samo, Shakeel A. Kamboh, Jane Labadin and A. R. H. Rigit, "An Improved Mathematical Model for Computing Power Output of Solar Photovoltaic Modules," International Journal of Photoenergy. March, Vol 2014.
18. Saloux, A. Teyssedou, and M. Sorin, "Explicit model of photovoltaic panels to determine voltages and currents at the maximum power point," Solar Energy, vol. 85, no. 5, pp. 713– 722, 2011.
19. Chow, T.T. (2003), "Performance analysis of PVT collector by explicit dynamic model," Solar Energy, vol. 75, pp. 143-52.
20. Bhalchandra V. C and Sadawarte Y. A. (2015). *The Factors Affecting the Performance of Solar Cell*. International Conference on Quality Up-gradation in Engineering, Science and Technology (ICQUEST2015), India, *International Journal of Computer Applications* (0975 – 8887).

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS