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Temperature Effects on Optimal Performance of PV Module

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ABSTRACT

The commonly used renewable energy source (RES) is solar energy. However, the production of this energy from PV modules has a lot of challenges and still needs technological improvement. This research investigates the effects of temperature on Photovoltaic (PV) module optimal performance. An experimental setup of a Monocrystalline (MC) module was used and data on the temperature and other parameters were measured using appropriate measuring tools. The relationship between module temperature and other parameters was evaluated using Pearson product correlation. The findings of this study showed that the temperature is significant for the Monocrystalline PV module to operate at its optimal. Also, the finding revealed that there is a weak correlation between the open circuit voltage (OCV) of the panel and the temperature, however, the PV module temperature has a strong and positive correlation with other parameters namely; solar irradiance, short circuit current (SCC), output power and conversion efficiency (CE) with a correlation coefficient (CC) of 0.94, 0.93, 0.92 and 0.93 respectively. The conversion efficiency of the PV module increases when its temperature is within the maximum operating temperature and tends to decrease when the temperature is beyond the design operating temperature of the module. This implies that temperature is also a key parameter to consider when designing a PV module system for optimal performance. This research recommends that temperature should be considered in the design of PV modules to power any equipment or machines for better performance.

Keywords: Temperature, Photovoltaic, Efficiency, Correlation.

1 Introduction

Renewable energy sources (RES) have become a great way to alleviate the effect of climatic change on the environment. The trend in technology has paved way for the use of RES in most developed and developing countries which invariably serves as a way of sustaining the environment by reducing the dependence on nonrenewable sources of energy generation. However, this technology faced a lot of challenges in operating at its optimal performance [1]. One of the common RES aside from hydropower is solar energy (SE) which uses a solar PV module to convert sunlight directly to electricity [2]. Nnadi [3] studied the climatic effect on stand-alone solar energy supply performance for sustainable energy. The PV module was simulated on Matlab and the results were compared with other findings. The results of the research showed that the installation of a PV module away from obstruction enhanced the module's performance. However, the study did not state the relationship between temperature and operating parameters of the module in terms of correlation.

Also, the study of Tamunobereton-Ari [4] was focused on the influence of meteorological parameters on the efficiency of photovoltaic modules in some cities in the Niger Delta of Nigeria. The obtained results demonstrate that the solar flux and the output current were directly related to the solar panel efficiency. Additionally, the increased solar flux causes the output current of solar panels to rise, improving efficiency. Relative humidity was also seen to decrease the output current and boost efficiency. However, the researcher did not consider the effects of temperature on the PV parameters. Other reviewed literature [5]-[8] showed the effect of climatic and environmental factors such as ambient temperature, dirt and dust properties, shading, and acidic rain on the operation of the PV module in their region. The review of the existing literature shows that the PV module is often characterized by its operating parameters in which any deviation can lead to alteration in the module operation. Some factors that affect the performance of the PV module are environmental factors such as shading and climatic parameters such as solar irradiance and temperature. The environmental factors can be eliminated through human intervention while the effect of the climatic parameters can be reduced to improve the performance of the PV module. One of the climatic parameters that can be reduced is the temperature because of its thermal degradation on the module, which affects the output power and other parameters of the PV module [9]. This research evaluated the effect of temperature on monocrystalline PV module operating parameters. The discovery of the PV effect by Edmond Becquerel in 1839, was not useful at that time until 10 decades later after Shockley had developed a model for the p–n junction, Bell Laboratories produced the first solar cell in 1954. One of the major challenging factors is the CE of PV modules which is relatively low 15-25 % [10]. When the solar irradiance fall on the PV module the hole and electron drift towards the p-n junction which will allow the flow of current and the ideal characteristics of the diode under dark condition is presented in Fig. 1. The output power of the PV module depends on the level of penetration of the solar irradiance that falls on the PV module and the CE of the module. Under normal operating conditions the higher the solar irradiance the higher the output power, however, variation in operating conditions will lead to alteration in the output characteristics of the module. Since the temperature of each region differs from one other and temperature is one of the parameters that determine other operating parameters of a PV module, due to its thermal effect on the module. There is a need to model the effect of temperature in Ibadan on monocrystalline

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PV modules to know the effect of the temperature on PV that gives optimal performance.

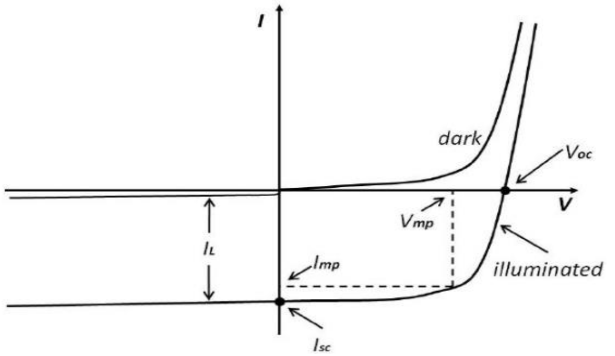

Fig. 1 I-V characteristics of an ideal diode solar cell when non-illuminated (dark) and illuminated.

2 Materials and Methods

An MC Photovoltaic module was set up from October (2017) to January (2018) at the University of Ibadan southwest Nigeria as presented in Fig. 2, with specifications shown in Table 1. The data was measured at 1hr intervals from 8 am in the morning till 6 pm in the evening with appropriate measuring instruments.

Fig. 2 View of the experimental setup.

The solar irradiance (W/m^2) incident on the surface was obtained using a solarimeter. Also, the Module temperature was measured with a k-type thermocouple temperature data logger. The voltage and current were determined using two different multimeters.

Table 1 PV Module specifications

Parameters	Value
Maximum power	150W
Maximum power tolerance	3%
(OCV)	23.1V
SCC	8.99A
Maximum power voltage	18V
Maximum power current	8.34A
Dimension (mm)	1480 by 670 by 30
Maximum system voltage	1000V
Maximum Overcurrent protection rating	15A
Module Application Class	A

The maximum power supplied by the PV module was computed using Eq. (1).

$$P = IV \tag{1}$$

where I is the current and V is the voltage.

Pearson's correlation between the module temperature and other parameters was computed using Eq. (2).

$$r = \frac{\sum_{i=1}^{n}(t-\bar{t})(p-\bar{p})}{\sqrt{\sum_{i=1}^{n}(t_i-\bar{t})^2}\sqrt{\sum_{i=1}^{n}(p_i-\bar{p})^2}} \tag{2}$$

where t is the temperature, $\bar{t}$ is the mean of temperature, p stand for other PV parameters considered such as OCV, current, solar irradiance, output power, and CE $\bar{p}$ is the mean of other parameters, i is the instant data while n is the sample size of the data. The photoelectric CE was calculated using equation (3).

$$\eta = \frac{P_{max}}{G \times A} \tag{3}$$

where η is the photoelectric CE, G is the solar irradiance incident on the PV module, A is the surface area of the PV module, and P_{max} is the maximum power generated from the PV module.

3 Results and Discussion

The results of the study are presented in Table 2 and Fig. 3-Fig. 7. Fig. 3, shows that as the module temperature increases, the OCV is slightly increasing when the module temperature was within the range of 27.7°C − 48.6°C. The OCV is maximum (20.6V) at a temperature of 36.6°C. The correlation coefficient between temperature and OCV in Table 1, suggests that there is a poor relationship between OCV and the temperature of the module. Also, with R-square value of 0.0656 implies only 6.5% of the observed data can be explained by the model. This implies that temperature can only explain its effect on voltage to an accuracy of 6.5%.

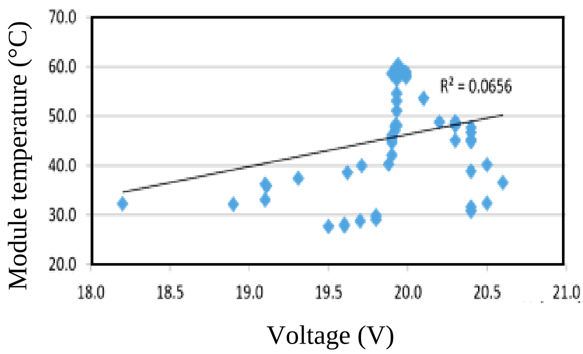

Fig. 3 The relationship between module temperature and voltage.

Table 2 Correlation results between temperature and other module parameters.

Parameter	R^2	Comments
OCV	0.256	Poor
Current	0.930	Strong
Solar Irradiance	0.938	Strong
Output Power	0.923	Strong
Conversion Efficiency	0.925	Strong

Fig. 4 shows the short circuit current also increases due to variations in temperature within the normal operating condition of the module. Also with a CC of 0.93, it implies that current and temperature have a strong and positive correlation. The R-square of 0.8648 in the model suggests that temperature can affect the current of a module up to 86.58%.

Fig. 5, shows a direct relationship between the module temperature and solar irradiance, and a CC of 0.938 implies that there is a strong relationship between the temperature module and solar irradiance. The R-square value of 0.8792 shows that temperature can affect the output power of the module up to 87.92%.

The relationship of module temperature with output power was observed as shown in Fig. 6, which indicates that as the temperature varies the output power increases and there is a strong relationship between the two variables as the CC is 0.923. At the peak temperature of 60°C, the maximum power was obtained. The R-square value of 0.8514 shows that temperature can affect the output power of the module up to 85.14%. This implies that the MC module subjected to a temperature of 60°C can give the maximum power output. This is against the study of [11] which states that solar modules perform better under a laboratory condition of 1000 W/m^2 incident solar irradiance, 25°C cell temperature. The temperature for the optimal performance for the monocrystalline PV module in Ibadan is 60°C.

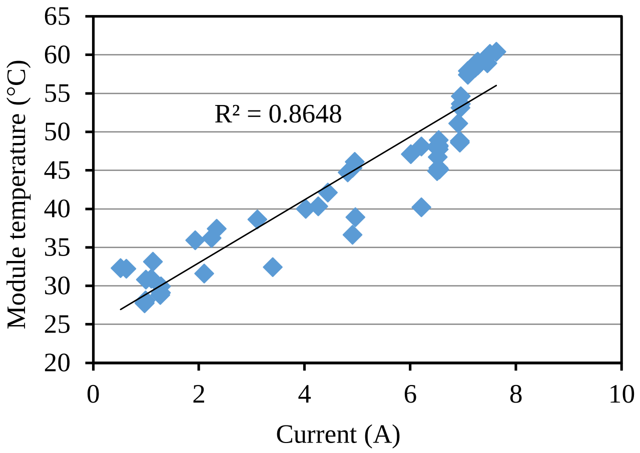

Fig. 4 The relationship between module temperature and Current

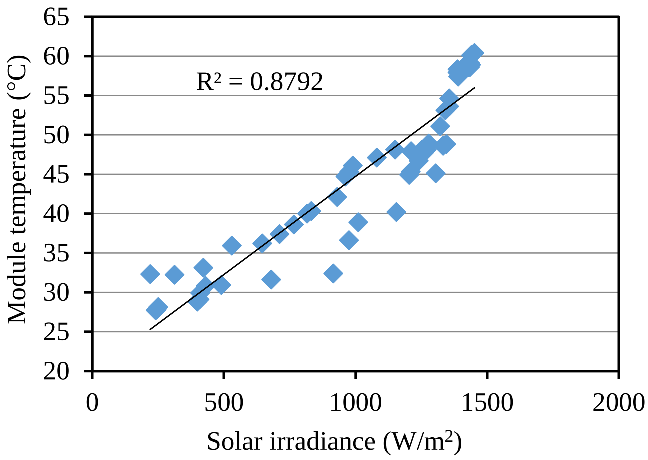

Fig. 5 The relationship between module temperature and solar irradiance

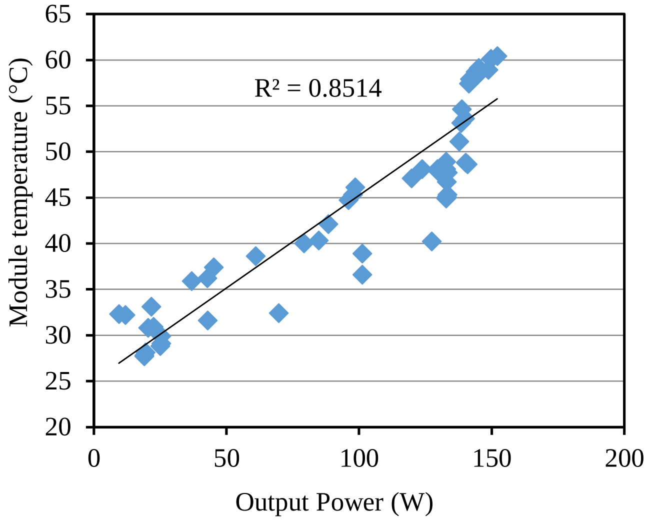

Fig. 6 The relationship between module temperature and output Power.

The results in Fig. 7, indicate that an increase in module temperature within the operating temperature limits leads to an increase in CE. The CE reaches a maximum of 15.4% when the module temperature is at a maximum of 60°C. This implies that the CE will continue to increase as the module temperature is within the operating limit. Also, the CC shows a strong relationship between the PV module temperature and output efficiency which shows that CE also depends on the module temperature. The R-square value of 0.8556 shows that temperature can affect the efficiency of the module up to 85.56%.

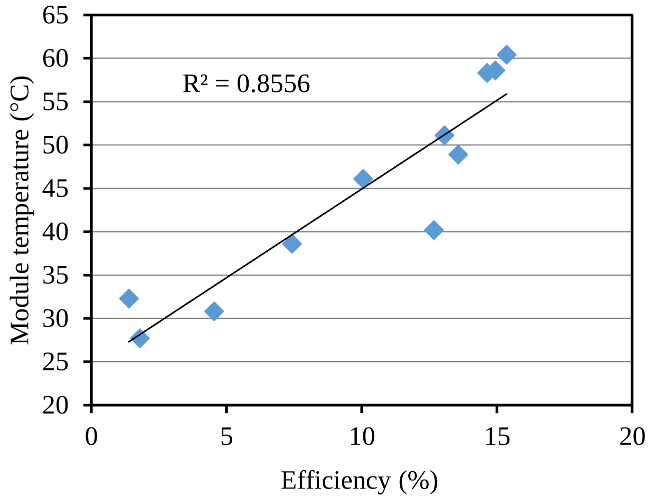

Fig. 7 Relationship between module temperature and efficiency

4 Conclusion

The research has shown that PV module temperature among other factors, has a great effect on PV performance. The findings of this study show that the PV module temperature has a positive and strong correlation with other parameters (Solar irradiance, short circuit current, output power, and CE). The temperature has a significant effect on the PV parameters to improve the performance of the PV module. Also, the study shows that the optimal temperature for the monocrystaline module in the study location is 60°C. This implies that temperature should be considered in the design of PV modules to power any equipment or machines for better performance.

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