DOI: https://doi.org/10.4038/sljp.v26i2.8127

INSTITUTE OF PHYSICS – SRI LANKA

Research Article

Modeling of Output Current of a Polycrystalline Photovoltaic Module via Ambient Temperature in Ilorin, Nigeria

Mufutau Abiodun Salawu[1*], Usman Abdulkareem[2], and Sabastine Chinedu Ezike[3]

[1]Department of Physics, University of Ilorin, Ilorin, Nigeria.
[2]Physics/Electronics Unit, Kwara State Polytechnic Ilorin.
[3]Department of Physics, School of Physical Sciences, Modibbo Adama University of Technology, Yola, Adamawa State, Nigeria.

Abstract

The effect of ambient temperature on the performance of a 130 W polycrystalline photovoltaic (PV) module was explored in this study. With field data at Ilorin, Kwara State, Nigeria, the output current of a 130 W PV module was modeled using ambient temperatures. For field observations, an instrumented meteorological mast was set up at the experimental site located (8° 30' N, 4° 33' E) at Kwara State Polytechnic in Ilorin, Nigeria, for two weeks (1st to 14th July 2019). At 10-second intervals, the PV cell output current and ambient temperatures from the instrumented meteorological mast were recorded. A data logger (fabricated) storage module was used to store the sampled data. The saved data was further reduced to 20 min averages using the Microcal Origin data analysis program after erroneous measurement values were removed (quality assurance and quality control). With the MBE of 0.01 Wm^{-2}, RMSE of 0.13 Wm^{-2}, and r = 0.61, the predicted output current, OC_P, was compared to the actual measured output current, OC_m, and very good agreement was found. As a result, even with a short set of measured ambient temperature data, the estimator explored in this study is capable of predicting the performance of a polycrystalline PV cell in terms of its output current in the absence of direct measurement of the output current.

Keywords: Data logger; modeling; module; polycrystalline; Photo-Voltaics.

* Corresponding author: saluwa.ma@unilorin.edu.ng

1. INTRODUCTION

Solar energy is the most abundant and widely available renewable energy source, with a high potential for replacing fossil fuels and thereby lowering greenhouse gas emissions (Zhang *et al.,* 2020). Many solar energy systems are being explored around the world, but photovoltaic cells are gaining traction due to their rapidly improving technology and potential uses in meeting the ever-increasing energy demands of developing and developed nations. When evaluating the performance of a photovoltaic (PV) module, its efficiency is critical. Its performance is essentially determined by the temperature of the PV module, the amount of irradiation received, and the spectrum content of the input photons (Muhammad *et al.,* 2014). Several studies have found that as the temperature rises over the usual operating temperature, the performance of photovoltaic modules decreases due to increased internal carrier recombination rates produced by higher carrier concentrations. The output power of a PV module is dependent on its operating temperature. The temperature of PV modules is also said to be affected by climatic factors such as ambient temperature (T_A), solar radiation, materials, and system-dependent features such as glazing (Dubey *et al*., 2013).

When solar radiation illuminates a PV module, approximately 20% of the energy is converted to electric power, while the rest is converted to heat. Research articles on the properties of PV modules have been reported, with a particular focus on the impact of solar irradiation and ambient temperature on their performance (Swapnil *et al.,* 2013); (Sumaryada *et al.,* 2019); (Aburiya *et al.,* 2007); (Premalatha and Rahim, 2007); (Panagea *et al.,* 2014); (Fesharaki *et al.,* 2011); (Panagea *et al.,* 2014); (Xu *et al.*, 2013); (Kawajiri, 2013). Other researchers have also reported the impact of climate variability on PV performance (Amelia *et al.*, 2016); (Sanusi *et al.*, 2014); (Petrana *et al.*, 2018); (Ioanna *et al.*, 2014); (Mesude *et al.,* 2014); (Marcu *et al*., 2016); (Sumaryada *et al*., 2019); (Salawu *et al*., 2016).

The focus of this study is on measuring the output current of a 130 W polycrystalline PV module and developing a parametric equation for forecasting its output current from various ambient temperature data in Ilorin, Nigeria.

2. MATERIALS AND METHOD

The following is the linear regression equation for parameterizing the output current of a polycrystalline PV from ambient temperature measurements:

$$\mathrm{OC}_P = a(T_A) + b \tag{1}$$

where OC_P is the predicted output current, a is the slope, T_A is the ambient temperature and b is the intercept. The parameters of the linear regression equation (a and b) were estimated from the calibration (here: a = 0.07 and b = 8.71). The performance of the parameterized approach was tested statistically by estimating the mean bias error (MBE) and root mean square error (RMSE) respectively. The two errors can be estimated through equations (2) and (3) as follows;

$$MBE = \frac{\Sigma(OC_p - OC_m)}{n} \tag{2}$$

$$RMSE = \sqrt{\frac{\Sigma(OC_p - OC_m)^2}{n}} \tag{3}$$

where OC_p and OC_m are the parameterized and the measured mean values of output current, respectively and n is the total number of observations. A low RMSE and MBE are preferable, whereas a positive or negative MBE suggests overestimation or underestimation of values, respectively. On-site, an instrumented meteorological weather mast was constructed to monitor the output current of the polycrystalline PV system and the ambient temperature. The devices were put up for two weeks at an experimental site near Kwara State Polytechnic's Physics/Electronics Laboratory in Ilorin, Nigeria (1st to 14th July 2019). The 130 W solar PV was installed on a 2.7 m tall mast that was oriented at 1.41 m above ground level. Between 10 a.m. and 6 p.m local time, measurements were taken every 10 seconds and averaged across 20-minute intervals. A data logger storage module was used to store the sampled data. The Microcal Origin data analysis software was used to further decrease the recorded data.

3. RESULTS AND DISCUSSION

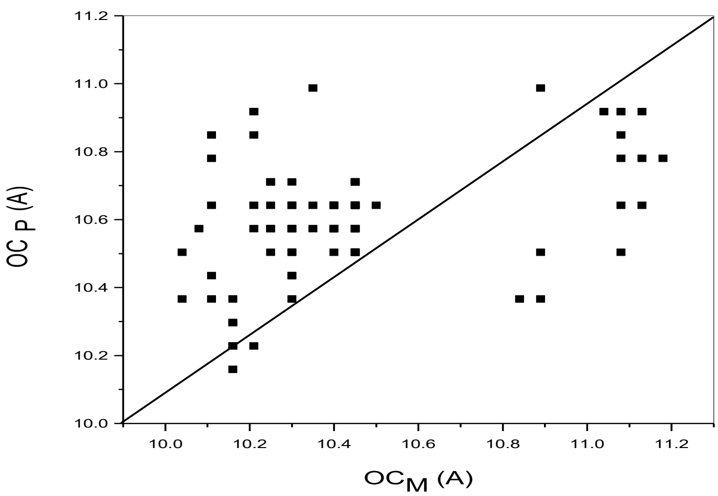

Figure 1: Scatter plot showing the tested predicted output current (OC_P) against the measured output current (OC_M) of the polycrystalline PV.

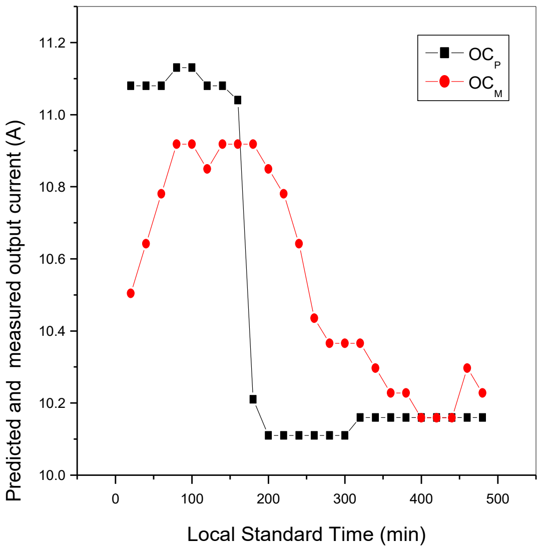

Figure 2: Results of the predicted and measured output current against local time (min) of a polycrystalline PV for July 1, 2019.

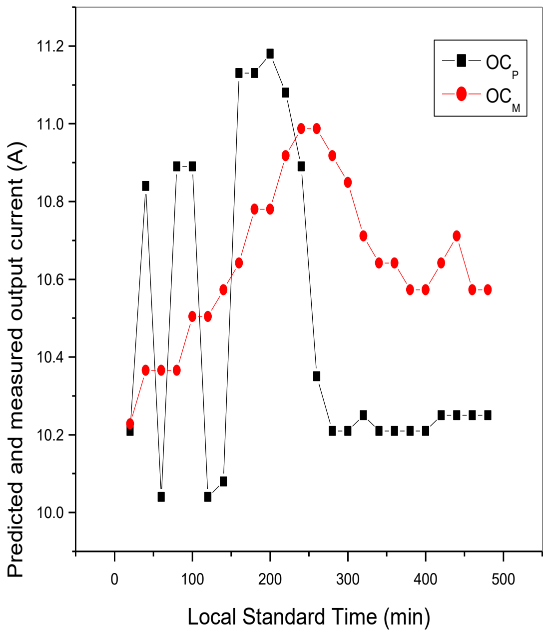

Figure 3: Results of the predicted and measured output current against local time (min) of a polycrystalline PV for July 7, 2019.

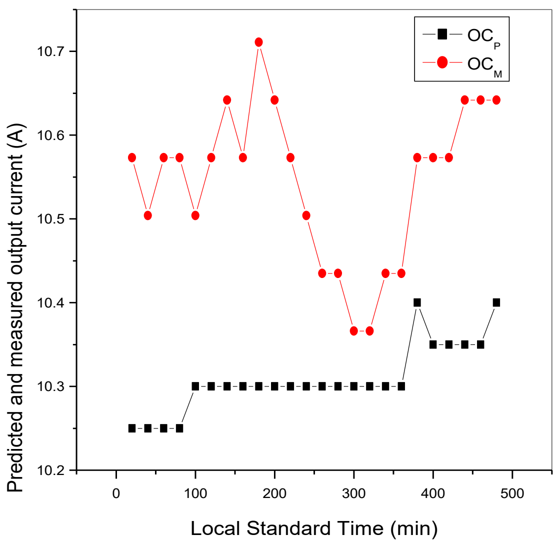

Figure 4: Results of the predicted and measured output current of polycrystalline PV against local time (min) for July 10, 2019.

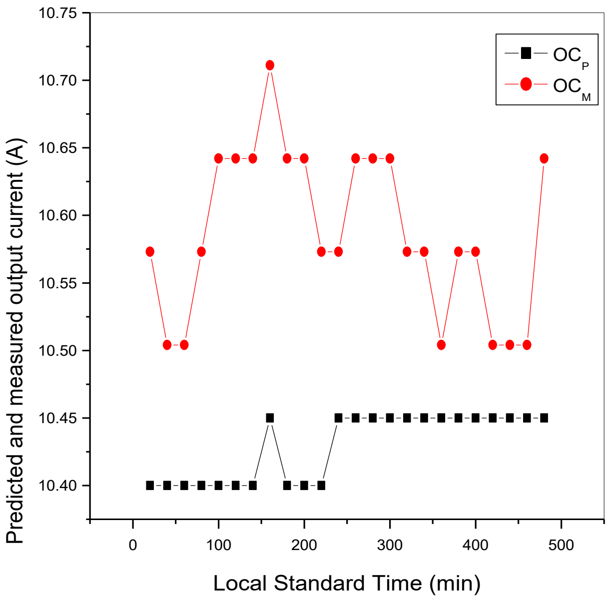

Figure 5: Results of the predicted and measured output current of a polycrystalline PV against local time (min) for July 14, 2019.

Figure 1 depicts the proposed model's accuracy in predicting the output current of the 130 W polycrystalline module. Graphical and statistical methodologies were used to compare the expected data from the predicted model with the measured experimental data set. The output current was calculated using linear regression (equation 1) from ambient temperature observations in Ilorin, Kwara State, Nigeria. The slope and intercept of the linear regression parameters obtained from the calibration data set were 0.07 and 8.71 Wm^{-2}. The coefficient of regression was found to be $r = 0.61$, indicating a high correlation between the anticipated and measured values.

Figures 2-5 show the diurnal variation of anticipated and measured output currents of a 130 W polycrystalline PV module for a few days of our measurements. The anticipated and measured output currents of the polycrystalline PV module are highly correlated with the time of observations. The results showed that the two variables were in good agreement, with a correlation value of 0.61 and a very low mean bias error of 0.01 $Wm^{-2.}$

4. CONCLUSION

The experimental data measured for the output current agrees well with the model suggested in this work for estimating the output current of a polycrystalline PV module via ambient temperature. Within the limits of experimental error, the model equation can be used to forecast the output current of a polycrystalline PV module.

Declaration of Competing Interest

The authors state that they have no known competing financial or conflicting interests or personal ties that could have influenced the work presented in this study.

Data access statement

More information on the data can be requested from the corresponding author.

Acknowledgments

The Department of Physics, Kwara State Polytechnic, Ilorin, provided the support to the authors.

References

1. Aburiya, M.A. & Mutaka, M.M. (2007): The effect of solar irradiance and ambient temperature on solar PV module output in Northern Ghana, Ghana Journal of Development Studies, Vol. 4, No 2, 117-125.
2. Amelia, A.R.; Irwan, Y.M., Leow, W.Z., Irwanto, M., Safwati, I. & Zhafarina, M. (2016): Investigation of the Effect of Temperature on Photovoltaic (PV) Panel Output Performance, International Journal on Advanced Science Engineering Information Technology, Vol. 6, No 5. ISSN: 20885334.
3. Fesharaki, V.J., Majid D. & Fesharaki, J.J. (2011): The Effect of Temperature on Photovoltaic Cell Efficiency, Proceedings of the 1st International Conference on Emerging Trends in Energy Conservation - ETEC Tehran, Tehran, Iran, 20-21.
4. Ioanna S. P., Ioannis K. T., Aristeidis G. K., & Manolis G. G. (2014): Climate Change Impact on Photovoltaic Energy Output: The Case of Greece, Hindawi Publishing Corporation Advances in Meteorology, Article ID 264506, 11 pages http://dx.doi.org/10.1155/2014/264506.
5. Kawajiri, K. (2011): Effect of Temperature on PV Potential in the World, Environ. Sci. Technol., American Chemical Society dx.doi.org/10.1021/es200635x. 45, 9030–9035.
6. Mesude B, Yosoon C. & Jeffrey R. S. B. (2014): Temperature-Dependent Power Modeling of Photovoltaics, Energy Procedia 57, 745 – 754.
7. Muhammad T., Jan, O. O & Tor O. S., (2014): Irradiance dependent temperature coefficients for MC solar cells from Elkem solar grade silicon in comparison with reference polysilicon, 4th International Conference on Silicon Photovoltaics, Silicon PV, Energy Procedia 55, 602–607.
8. Marcu, M., Niculescu, T., Slusariuc, R . I & Popescu, F.G. (2016): Modeling and simulation temperature effect in polycrystalline silicon PV cells, IOP Conf. Series: Materials Science and Engineering 133, 012005 doi:10.1088/1757-899X/133/1/012005.
9. Premalatha L and Rahim N. A, (2007): The effect of Dynamic weather conditions on three types of PV Cell Technologies- A comparative Analysis, Energy procedia, 107, 275-282.

10. Salawu M. A, Alabi, A.B, Ajayi A. A and Akomolafe .T. (2016): Effects of Working Temperatures and Metal Back Contacts on the Efficiencies of CdS/CdTe Thin Film Solar Cells, Journal of the Nigerian Association of Mathematical Physics 36 (2), 337-342.
11. Subhash C., Purohit, A., Anshu S., Arvind, S. P. N., Dhaka, M.S. (2015): A study on Photovoltaic Parameters of mono-crystalline Silicon Solar cell with Cell temperature. Energy Reports 1, 104-109.
12. Swapnil, D., Jatin, N. S. & Bharath S. (2013): Temperature-Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World. Energy Procedia 33, 311 – 321.
13. Sanusi Y.K., Ojeniyi A. & Norani N. (2014): "Analysis of Atmospheric Parameters Variation on Efficiency of Polycrystalline PV System in a Tropical Station." Applied Mechanics and Materials, vol. 661, Trans Tech Publications, Ltd., pp. 160–167. Crossref, doi:10.4028/www.scientific.net/amm.661.160.
14. Subhan P., Eko A. S., &Adi J. (2018): Solar panel performance analysis under Indonesian tropic climate using Sandia PV array performance model and five parameter performances model, E3S Web of Conferences 67, 02048, https://doi.org/10.1051/e3sconf/20186702048.
15. Sumaryada T., Afgan S., Heriyanto S. (2019): Simulation of the extra-terrestrial and terrestrial performance of GaAs/Ge dual-junction solar cells, Kuwait J. Sci. 46 (4) pp. 58-65.
16. Xu G., B. Hallam, Z. H., Chan, C., Yao, Y., Chong C. & Wenham, S. (2013): Over 700 mV Implied Voc on p-Type CZ Silicon Solar Cells with Double-Sided Laser Doping, Energy Procedia, 33, 33 – 40.
17. Zhang X. & Xu, M. (2020): Assessing the Effects of Photovoltaic Power plants on Surface Temperature Using Remote Sensing Techniques, Remote Sens., 12, 1825; doi:10.3390/rs12111825 www.mdpi.com/journal/remotesensing.