Evaluation of the Effect of Solar Radiation on Photovoltaic Cell Performance

Y. OLOTU[1*], A. I. OMOAKHALEN[2], R. ISHIEKWENE[3], S. K. ABOLAJI[4], P. A. IMANOGOR[1]

[1]Department of Agricultural & Bio-Environmental Engineering.
Federal Polytechnic, Auchi, Nigeria
[2]Department of Mechanical Engineering
Federal Polytechnic, Auchi, Nigeria
[3]Department of Electrical/Electronic Engineering
Delta State Polytechnic, Ogwashiuku, Nigeria
[4]Department of Electrical/Electronic Engineering
Federal Polytechnic, Auchi, Nigeria

Email : realyahaya@yahoo.com

Abstract - Solar energy is one example of a renewable energy source that has the ability to create clean, environmentally friendly energy, which has been a crucial component of climate change mitigation strategies. Renewable energy sources are complementary energy sources. The study evaluated the impact of solar radiation on the output of a set of photovoltaic cells in response to current and voltage generation. To evaluate the solar radiation and PV cell temperature on a regular basis, a mono-C-Si module array of four (4) 100 W photovoltaic cells was installed on a south-facing mounting with a 30° tilt angle and equipped with temperature and irradiance sensors. The irradiance was measured using a CMP II pyranometer, and the DC current was measured using a current shunt. The findings demonstrated a direct and proportionate relationship between air temperature and solar radiation and photovoltaic cell temperature (PV temperature). The amount of current and power generated is directly influenced by solar radiation. As a result, when solar radiation is increased from 100 W/m^2 to 900 W/m^2, the generated current increases from 0.9 A to 4.2 A. This means that when solar radiation is increased from 100 W/m^2 to 800 W/m^2, the generated current and power increase by 4.5 and 9.1 times, respectively, while the generated voltage increases by 1.9 times within the PV temperature range of 22.1°C to 27.1°C. Consequently, the generated power and current showed a minor loss, and the PV cell generated voltage indicated a substantial decrease, despite the rise in solar radiation from 900 W/m^2 to 1000 W/m^2 at a PV temperature of 30.9°C. At PV temperatures between 25.0°C and 27.1°C with a maximum solar irradiance of 900 w/m^2. The solar panel module with the specified characteristics could produce optimal efficiency, it has been concluded. As a result, it is advised that internal and external solar panel cooling systems be included in the development of PV cells because increased air temperature could catalyze photovoltaic temperature and solar radiation.

Keywords - Solar radiation, Photovoltaic cell temperature, Power, Voltage, Current.

I. INTRODUCTION

The global energy agreement to transition to clean and green energy was never only initiated to increase the energy mix but also to preserve a healthy environment and boost country-based gross domestic product (GDP). Solar energy is the planet's most plentiful source of renewable energy, according to [1]. The results back up [17] assertion that the amount of solar energy that reaches the earth's surface in less than an hour is enough to supply all of the world's energy needs for a whole year. Solar energy is safe, reliable, and easily accessible, as demonstrated by [2]. However, switching to clean and ecologically friendly energy sources, like solar energy, not only lowers greenhouse gas emissions but also acts as a strategy for reducing climate change. Solar energy has grown more desirable due to its efficiency, sustainability, and ease of use, according to [3].

The photovoltaic system, which is the smallest part of the solar cell, converts solar energy directly into direct current voltage [4]. According to the IEC 61215 standard, photovoltaic module performance is rated using a single operating point under standard test conditions, which include a 1000 W/m^2 irradiance, a module temperature of about 25^{o}C, and a 1.5 A. M. spectrum [5]. The ratings are very helpful for photovoltaic system engineers and designers to project seasonal and annual energy yield, according to [5]. Under a variety of real-world operating conditions, photovoltaic systems' performance varies [5]. According [5], the ratings are particularly helpful for engineers and designers of solar systems to forecast seasonal and annual energy yield. A variety of real-world operational variables affect how well solar systems work [5]. Low photovoltaic (PV) panel efficiency has been linked to a number of parameters, including canopy coverage, shade, dust, particle matter settling, temperature, and solar radiation, according to [6] and [7]. According to [4], the effects of temperature and solar radiation on the performance of photovoltaic cells are more pronounced. Solar radiation has an impact on the performance of PV cells, according to [8]. A drop in solar radiation automatically causes solar panels to lose electricity, while an increase in the surrounding temperature causes photovoltaic cells to operate less efficiently [4, 9].

Due to topographical factors and how close different countries are to the equator, the earth's solar radiation is less than extraterrestrial radiation [10]. According to a study by [11] on the impact of climatic factors on solar panel performance, solar flux determines PV efficiency and current output, and relative humility lowers the current output of a solar panel array. The accumulation of dispersed particulate matter on solar panel surfaces presents another drawback in regions with solid mineral exploration and pollutant emission. The earth's solar radiation is less than the extraterrestrial radiation and is a function of geographic location and the position of various nations to the equator [10]. The study by [11] on the effects of meteorological variables on the performance of solar panels indicated that current output and the efficiency of PV are dependent on solar flux and that relative humility causes a decline in the current output of an array of solar. The impact of the environment on the functionality of photovoltaic cells has been the subject of several research [12, 13]. Overall, their research concluded that the PV's ability to produce energy is influenced by the sun's intensity. Generally, weather and environmental factors have a significant impact on effectiveness and power yield from a network of solar panels [14].

In this study, the effect of the intensity of solar radiation in Auchi (Nigeria), on the photovoltaic cell is evaluated using the computed and measured solar radiation on a daily basis for a 5-year duration.

II. EXPERIMENTAL SETUP

Auchi is in Edo State, southern Nigeria, at latitudes 7.0669° N and 6.2748° E and an elevation of 222.9 m above sea level. However, the main experimental site is Federal Polytechnic, Auchi. The study area experiences an average of eight (8) hours of sunshine during the dry season (November to March) and five (5) hours of sunshine during the wet season (April to October). Annual climatic variables such as relative humidity of 63%, minimum temperature (24.1 ^{o}C), maximum temperature (35.1 ^{o}C), wind speed of 7.4 km/h, rainfall depth of approximately 1430 mm, and elevation of 222.1 m above sea level are typical. Figure 1 shows the location of the study area.

According to Charfi et al. (2013) and Nwankwo and Avwiri (2014), a mono-C-Si module array of four (4) photovoltaic cells was set up on a south-facing mounting with a 30° tilt angle. The PV was positioned in a fixed position to receive sunlight from all directions (2021). With a module of 100 W and 12 V, respectively, temperature and irradiation sensors were built within the solar panels to track and record daily solar radiation and PV cell temperature. The maximum power point of the PV module was monitored using the power optimizer of the Solar Edge sensor. The DC voltage and current were recorded every second. A CMP II pyranometer created was used to measure the irradiance, while a current shunt was utilized to measure the DC current. Using air particulate sensors 2.5 and 10.0, suspended particulate matter (dust) and current meteorological conditions (lowest temperature, maximum temperature, and relative humidity) were measured.

Fig. 1 (a) Map of Nigeria showing Edo State; (b) Map of Edo North district; and (c) Map of Auchi indicating the experimental field at Auchi Polytechnic-Campus One.
[Source: Author's Arcmap 10.1 Production, 2022]

The photovoltaic current was empirically calculated as follows:

$$I_{ph} = [I_{sc} + K_i(T_c - T_r)].\frac{G}{G_r} \quad (1)$$

Where : I_{hp} is photovoltaic current of the PV cell

Isc is the short circuit current under 25°C and 1000 w/m^2.

K_i is the Temperature factor of short circuit current.

T_c is the PV cell temperature (in Kelvin)

T_r is the reference temperature (298.15°K for 25°C)

G is the solar radiation level under W/M^2

G_r is the reference of solar radiation level (1000 w/m^2)

PV cell temperature (Tc) was calculated using the approach of Ross and Smoker (1999) as follows:

$$T_c = T_{air} + \frac{NOC}{100} S \quad (2)$$

Where : T_{air} is the air temperature

NOCT is the nominal operating cell temperature

S is the insolation in mW/cm^2

Panel power is 100

[15] reported that the best module is operated at a NOCT of 33 °C, the worst at 58°C, and the typical module at 48°C, respectively. The photovoltaic panel characteristics are shown in Table 1. Plate 1 shows the array of solar panel.

Table 1. Characteristics for photovoltaic panel [15]

Variables	Numerical values
Maximum panel power	100 W
Maximum voltage	17.3V
Maximum current	5.75A
Open-current voltage	22V
Short-circuit current	6.32A
Panel efficiency	22%
Panel sizes	1600mm *1000 mm* 40 mm
Panel weight	12.5 kg
Operating temperature	33°C ………58°C

Fig. 2. Plate shows the array of solar panel

III. RESULTS AND DISCUSSION

The results presented in Tables 2 and 3 show the existing climatic dataset around the study area from 2020 and 2021, respectively. Average annual minimum and maximum temperatures of 23.6 °C; 31.7 °C and 22.3 °C; 31.6 °C were obtained in 2020 and 2021. Hence, the solar radiation of 4.73 W/m^2 and 44.8 W/m^2 was estimated, respectively. It is therefore revealed that the prevailing weather parameters have a significant impact on the generated solar radiation. An experimental study was conducted on the solar radiation to determine the efficiency of the photovoltaic cell in response to the solar radiation.

Table 2. Climatic variables Auchi Poly in 2020.

Mth	T_{min}	T_{max}	RH	W.S	SH	Sol.R
Jan	21.5	34.5	64.0	15.0	7.0	47.4
Feb	22.5	33.2	68.0	16.0	7.1	50.3
Mar	23.6	34.2	69.0	17.0	7.5	54.4
Apr	24.2	33.1	75.0	14.0	6.0	48.4
May	23.4	33.2	85.0	14.0	5.8	46.4
June	22.6	29.7	79.0	20.0	5.5	44.1
Jul	23.1	29.1	83.0	14.0	5.7	45.4
Aug	24.5	29.2	79.0	20.0	5.3	44.8
Sep	22.1	29.6	88.0	15.0	5.9	47.7
Oct	24.6	30.2	81.0	17.0	5.9	46.1
Nov	25.2	31.2	73.0	25.0	6.8	46.9
Dec	25.6	33.6	66.0	30.0	6.9	45.9
Ave	**23.6**	**31.7**	**76.0**	**18.0**	**6.3**	**47.3**

Hint: T_{min}: Minimum temperature (°C); T_{max}: Maximum temperature (°C); RH: Relative humidity (%), W.S: Wind speed (kh/h); SH: Sunshine hour (hours); Sol.R: Solar radiation (MJ/m^2/day).

Table 3 presents the outcome of 7-day field experimentation for a total of 13 hours from 7.00 am to 7.00 pm. The result shows a significant correlation between the air temperature (°C) and photovoltaic cell temperature (Table 4 and Fig. 2).

The temperature of a photovoltaic cell rises by one unit for every unit rise in ambient temperature. At 7:00 a.m., the lowest average air temperature of 25.5 °C matched the lowest PV temperature value of 22.1 °C, while at 2:00 p.m., the highest average air temperature of 33.2 °C matched the maximum PV cell temperature of 35.7 °C. It was determined that 1:40 p.m. was the time when photovoltaic performance was at its peak. At this temperature, both the ambient temperature and the temperature of a photovoltaic cell are equal. Studies by [2, 4], and [16, 17] support the findings.

Additionally, from 7:00 a.m. to 12:00 p.m., the results in Figure 2 and Table 3 demonstrate an increase in generated voltage (V) in response to increases in air temperature and PV temperature. As a result, as air and PV temperature raised more, the voltage and current generated decreased. With generated voltage and current values of 39.60 volts and 34.20 amps, the optimal PV operating system was thus discovered at 11:00 a.m. at PV and air temperatures of 24.9 °C and 29.1 °C, respectively.

The outcome in Figure 3 depicts the fluctuation in experimental and simulated PV temperature in response to the experimentation time. The average solar panel temperature was recorded at 7:00 pm to be 26.9 °C. The PV cell temperature rose gradually from 22.1 °C at 7:00 am to a high temperature of 35.7 °C at 2:00 pm and then steadily decreased at 3:00 pm (9 hours into the experiment).

Table 3. Climatic variables at Auchi Poly in 2021

Month	T_{min}	T_{max}	RH	W.S	SH	Sol.R
Jan	24.2	33.0	67.0	16.0	7.1	47.7
Feb	23.9	34.0	69.0	15.0	7.3	51.3
Mar	23.0	33.4	64.0	18.0	6.6	50.8
Apr	22.0	33.0	70.0	15.0	6.0	48.5
May	20.9	31.9	74.0	14.0	5.8	46.4
June	20.9	30.0	79.0	13.0	5.4	43.8
Jul	21.8	29.1	83.0	12.0	5.3	43.8
Aug	22.0	30.0	78.0	13.0	6.0	47.4
Sep	20.1	28.3	83.0	12.0	5.2	44.8
Oct	22.0	29.2	75.0	14.0	6.3	47.6
Nov	23.2	33.4	67.0	15.0	7.1	18.6
Dec	23.5	34.2	65.0	15.0	7.0	46.4
Ave	**22.3**	**31.6**	**73.0**	**14.0**	**6.3**	**44.8**

The changes were, however, inversely related to the air temperature at each stage. The simulated and experimental PV cell temperature records showed a discrepancy of less than 5%, indicating that the PV cell temperature increased at midday. The results corroborate a study by [16] that found PV tube temperatures rose during the midday.

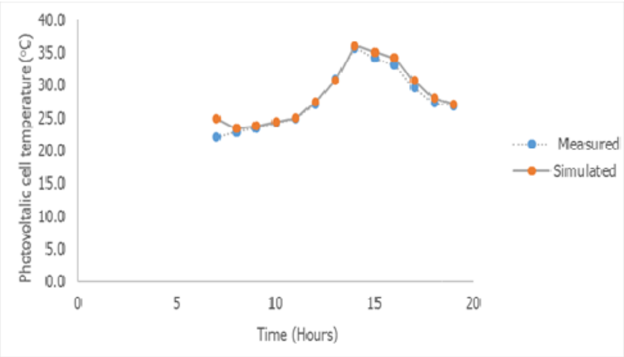

Fig. 3. Variation of photovoltaic cell temperature in response to time.

PV-generated voltage in response to changing solar radiation is shown in Figure 4 as measured and simulated voltage. The voltage increase (V) in response to solar radiation is very slightly different from the mean experimental and modelled voltage of 1.34.

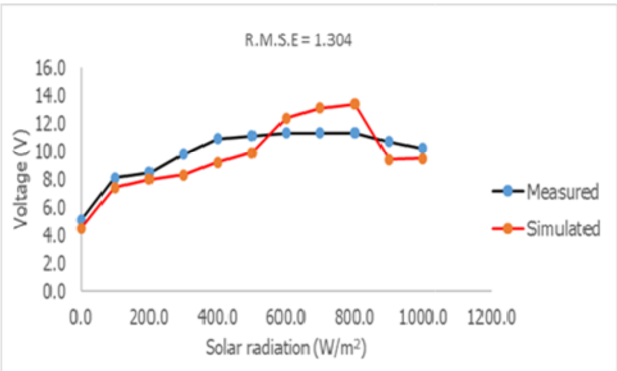

Fig. 4. Relationship between voltage and solar radiation.

The voltage grew from 4.2 V against a solar radiation value of 0.0 W/m^2 to 11.0 W/m^2, its greatest voltage value, at a solar radiation value of 500 W/m^2, and remained steady at 800 W/m^2. An increase in solar radiation above this point (500W/m^2 to 800W/m^2) has a negligible impact on the voltage produced. When the sun radiation rose from 900 W/m^2 to 1000 W/m^2, however, the voltage began to fall. The findings are consistent with a study by [4] that demonstrated a little rise in open-circuit voltage with an increase in solar radiation at PV cell temperatures of 0 ^{o}C and 25 ^{o}C, respectively.

According to [2], when solar radiation levels above 800 W/m^2, the generated voltage declined. They came to the conclusion that this development may be linked to the PV cell temperature, which was thought to be higher than 25 ^{o}C.

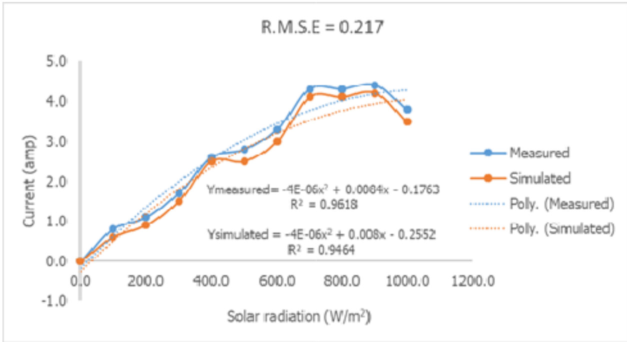

Fig. 5. Relationship between current and solar radiation.

The result in Figure 5 shows the relationship between the generated current and solar radiation. The R.M.S.E. value of 0.217 showed the variation in the mean experimental and simulated current. The current increased with an increase in solar radiation from 100 W/m^2 to 900 W/m^2, with a slight drop in current at 800 W/m^2. However, the current dropped further beyond the sol. rad. value of 900 W/m^2. As a result, behavioural changes in generated current could be linked to high photovoltaic cell temperature as sol. rad. increases from 900 W/m^2 to 1000 W/m^2. Therefore, the initial increase generated is highly significant. When solar radiation was increased from 100 W/m^2 to 800 W/m^2, the current increased by 4.5 times.

Overall, there was a direct proportional link between solar radiation and output power, meaning that for every unit increase in solar radiation, there is an equal increase in generated power.

Figure 6 demonstrates a significant increase in power output in response to an increase in solar irradiation, which rises laterally with time and photovoltaic cell temperature. The power rose from 5.1 watts at 200 W/m^2 of solar radiation to a maximum of 46.2 watts at 700 W/m^2. However, the amount of electricity generated stayed constant between 700 and 900 W/m^2 of solar irradiance and began to decline at 900 W/m^2 to the lowest amount of 41.6 watts at an increased solar radiation of 999 watts.

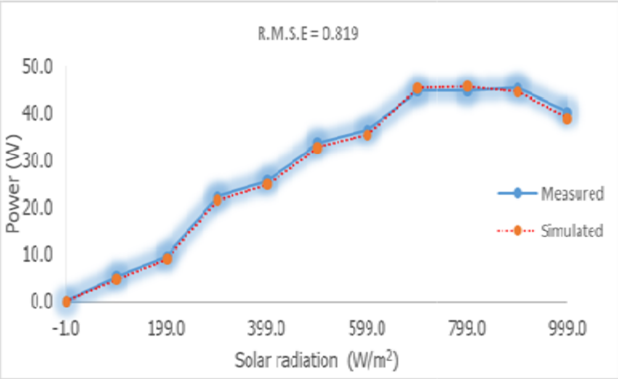

Fig. 6. Solar radiation effect on power generated.

The findings of the experiments showed that the lowest and highest generated powers were calculated at 7:00 a.m. and noon, respectively, and that these periods corresponded to PV temperatures of 22.1 °C and 27.1 °C. As a result, despite an increase in solar radiation, the peak value of produced power declined progressively from 2:00 to 3:00 p.m. and remained constant between 1:00 and 2:00 p.m. It follows that it is logically plausible that elements like air temperature, PV temperature, and solar radiation could have a significant impact on a photovoltaic module's efficiency. The conclusion is highly supported by a number of investigations, including [2;8;9]. Figures 5 and 6 show the responses of measured and simulated power and voltage generation to solar radiation.

IV. Conclusion

Due to the high air temperatures year-round, Auchi and its surroundings are characterized by strong sun irradiation, which benefits the possibility of solar power generation. A peak generated power of 47.1 watts was detected at a photovoltaic cell temperature of 27.1 °C, according to the study's findings, while additional increases in PV temperature resulted in a decrease in module-derived current and power despite an increase in solar radiation level. The overall findings indicate that high solar radiation and low PV temperature would boost the production of photovoltaic energy. As a result, it is advised that solar panels have a cooling system for the photovoltaic modules.

V. Acknowledgments

The authors gratefully acknowledge Miss Rabiat Deborah OLOTU and Muhammad-Jamiu OLOTU for their editorial reviews. In addition, the Department of Electrical and Electronic Engineering at Auchi Polytechnic in Auchi is also acknowledged for the release of datasets on photovoltaic temperature. Finally, the holistic participation of all authors is well acknowledged.

References

[1] R. G. Nwanko, and G. O. Avwiri, "*Environmental effects on the performance of solar photovoltaic panel*''. International Journal of Innovative Scientific and Engineering Technologies Research, vol.9 (3), pp. 16-26, December 2021.

[2] M. J. Buni, A.A. Walie, and K.A.N. Al-Asadi, "*Effect of solar radiation on photovoltaic cell*''. International Research Journal of Advanced Engineering and Science, vol. (3), pp.47-51., December 2018.

[3] S. S. Inamdar, and A. P. Vaidya, "*Performance analysis of solar photovoltaic module for multiple varying factors in MATLAB/Simulink*, Smart Technologies and management for Computing Communication, Controls, Energy and materials (ICSTM)''. International Conference on IEEE, pp. 562-567, March 2015.

[4] A. Karafil, H. Ozbay, and M. Kesler, "*Temperature and solar radiation effects on photovoltaic panel power''*. Journal of New Results in Science, vol. (2), pp. 48-58, July 2016.

[5] Sustainable-Technologies, "*The effect of irradiance and temperature on the performance of photovoltaic module''*. Technical Brief, pp.1-4. May 2022. Available : www.sustainabletechnologies.

[6] M. Irwanto, Y.M. Iranwan, I. Safwati, W.Z. Leow, and N. Gomesh, "*Analysis simulation of photovoltaic output performance*''. IEEE 8th International, pp.477-481, May 2014.

[7] R. Bhol, A. Pradhan, R. Dash, and S.M. Aliu, "*Environmental effect assessment on performance of solar PV*''. International Conference on IEEE, Pp. 1-5., January 2015.

[8] C. P. C. Bong, H. Hashim, J. Ho, C. S., Tan, and C. T. Lee, '*'Review on the renewable energy and solid waste management policies towards biogas development in Malaysia*''. Renewable and Sustainable Energy Reviews, vol. 70, 988–998, May 2017.

[9] C. Chuntian, and K. W., '*'Three-person multi-objective conflict decision in reservoir flood control''*. European Journal of Operational Research, vol.142(3), 625–631, January 2002.

[10] H. P. Garg, and G. Datta, "*Fundamentals and characteristics of solar radiation*''. Renewable energy, vol (5), pp. 305-319, February 1993.

[11]V. B. Omubo-Pepple, I. Tamunobereton-Ari, and M.A. Brigga-Kamara, "*Influence of meteorological parameters on the efficiency of photovoltaic module in some cities in Delta of Nigeria*''. Journal of Asian Science Research,vol. 3: pp. 107-113, November 2013.

[12]J. A. Amusa, S. O. Azi, and E. A. Edah, "*The effect of ambient temperature and solar panel's surface temperature on output performance of solar system".* Scientia Africana, vol.11: pp.53-64., June 2021.

[13]J. M. Olchowik, S. Gulkowski, K. J. Cieslak, J. Banas, D. Szymezuk, D.K. Zabielski, J. Mucha, M. Zdrojewska, J. Adamczyk, and R. Tomaszewsk, '*'Influence of temperature on the efficiency of monocrystalline silicon solar cells in south-eastern Poland condition*''. Material Science-Poland, vol.3: pp. 107-113, May 2006.

[14]C. O. Nwokocha, and C. O. Okujagu, "*Atmospheric visibility trends in Niger Delta Region Nigeria* 1981-2021''. International Scholars Journals, vol.3 (6), pp. 138-144. September 2013.

[15]J. R. G. Ross, and M. I. Smokler," *Flat-plate solar array"*. Final Report, pp. 86-89. May, 1986.

[16]W. Charfi, M. Chaabane, H. Mhiri, and P. Bournot, "*Performance evaluation of a solar photovoltaic system*". Energy Reports, vol. 4: pp.400-406, May 2018.

[17]K. Saikia, "*Environmental factor affecting the performance of solar photovoltaic module*''. Central University of Jharkhand, vol.4(225), pp.1-2, October 2016.