Performance of 20 Watts Polycrystalline Silicon Solar Module under Yola Climate, North-East Nigeria

Ndenah M. Linah, Osita C. Meludu, Joseph Aidan, and Moses E. Kundwal

***Abstract*—The performance of a 20 Watts polycrystalline silicon solar module was evaluated under Yola climatic condition. It was found that the values of short circuit current (I_{sc}), open circuit voltage (V_{oc}), maximum current (I_{max}) and maximum voltage (V_{max}) of the solar module were slightly different from those labeled under Standard Test Condition (STC). This was due to lower solar irradiance under Yola climate compared to that at STC, which resulted to changes in power and efficiency of the module. The power rating of the module at STC was 20 Watts but it was found to be 12.49 Watts between 12:00 noon and 12.15 pm when the solar irradiance was 780 Wm^{-2}. In addition, the efficiency of the module, which was 15 % at STC, was found to be 12 % at maximum irradiance of 780 Wm^{-2}. The Fill-factor (FF) of the solar module on the other hand was 0.71 at STC but it was found to be 0.77 at solar irradiance of 780 Wm^{-2}.**

***Index Terms*—Efficiency, Maximum Voltage, Maximum Power, Solar Irradiance, Solar Module.**

I. Introduction

The output of a photovoltaic device operating outdoor under real working condition is influenced by many environmental factors such as module temperature, incident solar irradiance and spectral irradiance distribution [1]. It is important to note that photovoltaic devices are usually designed on the basis of standard meteorological data. However, changes in solar irradiance and ambient temperature are not captured or considered in the design processes. The data gives only absolute broad-band global irradiance [2]. Thus, the data provided, most often, are taken at Standard Test Conditions (STC), which hardly ever occurs in practice [3]. It is therefore important to know the physical performance of a photovoltaic module under varying solar irradiances and changing ambient temperatures.

A precise knowledge of solar radiation parameters at any geographical location is of vital importance for design, development and size estimation of most solar energy devices, including solar photovoltaic (SPV) systems [4, 5]. These solar radiation parameters include solar irradiance (solar intensity), peak sun hours and ambient temperature, among others. It has been reported [6] that values of maximum current (I_{max}), maximum voltage (V_{max}), short circuit current (I_{sc}) and open circuit voltage (V_{oc}) for a particular solar module at STC are not truly reflected when characterized at different locations. This is due to changes in ambient temperature and solar irradiance [1]. On an average, the real power of photovoltaic (PV) modules falls around 5% below the corresponding nominal power mentioned by the manufacturers on their data sheet [6]. In some cases, the difference between the real and nominal power was observed to be up to 16% or more [7]. The variations in electrical parameters of solar modules due to changes in solar irradiance and ambient temperature from one location to the other can bring about changes in module efficiency, module power rating and, indeed, the overall power of the SPV system from those measured at STC.

Characterization of solar module at different locations in Nigeria as a whole and Yola in particular, may not have been taken into consideration by SPV system engineers before installations are finally done. This could lead to wrong estimate of SPVs with respect to load requirements at different locations. The objective of this study was to determine electrical parameters, maximum power, Fill factor and efficiency of a 20 Watts polycrystalline silicon solar module at different incident solar irradiances and ambient temperatures under Yola climate.

II. Theory

Figure 1 shows the I-V and P-V characteristic curves of a solar module for certain irradiance (H). The current from a PV cell depends on the amount of solar radiation falling on the cell. When the solar module is short-circuited, the current is at maximum (short-circuit current, I_{sc},) and the voltage across the solar module is zero. When the PV cell circuit is opened, with the leads not making a circuit, the voltage is at its maximum (open-circuit voltage, V_{oc}), and the current is zero. In either case, whether at open circuit or short circuit, the power (current × voltage) is zero.

The maximum power (P_{max}) passes from a maximum power point (point C on Figure 1), at which point the load resistance is optimum, R_{opt}, and the power dissipated in the resistive load is maximum and given by:

$$P_{max} = I_{max} V_{max} \quad (1)$$

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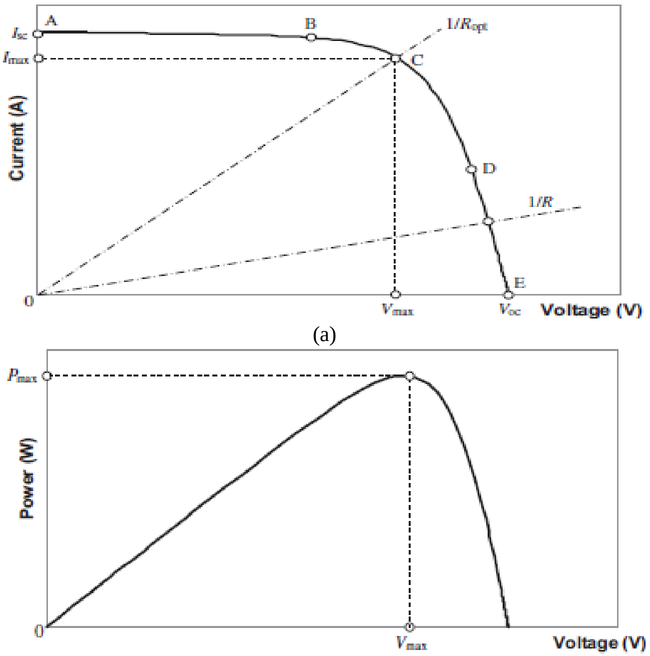

Fig. 1: (a) Current-voltage (I-V) characteristic curve (b) Power-voltage (P-V) characteristic curve [8]

Point C on the curve is also called the maximum power point, which is the operating point at which the output power is maximized. Given P_{max}, an additional parameter, called the fill factor, FF, can be calculated from:

$$FF = \left(\frac{P_{max}}{I_{sc}V_{oc}}\right) = \left(\frac{I_{max}V_{max}}{I_{sc}V_{oc}}\right) \quad (2)$$

Figure 2 shows the effects of irradiance and temperature on I-V characteristics curve. As irradiance increases, the short circuit current increases greatly but open circuit voltage increases slightly. The fill factor is a measure of the real I-V characteristic. For good cells, its value is greater than 0.7 [8].

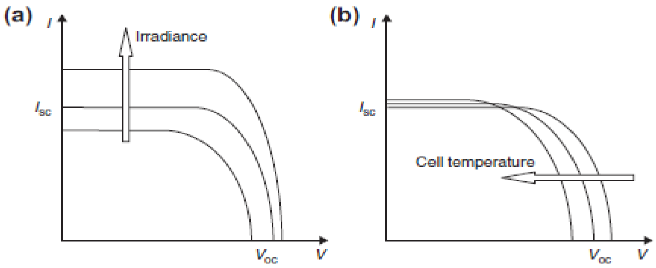

Figure 2: Effect of irradiance and temperature on I-V characteristics [8]

The fill factor decreases as the solar module temperature increases. Thus, by illuminating and loading a PV cell or module so that the voltage equals the PV cell's or module's maximum voltage (V_{max}), the output power is maximized. Other fundamental parameters that can be obtained from Figure 2 are the short-circuit current and the open-circuit voltage. The short-circuit current, I_{sc}, is the highest value of the current generated by the solar module and is obtained under short-circuit conditions when voltage (V) is equal to zero. The open-circuit voltage is obtained when the generated current (I) is also zero. Another parameter is the efficiency. It is defined as the ratio of maximum electrical power output (P_{max}) to the incident light power (P_{in}).

$$\text{Maximum efficiency } (\eta) = \frac{P_{max}}{P_{in}} = \frac{I_{max}V_{max}}{AH} \quad (3)$$

where A = solar module surface area (in m^2) and
H = Irradiance (in kWm^{-2}).

Efficiency is commonly reported for a PV cell at a temperature of 25^0C and irradiance of 1000 Wm^{-2} at solar noon. An improvement in cell or module efficiency is directly connected to a cost reduction in photovoltaic system. The V-R characteristic curve on the other hand is an exponential curve which indicates the extent to which voltage of the photovoltaic module increases with increase in resistance.

III. Experimental

The experimental set-up, which is made up of a 20 W polycrystalline silicon PV module, resistive load, voltmeter and ammeter were connected as shown in Figure 3. The module was mounted on a locally constructed Solar Module Characterization Table (SMCT). In order to maximize the collection of solar radiation on the module, a tilt angle of 240 facing the south was used.

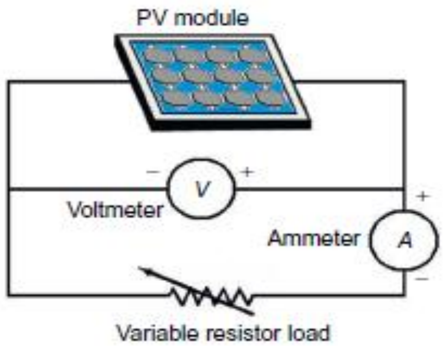

Fig. 3. Circuit diagram for characterization of the PV module [9]

The Maximum power, Efficiency, Fill factor (FF) and Electrical parameters of the 20 W polycrystalline solar module under Standard Test Condition (STC) at irradiance of 1000 Wm^{-2}, Air Mass (AM) 1.5, and cell temperature $T_{C=}$ 25 ^{0}C are given by the manufacturer on the module data sheet as: Maximum power (P_{max})= 20 W, Efficiency(η)=15 %, Fill factor (FF)= 0.71, Open circuit voltage (V_{oc})=22.05, Short circuit current (I_{sc})=1.28 A, Maximum current (I_{max}), and Maximum voltage (V_{max})=17.5 Volts.

Several values of currents and voltages against changes in load resistance were obtained at different solar irradiances of 780 Wm^{-2}, 765 Wm^{-2} and 750 Wm^{-2} respectively. A pyranometer, which was placed at the same angle of tilt as the solar module, was used to measure these changes in solar intensities.

IV. Results and Discussion

The measured current, *I* (in Amperes), the corresponding values of voltage, *V*(in Volts) and resistance, *R*(in Ohms) were plotted at 780 Wm^{-2}, 765 $Wm^{-2}$and 750 Wm^{-2} respectively to give the *I-V*, *P-V* and *V-R* characteristics for the module. The curves for these characteristics have shown exponential relationship [9]. For a given irradiance (or solar

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intensity), the operating voltage and current varied with load resistance, *R*. The maximum operating voltage (V_{oc}) corresponded to open circuit conditions when the voltage was zero at short circuit condition. Thus, I_{sc} and V_{oc} were the two limiting parameters that were used to characterize the photovoltaic device at the location. For any irradiance measured by the pyranometer, different values of current and voltage were obtained. It is clear from these graphs that power of the solar module increases with increase in solar irradiance and vice-versa. At certain instant in the cause of the experiment, the solar intensity fluctuated between 780 Wm^{-2} and 760 Wm^{-2} resulting in kinks or constrictions on the *I-V* and *P-V* characteristic curves. Similar results were observed [10].

Figure 4 shows the *I-V* characteristic curves at different solar irradiances (780 Wm^{-2}, 765 Wm^{-1} and 750 Wm^{-1}). The curves were used to determine the short circuit current (I_{sc}), the open circuit voltage (V_{oc}), the maximum current (I_{max}) and maximum voltage (V_{max}) of the module at each of the solar irradiance in order to determine the module power rating, maximum efficiency and Fill factor. Figure 5 presents *P-V* characteristic curves at different solar irradiances. Figure 6 represents plots of measured average voltage (V_{av}) and load resistance (*R*). The slope of any linear section on the curve gives the value of current (in Amperes). The voltage tends to increase exponentially as the resistance increases. The shape of the curve shows that the solar module is composed of good cells.

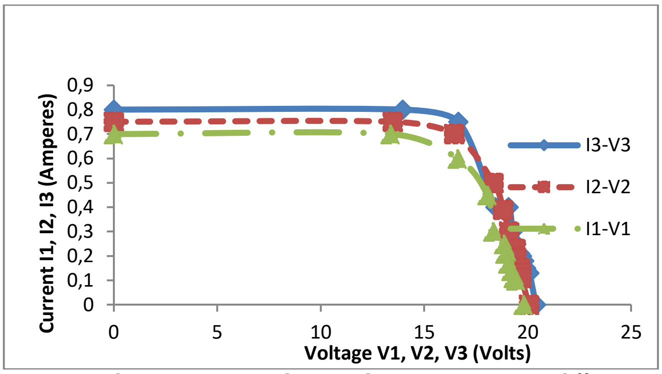

Figure 4 The I1-V1, I2-V2 and I3-V3 Characteristic curves at different solar irradiances of 750, 765, and 780 Wm-2

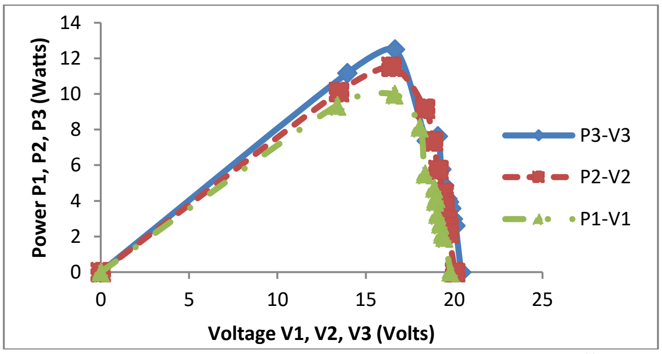

Figure 5 The P1-V1, P2-V2 and P3-V3 Characteristics curve at different solar irradiances of 750, 765, and 780 Wm-2

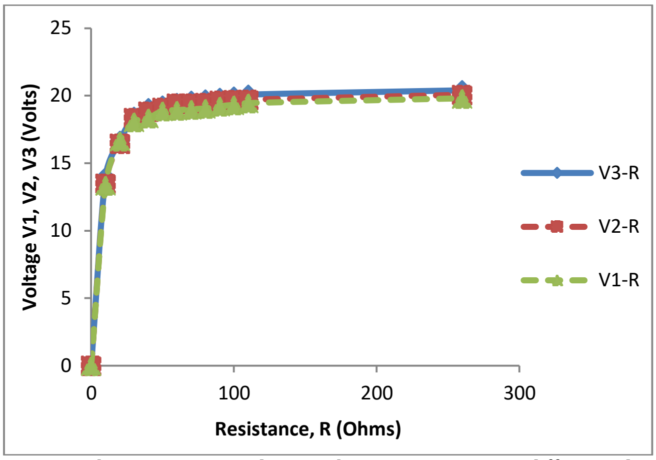

Figure 6 The V1-R, V2-R and V3-R Characteristic curves at different solar irradiances of 750, 765, and 780 Wm-2

The maximum power, Fill Factor (*FF*) and maximum efficiency of the module at varying solar intensities, Air Mass (AM) 1.5 at 35^{0}C ambient temperature were obtained using Equations (1), (2) and (3) respectively. It was found that for the for the I_1-V_1 characteristic curve, I_{1sc}=0.70 A; V_{1oc}= 19.80 V; I_{1max}=0.6 A and V_{1max}=16.65 V. Using these parameters, the power and efficiency of the module at solar irradiance of 750 Wm^{-2} were 9.98 W and 9.81 % respectively while the Fill-factor was found to be 0.72. For the I_2-V_2 characteristic curve, I_{2sc}=0.75 A; V_{2oc}=20.06 V; I_{2max}=0.70 A; V_{2max}=16.45 V at solar irradiance of 765 Wm^{-2}. From these results, the maximum power, the Fill-factor and the efficiency of the solar module were, 11.52 W. 0.77 and 11.2 % respectively. I_3-V_3 characteristic curve; I_{3sc}=0.80 A, V_{3oc}=20.40 V, I_{3max}=0.75 A, and V_{3max}=16.65 V. Here, the maximum power at solar irradiance of 780 Wm^{-2} was found to be 12.49 W while the Fill-factor and efficiency of the module were 0.77 and 12 % respectively. The maximum power of the 20 Watts polycrystalline silicon solar module (found to be 12.49 W) at 12.00 AM to 12.15 PM is less than the rated power (20 W) prescribed by the manufacturer on the module. This represents a marked decrease in rated power of the solar module by 37.55 %. The maximum efficiency of the poly-crystalline silicon solar module was found to be 12 % at the location. This efficiency was 92.31% of the minimum value of efficiency (13 %) for all functional polycrystalline silicon solar modules [7, 11].

The reason for the low efficiency in this regard could be attributed to the partially cloudy atmosphere under which the experiment was conducted resulting to fluctuation of solar intensities. The other reason could be a validation of the report presented in literatures that the performance values (I_{max}, V_{max}, I_{sc}, and V_{oc}) of solar modules vary from one location to the other, depending on whether the solar module was under a clear sky or under a hazy and cloudy atmosphere. In other words, the performance values depend on the intensity of the sun at the location of study; which may be low or high. The magnitudes of the fill factor obtained (i.e, 0.77 at solar irradiances of 780 Wm^{-2} and 765 Wm^{-2} and also 0.72 at 750 Wm^{-2}) are in agreement with standard values for solar cells and modules since he fill factor of a good solar cell or module must be equal or greater than 0.7[8].

The results obtained clearly showed that as the solar

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irradiance increases, the short circuit current (I_{sc}) increases greatly while the open circuit voltage (V_{oc}) increases slightly, detecting a new curve. This led to changes in maximum power, being highest at maximum solar irradiance of 780 W/m^2 in this study. The efficiency of the module decreases with decrease in solar irradiance. At solar irradiance of 750 Wm^{-2}, 765 $Wm^{-2}$and 780 Wm^{-2} the efficiency of the solar module increases slightly and tends to remain nearly constant at higher irradiances provided the average ambient temperature remains nearly constant.

V. Conclusion

The current-voltage (*I-V*) and power-voltage (*P-V*) characteristic curves for this study showed that the magnitude of short circuit current, open circuit voltage, and maximum current and maximum voltage obtained at a maximum solar irradiance of 780 Wm^{-2}were lower than those labeled on the module data sheet for Standard Test Condition (STC). As a result, the power and efficiency of the module in Yola showed marked decrease in magnitude from those obtainable at STC. The decrease in solar irradiances to 765 Wm^{-2} and 750 Wm^{-2} with time of day on the other hand resulted in further reduction in solar module power and efficiency. The magnitude of the Fill-factor (*FF*) of the module was however found to be slightly above 0.7 at all irradiances measured in the study. This shows that the solar module is made up of good cells and attests to the fact that the graphs (Figures 4, 5 and 6) depict real characteristics of the solar module. The electrical parameters such as V_{oc}, I_{sc}, I_{max} and V_{max} of the solar module obtained in the study differ from the values at STC. Hence, in order to avoid wrong Solar Photovoltaic (SPV) system estimates based on load requirements at any given location, characterization of solar module or any photovoltaic device is necessary.

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