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The Effect of Irradiance and Temperature on the Performance of Monocrystalline Silicon Solar Module in Kakamega

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Authors' contributions

This work was carried out in collaboration between all authors. Author LMM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors WHB and MM managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Solar energy can be harnessed as photovoltaic energy or solar thermal. Photovoltaic modules provide safe, reliable, and maintenance-free, without noise and environmentally friendly source of power This paper evaluates the outdoor performance of a monocrystalline silicon module based on irradiance and temperature in Kakamega region. The outdoor performance characterisation of a 20 W mono-crystalline silicon module was investigated under different values of solar irradiance and module surface temperature in Kakamega, Kenya. Short circuit current of the module increased significantly with increasing irradiance while open circuit voltage was least affected. Both fill factor and efficiency showed a similar trend with irradiance, increasing slightly and then reducing. The response variables; fill factor, efficiency, open circuit voltage and maximum power were found to reduce with increase in surface temperature while short circuit current increased slightly. The average efficiency, fill factor, short circuit current and open circuit voltage for the module was found to be 10.11%, 0.65, 0.65A, and 19.78V respectively. Maximum Voltage, maximum current and maximum power were found to be 16.78V, 0.48A and 8.11W respectively. A good knowledge of the power output of a solar module and how it varies with solar irradiance and temperature would give accurate information which is vital in sizing and design of photovoltaic system.

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Keywords: Operating parameters; perfomance characterisation; photovoltaic sizing; solar module; renewable energy.

ABBREVIATIONS

FF : Fill Factor
NASA: National Aeronautic Space Administration
V_{OC} : Open Circuit Voltage
I_{SC} : Short Circuit Current
P_{MAX} : Maximum Power
V_{MP} : Voltage at Maximum Power
I_{MP} : Current at Maximum Power

1. INTRODUCTION

Ever since the industrial revolution, humans have sought to generate power from a variety of energy sources. Much of the energy is generated in power plants, which use large quantities of fossil fuels which are rapidly diminishing, thus the need to switch to the use of renewable energy.

Kenya is a developing country with one of its vision 2030 goals being to attain a 24-hour economy and so there is a need to boost energy production in the country from renewable energy sources.

In Kenya, renewable energy sources include hydro, wind, solar, biomass and geothermal. Currently, Kenya heavily relies on hydro as the predominant source of electrical energy production averaging 70% [1]. However, the recent prolonged droughts have affected power generation, leading to power rationing in most parts of the country, including industrial zones, where constant power supply is essential. Therefore, there is a need to explore solar energy generation which is environmentally sensible alternative to fossil fuels. Solar energy can be harnessed as photovoltaic energy or solar thermal. Photovoltaic modules provide safe, reliable, and maintenance-free, without noise and environmentally friendly source of power [2]. Kenya sits astride the equator hence it receives an abundant amount of solar radiation in a year. During their manufacture in industry, photovoltaic (PV) modules are characterised at indoor standard test conditions (STCs) using the irradiance of 1000 W/m^2 from a simulation lamp and a temperature of 25°C [3]. However, the outdoor performance conditions may not necessarily agree with the indoor STC hence the factory rated values are found to differ during their practical use due to the change in the position of sun, amount of solar radiation, cloud cover, module temperature and geographical location [4]. Most PV sizing and installations at the region have been done based on the Standard Test Conditions which are very different from the ambient conditions in the region.

A good knowledge of the power output of a solar module and how it varies with solar irradiance would give accurate information which is vital in sizing and design of photovoltaic system [1] to harness solar energy. This study sought to determine the effect of solar irradiance and module surface temperature on the performance of mono-crystalline silicon solar module to establish data that could guide future guidance on PV sizing and installation in Kakamega.

2. THEORY OF PHOTOVOLTAICS

The I-V curve of a PV module describes its energy conversion capability at the existing conditions of irradiance (light level) and temperature. It represents the combinations of current and voltage at which the module could be operated or loaded, if the irradiance and cell temperature could be held constant [5]. It is modelled according to equation 1 [6].

$$I = I_{ph} - I_0\left(exp\left[\frac{V + IR_S}{mkT}\right] - 1\right) - \frac{V + IR_S}{R_p} \quad (1)$$

Where *I*, I_{ph}, I_0, *V*, m, *k*, *T*, *Rs*, *and* R_p are the ideal current, photocurrent, reverse saturation current, voltage across the PV system terminals, the ideality factor, Boltzman's constant, ambient temperature in Kelvin, cell series resistance and cell shunt resistance respectively. From equation 1, Current-Voltage characteristic curve can be plotted.

The performance characteristics of a solar module is determined by the cell key parametres such as the maximum power, the open circuit voltage, the short circuit current, the fill factor and the cell conversion efficiency which can be determined from the I-V characteristic curve. I_{sc} is the light generated current obtained when the load is zero in the circuit [3]. It is determined as:

$$I_{sc} = I_{sp} - I_0\left[e^{\frac{q(R_s I_{sc})}{mkT}} - 1\right] for\ V = 0 \quad (2)$$

Where *q* is the charge of an electron, *m* is the diode quality factor [7].

V_{oc} is the voltage measured when the PV device terminals are isolated. It relates to the voltage that occurs when no current is passing through the cell [3,7]. It is calculated as:

$$V_{oc} = \frac{mkT}{q} ln\left(\frac{I_{sc}}{I_0} + 1\right)\ for\ \ I = 0 \quad (3)$$

where k is the Boltzmann constant, T is temperature, I_{sc} is generated current, q is charge of an electron and I_o is the dark saturated current [8].

FF is the ratio of the maximum power from actual solar cell to the maximum power from ideal solar cell [4]. It determines quality of the cell. For a good panel, FF is between0.7 to 0.8 and for a bad one it may be 0.4 [4].

$$FF = \frac{P_{max}}{V_{oc} * I_{sc}} = \frac{I_{max} * V_{max}}{V_{oc} * I_{sc}} \quad (4)$$

Efficiency is the ratio of the electrical power output, P_{out} compared to the solar power input, P_{in} into the PV cell [3].

$$\eta = \frac{P_{out}}{P_{in}} \rightarrow \eta_{max} = \frac{P_{max}}{P_{in}} = \frac{V_{oc} * I_{sc} * FF}{I_t * A_c} \quad (5)$$

Where power in, P_{in} = Irradiance (W/m^2) * cross-sectional area of solar cell (m^2).

3. MATERIALS AND METHODS

A mono-crystalline module rated 20 W, digital multimeter, digital thermometer and 50 Ω variable resistor were used. Table 1 illustrates the module parameters.

Table 1. Module parameters

Module parameters	
Open Circuit Voltage, V_{oc} [V]	21.6
Short Circuit Current, I_{sc} [A]	1.2
Voltage at Maximum Power, V_{mp} [V]	18
Current at Maximum Power, I_{mp} [A]	1.1
Maximum Power Point [W]	20
Fill Factor	0.764
Efficiency	14.69%
Area [m^2]	0.135

Outdoor performance measurement was conducted at Kakamega high school latitude 0.2827^{0}N and longitude 34.7519^0 E. These coordinates were determined by zooming in and locating it on Google maps. The module was placed in N-S direction throughout the research period. Values of irradiance were obtained from NASA surface and metrological website whose data is recorded in 3-hour interval from 9 AM to 3 PM. Hourly values were then extracted by extrapolation [9]. To obtain short circuit current at given values of irradiance the module was connected directly to the multimeter and the current measured. The same procedure was used to obtain open circuit voltage. For I-V characterisation, a 50 Ω variable resistor was connected in series with the module as shown in Fig. 1 and values of current and voltage obtained in steps of 10 Ω. The measurements were done over a period of 6 months and average data used for analysis.

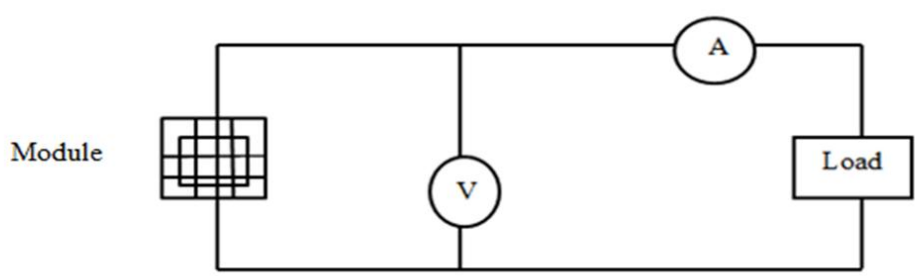

Fig. 1. Circuit diagram for I-V characteristics

4. RESULTS AND DISCUSSION

Fig. 2 shows temperature variation at different times of the day. Average module surface temperature was observed to increase from 30.3°C at 9 A.M to 37.2°C at noon then dropped 31.5°C at 4.30 P.M. Maximum surface temperature was registered at noon.

Fig. 3 shows average evolution of irradiance at different times of the day. Maximum solar irradiance was registered at noon.

Fig. 4 illustrates the I-V curves obtained at different values of irradiance. From the figure, it was observed that I_{SC} increased with increase in irradiance intensity, while V_{OC} was least affected by the change in irradiance. Increase in the intensity of the radiation increases the photocurrent generated hence leading to increased short circuit current [10]. This result is confirmatory to the work done by Tobnaghi and Naderi [10], Arjyadhara et al. [11].

As the solar insolation varies throughout the day, so does the power produced by the module [11]. The peak of the curve obtained in Fig. 5 corresponds to maximum power point of the module at each irradiance value, where the module produced maximum I-V values. Due to fluctuations in irradiance level, the I-V curve was seen to change and so the maximum power point. It can be seen from Fig. 3 that the maximum power produced by the module increased with the solar irradiance. This variation of power with irradiance agrees with the study done by Arjyadhara et al. [11].

Fig. 6 illustrate the behavior of FF with increasing irradiance. On average FF was observed to increase with irradiance at low intensities, from 0.65 to 0.66 and then it dropped for irradiance above 0.66. This increase in FF is due to increased light generated current as irradiance increased [12]. The drop if FF at high intensities is attributed to the corresponding rise in temperature which lowers the quality of the module [11]. As FF approaches unity, the quality of the module gets better [11]. This behavior of FF with irradiance agrees with the work done by Ugwuoke and Okeke [13].

From Fig. 7, power output of the module was seen to increase with increasing irradiance. Maximum power was therefore seen to be produced at 0.77kW /m^2 in this region. The increase in power is due to increased voltage and PV generated current with increasing irradiance. This variation of power with irradiance agrees with the study done by Arjyadhara et al. [11].

Fig. 8 it was observed that the highest conversion efficiency of the silicon module was found to be 11.48% at irradiance 0.55kW/m^2 while the lowest efficiency was 8.78% at irradiance 0.77kw/m^2. This lower efficiency at high irradiance was attributed to the highest temperature registered at the same time which reduces voltage output that lowers power output. This behaviour of efficiency with irradiance was observed in the work done by Ugwuoke and Okeke [13].

From Fig. 9 voltage is strongly affected by surface temperature than current. As module surface temperature increases,the band gap of the semiconductor reduces hence more incident energy is absorbed. More charge carriers are raised from the valence band to the conduction band resulting in a slight increase in I_{sc}. Reverse

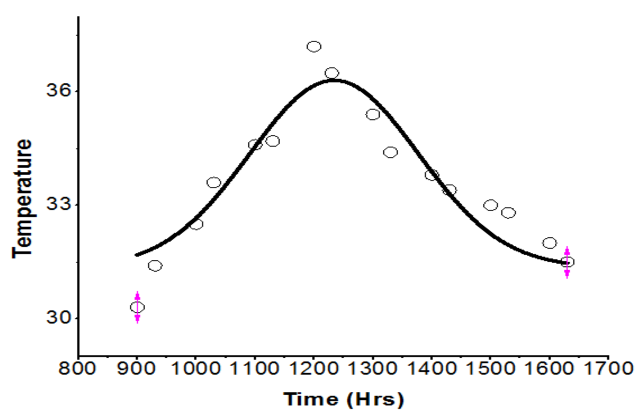

Fig. 2. Average variation of surface temperature at different times of the day

saturated current also increases. PV modules have a positive temperature coefficient of I_{SC} [10]. As temperature increases thermally generated electrons increase the rate of phonon vibrations that hinder electron hole generation. This thermally generated electrons begin to dominate the electrical properties of the semiconductor leading to decrease of voltage [14,15]. Hence PV modules have a negative temperature coefficient of $V_{OC.}$ This behaviour of V_{OC} and I_{SC} with temperature agrees with the study done [13,11,10].

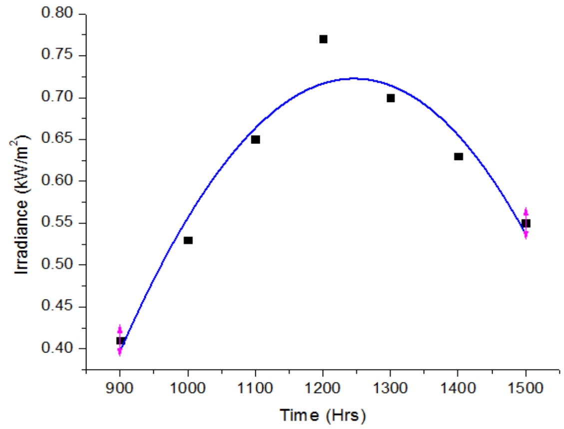

Fig. 3. Average variation of solar irradiance at different times of the day

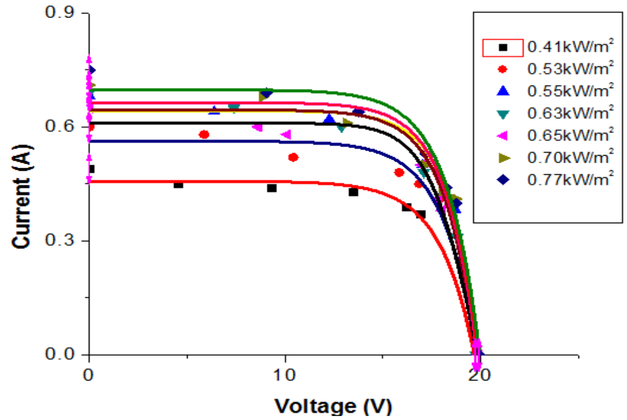

Fig. 4. I-V curves at different values of irradiance

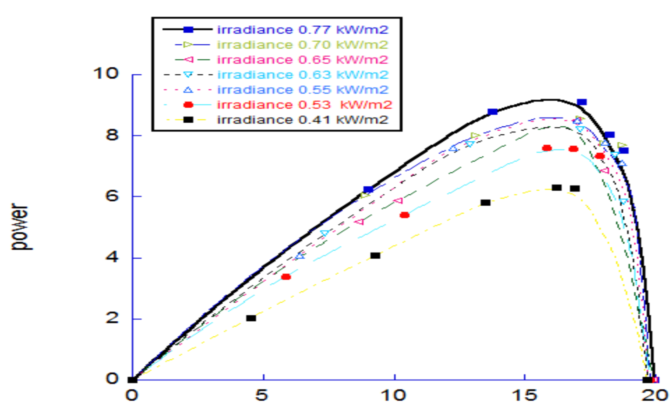

Fig. 5. P-V curve

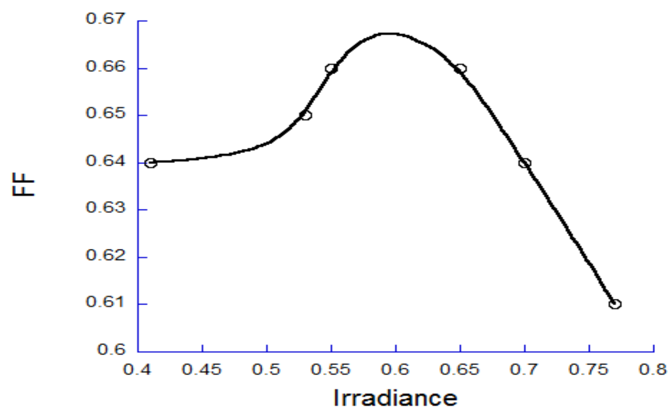

Fig. 6. Effect of increasing irradiance on FF

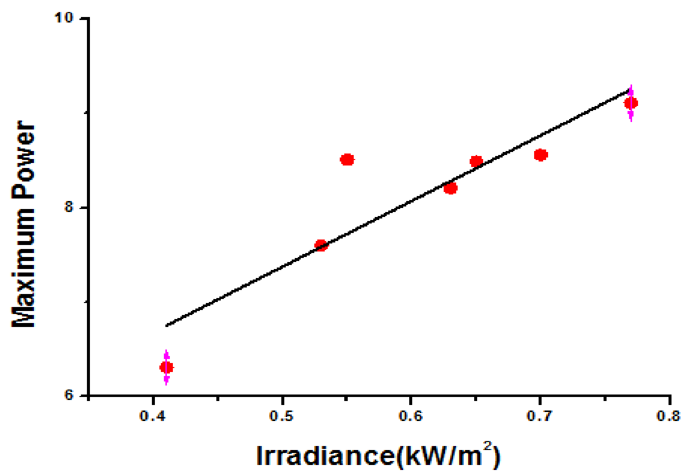

Fig. 7. Variation of maximum power with irradiance

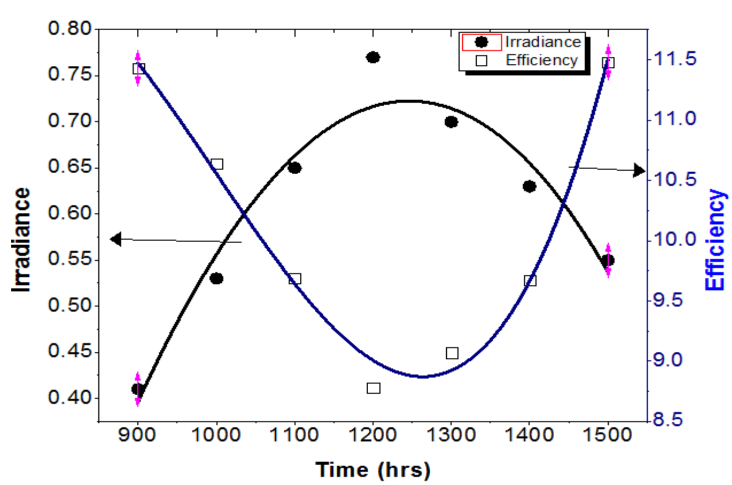

Fig. 8. Variation of efficiency and irradiance with time averaged over 6 months

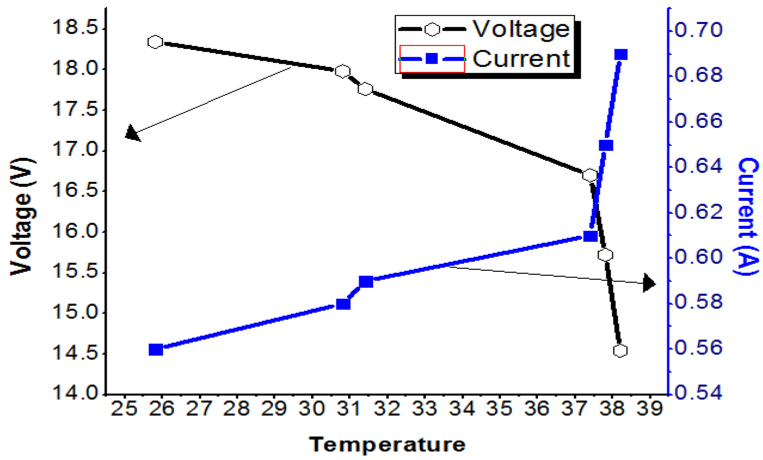

Fig. 9. Temperature effect on short circuit current and open circuit voltage

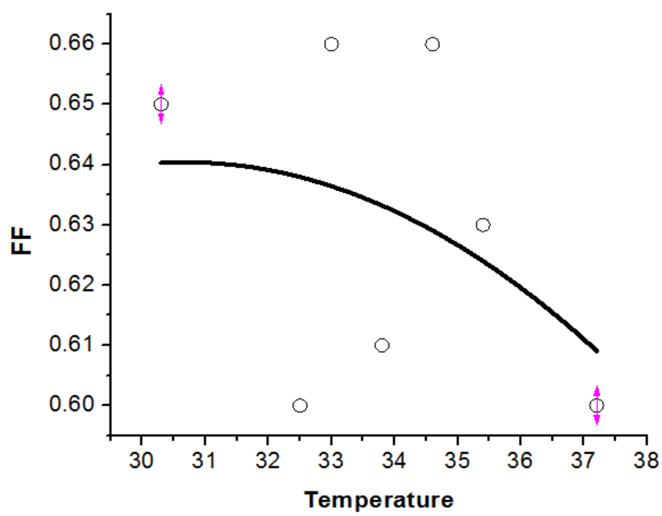

Fig. 10. Effect of increasing temperature on FF

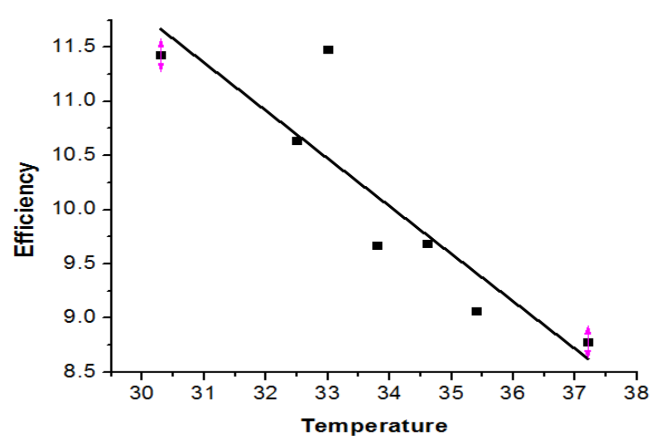

Fig. 11. Efficiency variation with temperature

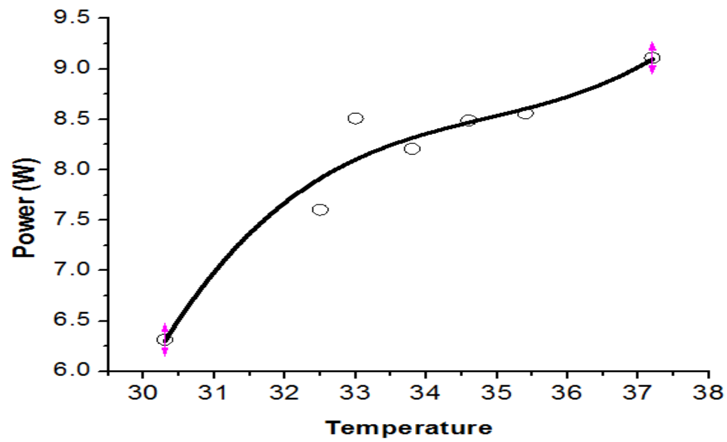

Fig. 12. Power variation with temperature

From Fig. 10, the FF of the module decreased with increasing temperature. This result agrees with the work done by Fesharaki et al. [16].

From Fig. 11 conversion efficiency of the module decreases with increase in module surface temperature. This phenomenon is attributed to the reduction of voltage and FF as temperature increase. Power output from the module reduces and this lowers the conversion efficiency. This behavior of efficiency with temperature agrees with the results of the experiment done by Fesharaki et al. [16], Amelia et al. [17], Tobnaghi et al. [15].

Fig. 12 describes the output power produced by the module during the experiment. The maximum output power was found at 37.2°C (9.11W) while the minimum power output was found at 30.3°C (6.31W). This results show that at lower temperatures, the output power generated by solar module increased with module surface temperature, due to the increased output current, However, at elevated temperatures, [15] proved that voltage decreases while current slightly increases. Thus, the increase in output current with decreasing voltage resulted in the low production of power. This is because, as the module becomes warmer there is increased thermal resistance and therefore the photo-generated electrons move slowly throughout the module. Power goes down because few electrons go through the lattice in the same amount of time [17]. This result agrees with Fesharaki et al. [16].

5. CONCLUSION

This study established the effect of solar irradiance and temperature on the performance of monocrystalline module in Kakamega. The performance of this module was evaluated in terms of its response variables (V_{oc}, I_{sc}, FF, η , V_{mp} , I_{mp}, and P_{max}) as a function of solar irradiance and module surface temperature. V_{oc}, FF, η , and P_{max} were found to decrease with increasing module surface temperature while i_{sc} increased slightly with the rising temperature. on average, FF, V_{oc}, I_{sc}, η and P_{max} increased with increase in irradiance.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Renewable Energy Mapping and Monitoring in Europe and Africa. PV Status Reports; 2013.
   (Accessed 7 January 2017)
   Available:https://iet.jrc.ec.europa.eu/remea/pv-status-report-2013
2. International Energy Agency. Key world energy statistics. Chirat, Paris, France; 2007.

3. Tiwari GN, Dubey S. Fundamental of photovoltaic modules and their applications; 2010.
4. Bhalchandra C, Sadawarte Y. The factors affecting the performance of solar cell. International conference on Quality up-grading in Engineering, Science and Technology; 2015.
5. Solmetric. Guide to Interpreting I-V Curves; 2016.
(Accessed 29 September 2016)
Available:http://resources.solmetric.com/get/Guide%20to%20Interpreting201-v%20curves.pdf
6. Tayyan AA. PV system behavior based on datasheet. Journal of Electron Devices. 2011;9:335-41.
7. Rodrigues EG, Melicio R, Mendes VF, Catalao JS. Simulation of a solar cell considering single diode equivalent circuit model. Renewable Energies and Power Quality Journal. 2011;1(9):369-73.
8. PV Education. Solar cell structure; 2016. (Accessed 27 September 2016)
Available:http://www.PVeducation.org/pvcdrom/solar-cell structure
9. NASA. NASA Science Earth data; 2018. (Accessed 8 January 2017)
Available:http://www.eosweb.larc.nasa.gov
10. Tobnaghi DM, Naderi D. The effect of solar radiation and temperature on solar cells performance. Extensive Journal of Applied Sciences. 2015;3:39-43.
11. Arjyadhara P, M AS, Chitralekha J. Analysis of solar PV cell performance with changing irradiance and tempereature. International Journal of Enginering And Computer Science. 2013;2:214-20.
12. Zia R, Saleemi F, Naseem S, Kayani Z. Study the efficiency of single crystal CdTe/ZnCdS solar cell at various temperatures and illumination levels. Energy Reports. 2015;58-61.
13. Ugwuoke PE, Okeke CE. Performance assessment of three different pv modules as a function of solar insolation in South Eastern Nigeria. International Journal of Applied Science and Technology. 2012;2.
14. Dubey S, Sarvaiya JN, Seshadri B. Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world a review. Energy Procedia. 2013; 33:311–21.
15. Tobnaghi DM, Madatov R, Naderi D. The effect of temperature on electrical parameters of solar cells. International Journal of Advance Research in Electrical, Electronics and Instrumentation Engineering. 2013;2:6404-07.
16. Fesharaki VJ, Dehghani M, Fesharaki JJ. The effect of temperature on photovoltaic cell efficiency. International Conference onEmerging Trends in Energy Conservation; 2011.
17. Amelia AR, Irwan YM, Leow WZ, Irwanto M, Safwati I, Zhafarina M. Investigation of the effect temperature on photovoltaic (PV) panel output performance. International Journal on Advanced Science Engineering Information Technology. 2016;6:682-88.

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