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PERFORMANCE EVALUATION OF MONO-CRYSTALLINE PHOTOVOLTAIC PANELS IN FUNAAB, ALABATA, OGUN STATE, NIGERIA WEATHER CONDITION

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ABSTRACT
The current-voltage characteristic is the basic descriptor of photovoltaic device and is used to test the performance of PV panel. The manufacture specifications on solar panels are obtained under standard condition (solar irradiance of 1000 W/m^2, AM 1.5 and operating temperature of 25^{o}C) which is not the real operating condition the solar panels are exposed to on the installation site. With this, the information obtained from the manufacture specifications would not be sufficient to give accurate prediction of the performance of the solar panel. This study conducted performance evaluation on mono-crystalline photovoltaic panels in Federal University of Agriculture, Abeokuta, FUNAAB, Alabata, Ogun State, Nigeria weather condition. The research work was carried out on the field with six 80 W (480 W) solar panels of sunshine product made in Germany. The performance of the solar panel was evaluated from the short circuit current (I_{sc}), open circuit voltage (V_{oc}), maximum current (I_{max}), maximum voltage (I_{max}), maximum output power, conversion efficiency, normalized output power efficiency and fill factor of each solar panel. The maximum output power of each panel was obtained from the I-V and P-V curves. The conversion efficiency of the six 80 W (480 W) solar panels ranged from 9.44 to 10.56% while the normalized output power efficiency ranged from 69.7 to 70.1%. The fill factors and the maximum output power of the six panels respectively, are 0.57, 0.55, 0.57, 0.58, 0.60, 0.62 and 55.8, 54.1, 53.2, 59.4, 53.1, 59.4 W. A total of 335 W (69.8%) for the six panels was obtained. The results reveal that the actual performance of the solar panels does not correspond with the technical data provided by the manufacturer.

KEYWORDS: Photovoltaic panel, performance evaluation, Conversion efficiency, Fill factor.

INTRODUCTION
Modern energy enriches life in which no nation can survive without it. More so, a nation is considered rich not by amount of minerals, man power or industrial resources it possesses, but its level of technology it has acquired and scientific progress it is making, which depends ultimately on the supply and consumption of energy. There are several people on earth who use energy on every single day to make their live more productive, safer and healthier. The biggest driver of energy demand is the human desire to improve its standard of living. However, energy growth is directly linked to well-being, standard of living and prosperity across the globe. Thus, it is of great importance in heating, manufacturing, commercial activities, construction, doing work, transportation, communication, industrial production of goods, running machines in industry and health and social services. Meanwhile, future economic growth crucially depends on the

long-term availability of energy from sources that are affordable, accessible, and environmentally friendly (George, 2006; Ramadhas, 2016). Security, climate change, and public health are closely interrelated with energy (Ramchandra, 2011). To enhance the developmental trend in the country, there is every need to support the existing unreliable energy sector with a sustainable source of power supply through solar energy. One of Nigeria's key interests as a developing country is her energy security. All of us are affected in one way or the other by the currently limited power sources. If not on the high cost of fuel or the ever rising monthly electricity bill, it is on the high cost of commodities or worse still, on the heavy losses incurred when power is cut off for some time during power rationing. The shortage of power not only affects our productivity hence economy but also our social life. The recent rise in fuel prices coupled by negative effects of climate changes has forced energy stakeholders and policy makers worldwide to go back to the drawing board. The high fuel prices, partly caused by global energy demand and political reasons, have pushed the unit cost of energy to unprecedented high. Solar energy therefore offers an attractive alternative energy source for Nigeria. Although solar energy is available in plentiful and free of charge, it's very discouraging to note that the initial capital cost of installing a solar powered system is very inhibiting. Such a capital cost can only make sense if the running cost of the solar energy system is so low as to lead to a high savings to repay the high initial capital cost in a reasonable period of time.

From the solar radiation falling onto a PV panel only up to 20 % of the incident solar energy is converted to electricity (Zhang *et al.,* 2014). The remaining 80-90% is reflected or converted to heat (Ozgoren et al., (2013), Amelia *et al.*, 2016). As consequences, the accumulated heat energy increases the PV panel operating temperature. Under STC, the conversion efficiency of the PV panel is decreased by about 0.4 – 0.5 % for each degree rise in temperature (Natarajan et al., 2011). Overheating reduces the efficiency of the panels dramatically (Akarzadeh and Wadowski, 1996). In fact, it has been shown that the maximum efficiency of a solar panel, as a function of temperature, decreases at a linear rate set by the temperature coefficient (Li et al., 2014). The ambient temperature plays an important role in the photovoltaic conversion process (Siddiqui and Bajpai, 2012). Solar cells are exposed to temperature changing from 5 to 50 ºC (Tobnaghi et al., 2013). The maximum power output from solar cells decreases as the cell temperature increases (Akarzadeh and Wadowski, 1996). The solar modules's performance varies with actual location and prevailing environmental conditions to which they are subjected (Ettah et al., 2009, Elhadj Sidi et al., 2015). There is a lack of data on PV system operating under West African Weather Conditions. The parameters obtained from the performance evaluation of PV system are crucial for designing any small or Large PV system (Dajuma *et al.,* 2016). Nearly 80 % of cells on the market are crystalline silicon based cells (Tobnaghi et al., 2013).

Solar panels are slow in degradation if they are sealed properly, which make them durable particularly as they have no movable parts and requires little maintenance (Abdelkader et al., 2010). At present, almost 95% of available solar cells are made of silicon (Abdelkader et al., 2010). The silicon is used in PV cells for monocrystalline and multicrystalline wafer production and the production of thin film silicon modules. More than 90 % of produced solar cell every year is based on crystalline silicon wafers (Abdelkader et al., 2010). In general, performance of monocrystalline-silicon wafer is better in performance than the multi-crystalline-silicon wafer but is more expensive.

Solar energy of solar radiation can directly be harvested, utilised or photovoltaic converted into electricity using semiconductor devices called solar cells or panels. Due to dynamic weather condition from place to place the performance of solar panel varies from place to place. Many researchers have stated that photovoltaic panel electrical performance greatly depends on environmental conditions such as the temperature, solar irradiance, angle-of-incidence, solar spectral (air mass), and the types of PV cells (Rosyid, 2016). More so, the technical data provided by the manufacturer for these solar panels cannot be relied on to predict accurately the performance of solar panel. The electrical characteristics of each solar panel are obtained by the manufacturer under standard test conditions ((i.e., irradiance 1000W/m^2, module temperature 25ºC, and AM 1.5) (Ahmed and Khan, 2014) which do not represent the real operating condition the solar panels are subjected at installation site (Fuentes, 2007, Darwish et al., 2013,). Electrical characteristics of the solar panel include maximum rated power, open circuit voltage, short circuit current, maximum power voltage, maximum power current, and temperature coefficients. They serve as the electrical characteristics parameters used to evaluate the performance of solar panels. If care is not taking during purchase, the actual value of these electrical characteristics mentioned above may be far lower than the valued stated by the manufacturer. So the solar PV panel must be test before purchase. If it differs, it may be due to location of test, there is problem with the solar panel or the solar panel is bad. To have adequate knowledge and give accurate and sufficient information on the performance of the solar panel there is need to carry out performance test on the panel at the installation site. More so, performance test must be carried out on the solar panels to ensure that the provided solar PV panel would be able to produce the power required by the load without failing and to have better understanding on how it work. Output electrical characteristics of solar PV cell panels can be seen from the performance curve, called I-V curve. The current-voltage characteristic is the basic descriptor of photovoltaic device performance. The I-V curve can also be used to test the performance of PV/ solar modules. This research work is aimed at conducting performance evaluation on mono-crystalline photovoltaic panels in FUNAAB, Ogun State, Nigeria dynamic weather condition.

MATERIALS AND METHODS

MATERIALS

The materials used for this study were six 80W (480W) mono-crystalline photovoltaic panels of sunshine product made in Germany, power resistors, multimeter and 4mm Core Wires (red and black). All the technical data of the electrical characteristics of the panels obtained by the manufacture were rated under industrial Standard Test Conditions (STC) of solar irradiance of 1,000 W/m² with zero angle of incidence, solar spectrum of 1.5 air mass and 25°C cell temperature which was stated on the label of the panels.

METHODS

The study method was field investigation. The investigation on the mono-crystalline photovoltaic panels was carried out in Federal University of Agriculture, Abeokuta, FUNAAB (70^0N, 30^0E), Alabata, Ogun State. The site used for the field investigation is located at the back of the Agricultural and Bio-Resources Engineering laboratory of Agricultural Engineering department at Federal University of Agriculture, Abeokuta.

DETERMINATION OF THE PERFORMANCE OF THE MONO-CRYSTALLINE SOLAR PANELS:

The six (480 W) solar panels used for the study each has a maximum power rating, P_{max} of 80W, solar irradiance of 1000 W/m^2, cell temperature of 25ºC, current at maximum power point, I_{max} as 4.57 A, voltage at maximum power point, V_{max} as 17.5 V, short circuit current, I_{sc} as 5.12 A, open circuit voltage, V_{oc} as 22.05 V and output tolerance as $\pm 5\%$ as stated by the manufacturer. Electrical parameters of the panels such as current at maximum power point, voltage at maximum power point, short circuit current, open circuit voltage, maximum power output, conversion efficiency and fill factor were evaluated when the sun was at its peak between 12 noon and 15: 00.

MEASUREMENT OF THE OPEN CIRCUIT VOLTAGE, V_{OC} OF EACH PANEL

The open circuit voltages, V_{oc} of each panel were measured and recorded using a digital multimeter. The digital multimeter was configured to read DC voltage. Meanwhile, the positive and negative terminals of the multimeter were connected to each of the solar panels positive and negative terminals, respectively. Nevertheless, the open circuit voltages of each of the six solar panels were measured and recorded. Each value was compared to the manufacturer’s specification.

MEASUREMENT OF THE SHORT CIRCUIT CURRENTS, I_{sc} OF EACH PANEL

The short circuit currents, I_{sc} of each panel were measured and recorded using multimeter. The digital multimeter was configured to read DC voltage at 10 Amps. The positive and negative terminals of the multimeter were connected to each of the solar panels positive and negative terminals respectively. The short circuit current of each of the six solar panels were measured and recorded. Each value was compared to the panel specification.

MEASUREMENT OF THE V_{mp}, I_{mp} AND P_m OF EACH PANEL

To measure the voltage at maximum power point, V_{mp}, current at maximum power point, I_{mp}, and maximum power output, P_m of each of the six Panels a set of power resistors were used. The power resistors used were able to cope with the high power generated by the solar panels without been destroyed. The set of power resistors used for the measurement were; 1 Ohm, 3 Ohms, 7 Ohms, 15 Ohms and 50 Ohms. Each power resistor was connected to the panel and the voltage across the different power resistors were measured and recorded with the multimeter. The short circuit current and open circuit voltage were measured and recorded using the multimeter. The current through each resistor was calculated by dividing the measured voltage by the resistance. The power was calculated by multiplying the voltage times the current. For the short circuit current the corresponding voltage value was zero while for the open circuit voltage the corresponding current value was zero.

Output electrical characteristics of each solar cell panels were determined from the performance curve, called I-V curve. The I-V curve and P-V curve show the relationship between current and voltage and the power and voltage of the solar module, respectively. From the graphs the V_{mp}, I_{mp} and P_m for each of the six panels were also evaluated. According to the formula given by Bashir *et al.* (2014) the performance evaluation on the six 80W (480W) solar panels were carried out using:

$$\text{Maximum Power, Watts} = P_m = I_m \times V_m \tag{1}$$

Where,

I_m= Maximum output current, Amps and V_m= Maximum output voltage, Volts

$$\text{Normalized Output Power Efficiency, \%} = \frac{P_m}{P_{STC}} \tag{2}$$

Where,

P_m = Maximum output power, W

P_{STC} = Maximum output power at standard test condition, W

$$\text{Fill factor, FF} = \frac{I_{mp} \times V_{mp}}{I_{sc} \times V_{oc}} = \frac{P_m}{I_{sc} \times V_{oc}} \tag{3}$$

Where,

I_{mp} = Output current at maximum power, Amps and

V_{mp} = Output voltage at maximum power , Volts

Conversion (Module) Efficiency

$$Л = \text{Efficiency of the solar panel} = \frac{P_m}{E \times A} \tag{4}$$

Where,

Л = Efficiency of the solar panel, %; P_m= maximum power rating, W, E = Solar irradiance, W/m^2 and A=surface area, m^2.

Each solar panel contains 36 cells. The dimension of one of cell of the solar panel was measured as 12.5 cm by 12.5 cm. A = The surface area of each panel = number of cells × area of the one of the cell = 36 × 0.125×0.125 = 0.5625 m^2. Solar power conversion efficiency is the ratio of the electrical power output and the solar irradiance input over the device area, expressed as a percentage.

RESULTS AND DISCUSSIONS

Table 1 presents the field output current, output voltage and output power obtained from the panels 1,2,3,4,5 and 6 from 15/12/2015 to 17/12/2015 between 12 noon to 3 pm and the manufacturer's specification of the electrical parameters for each of the panels. From the table, the open circuit voltage, V_{oc} of the six panels measured were 22.0, 21.7, 21.5, 21.9, 21.6, 22.0 V indicating 99.9, 96.4, 95.6, 99.3, 98.0 % of the V_{oc} stated by the manufacturer's specification for the six panels respectively. For the short circuit current, I_{sc}, the six panels have value of 4.41, 4.53, 4.35, 4.64, 4.13, 4.39 Amp indicating 86.1, 86.5, 85.0, 90.6, 80.7, 85.7 % of the I_{sc} stated by the manufacturer's specification for the six panels respectively. It shows that the open circuit voltage, V_{oc} and short circuit current, I_{sc}, obtained on the field did not have the same values with the technical values given by the manufacturer. It revealed from the results that the condition (STC) in which the manufacturer obtained the technical values do not represent the real condition the solar panel were exposed to on the field. Many other researchers have also reported this same observation (King 1996;

Nishioka *et al.,* 2003; Buday, 2011; Ibrahim, 2011; Mustapha *et al.,* 2013). The performance evaluation on the solar panels was carried out to have adequate knowledge, obtained sufficient information and have better understanding on how they work. With these results, it was ascertained that the technical data provided by the manufacturer for solar panels cannot be relied on to predict accurately the performance of the solar panel.

Table 1. The field output current, output voltage and output power obtained from the panels 1, 2,3,4,5 and 6 and the manufacturer's specification of the electrical parameters for each of the panels.

S/N	Solar panel 1				Solar panel 2			
	Resistance (Ohms)	Voltage (Volts)	Current (Amps)	Power (Watts)	Resistance (Ohms)	Voltage (Volts)	Current (Amps)	Power (Watts)
1	short circuit	0	4.41	0	short circuit	0	4.53	0
2	1	4.4	4.39	19.32	1	4.6	4.53	20.83
3	3	12.5	4.17	52.13	3	11.9	4.09	48.67
4	7	18.8	2.69	50.57	7	18.7	2.66	49.74
5	15	20.9	1.39	29.05	15	20.7	1.38	28.57
6	50	21.6	0.43	9.29	50	21.2	0.42	8.90
7	open circuit	22.0	0	0	open circuit	21.7	0	0

S/N	Solar panel 3				Solar panel 4			
	Resistance (Ohms)	Voltage (Volts)	Current (Amps)	Power (Watts)	Resistance (Ohms)	Voltage (Volts)	Current (Amps)	Power (Watts)
1	short circuit	0	4.35	0	short circuit	0	4.64	0
2	1	4.3	4.31	18.53	1	4.6	4.58	21.07
3	3	12.3	4.10	50.43	3	12.6	4.20	52.92
4	7	18.6	2.65	49.29	7	19.8	2.83	56.03
5	15	20.2	1.34	27.07	15	21.0	1.40	29.4
6	50	21.1	0.43	9.33	50	21.6	0.43	9.29
7	open circuit	21.5	0	0	open circuit	21.9	0	0

S/N	Solar panel 5				Solar panel 6			
	Resistance (Ohms)	Voltage (Volts)	Current (Amps)	Power (Watts)	Resistance (Ohms)	Voltage (Volts)	Current (Amps)	Power (Watts)
1	short circuit	0	4.13	0	short circuit	0	4.39	0
2	1	4.2	4.22	17.72	1	4.3	4.26	18.32
3	3	11.9	3.89	46.29	3	12.5	4.16	52
4	7	18.6	2.62	48.73	7	19.5	2.79	54.401
5	15	20.2	1.3	26.26	15	20.9	1.39	29.05
6	50	21	0.42	8.82	50	21.6	0.43	9.29
7	open circuit	21.6	0	0	open circuit	22	0	0

S/N	Electrical Parameters for each of the Panels 1,2,3,4,5 and 6.	Manufacturer's Specification
1	Maximum Current at Maximum Power Point, I_m	4.57 A
2	Maximum Voltage at Maximum Power Point, V_m	17.5 V
3	Maximum Power, P_m	80 W
4	Short Circuit Current, I_{sc}	5.12 A
5	Open Circuit Voltage, V_{oc}	22.05 V

Figures 1-12 show the I-V and P-V curves for the six mono-crystalline PV panels from the field investigation carried out on the panels. The output current at max power point, output voltage at max power point, maximum output power were obtained from the I-V and P-V curves for the six mono-crystalline PV panels. The maximum output current, I_{mp} of the six solar panels obtained from the I-V and P-V curves were 3.6, 3.4, 3.5, 3.4, 3.3 and 3.6 Amps representing 78.8, 74.4, 76.6, 74.4, 72.2, 78.8 % of the value stated by the manufacturer for each of the solar panels respectively. However, the maximum output voltage, V_{oc} of the six panels obtained from the I-V and P-V curves were 15.5, 15.9, 15.2, 17.5, 16.1 and 16.5 Volts

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representing 88.6, 90.9, 86.9, 100.0, 92.0, 94.3 % of the value stated by the manufacturer for each of the solar panels respectively. It indicated that the maximum output current, I_{mp} and maximum output voltage, V_{oc} obtained on the field did not have the same value with the technical value given by the manufacturer except panel 4 which had open circuit voltage as that presented by the manufacturer. The results revealed that the condition (STC) in which the manufacturer obtained the technical values do not represent the real condition the solar panel were subjected to on the field. More so, the result shows that the maximum output power obtained from each of the solar panels tested was not the same as the output power gotten by the manufacturer at STC. Furthermore, the values of the maximum output power obtained from the six panels ranging from 53.1 to 59.4 W with normalized output power efficiency ranging 66.4 to 74.3%. The total output power gotten from the six (480 W) solar panels was 335 W which represent 69.8% of the total output power obtained by the manufacturer. Although this maximum power obtained from the solar panels was able to provide a continuous power supply throughout the period of incubation without any record of failure. Ugwuoke and Okeke (2012) achieved 37.52 W maximum power output from a solar mono-crystalline PV module at 1000 W/m^2 which representing 68.22 % of the manufacturer's power specifications for solar panel used. Hence, there is need to evaluate solar panels to be installed in order to have proper estimation of power they can provide rather than relying on the manufacturer's specification.

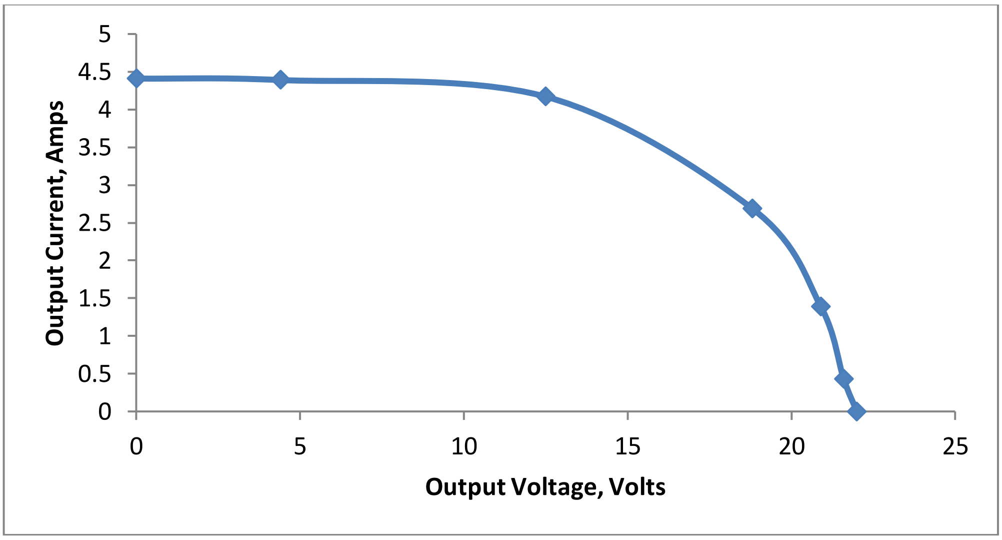

Figure 1. I-V curves for the mono-crystalline PV panels 1.

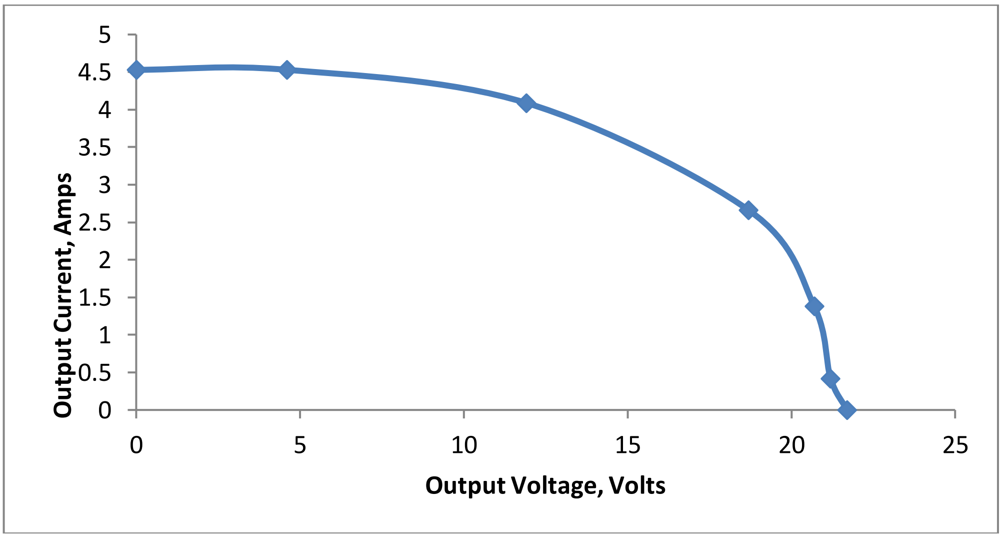

Figure 2. I-V curves for the mono-crystalline PV panel 2

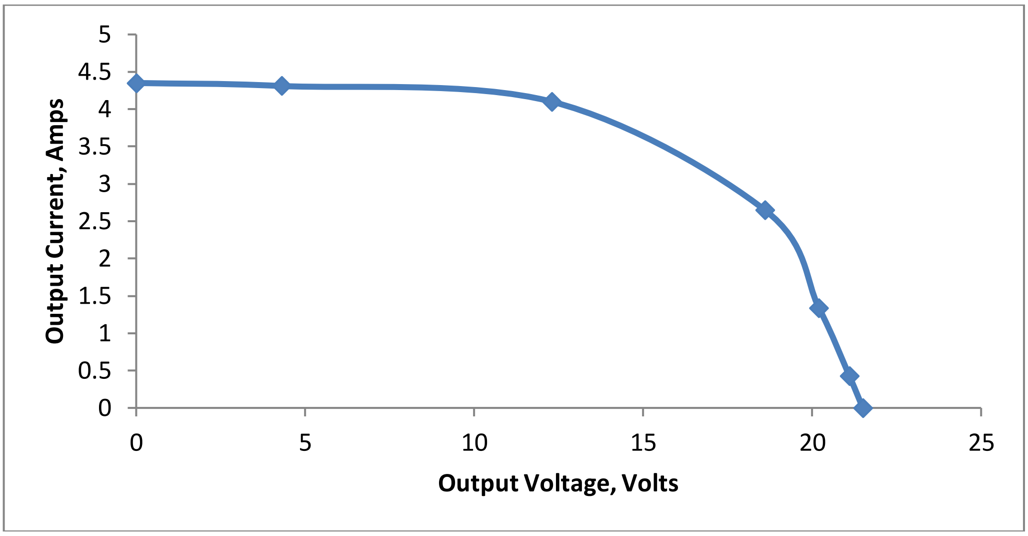

Figure 3. I-V curves for the mono-crystalline PV panel 3

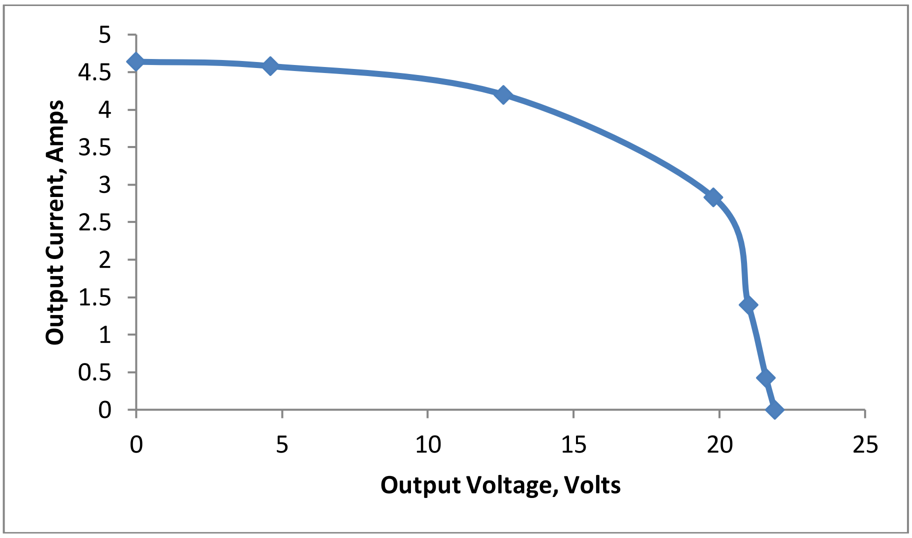

Figure 4. I-V curves for the mono-crystalline PV panel 4

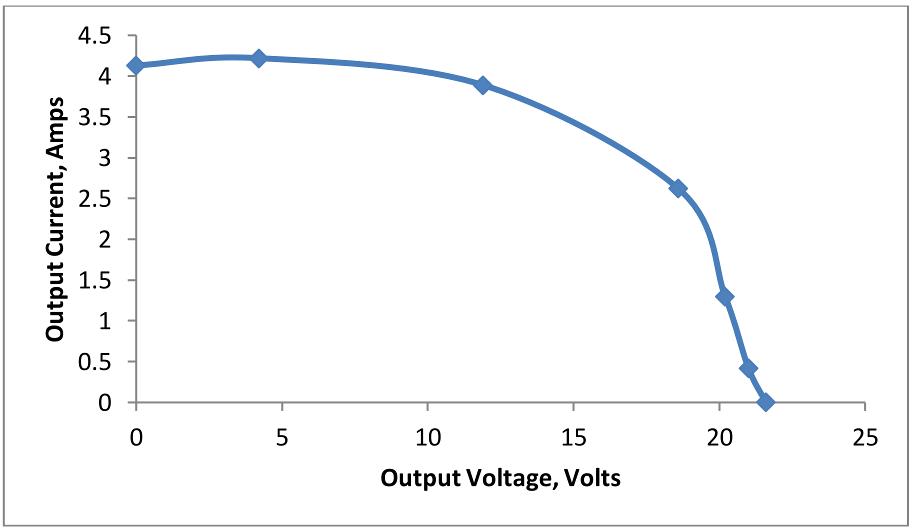

Figure 5. I-V curves for the mono-crystalline PV panel 5

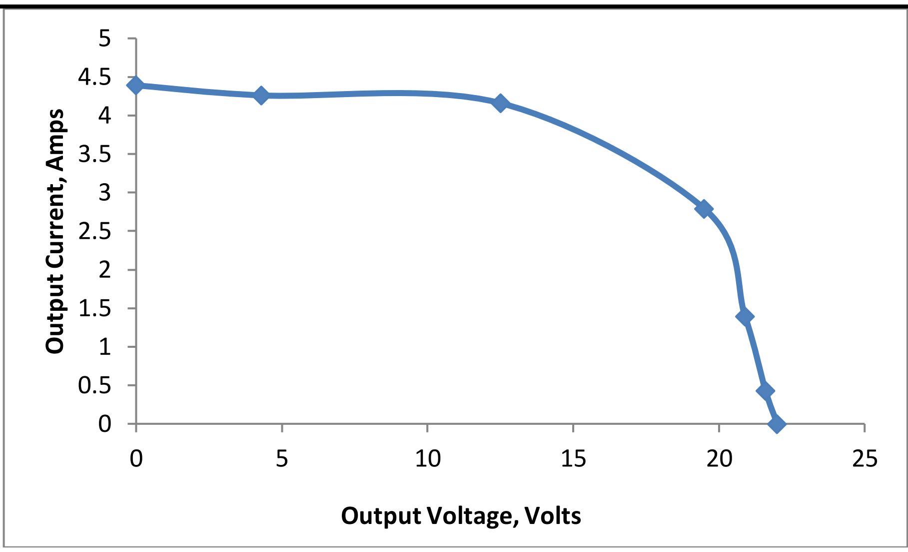

Figure 6. I-V curves for the mono-crystalline PV panel 6

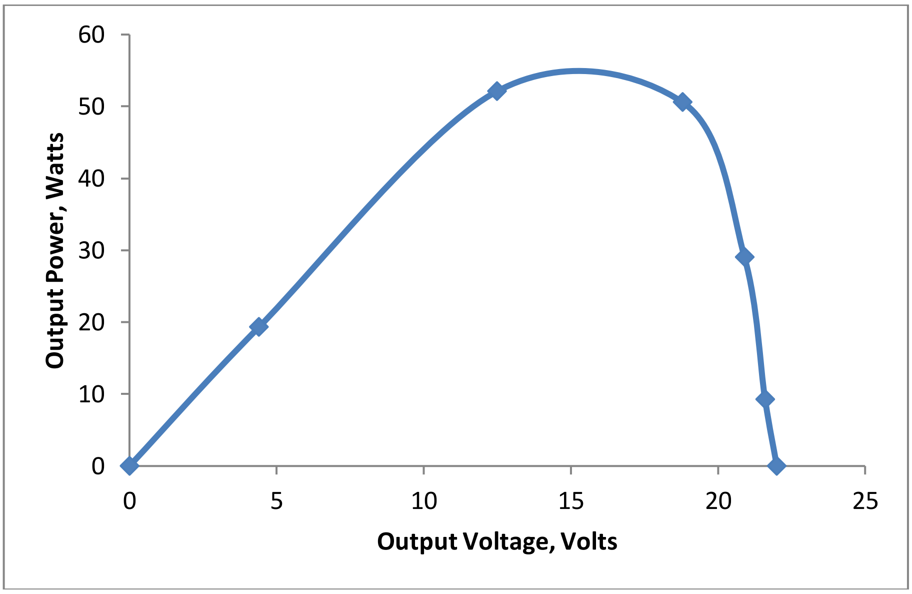

Figure 7. P-V curves for the mono-crystalline panel 1

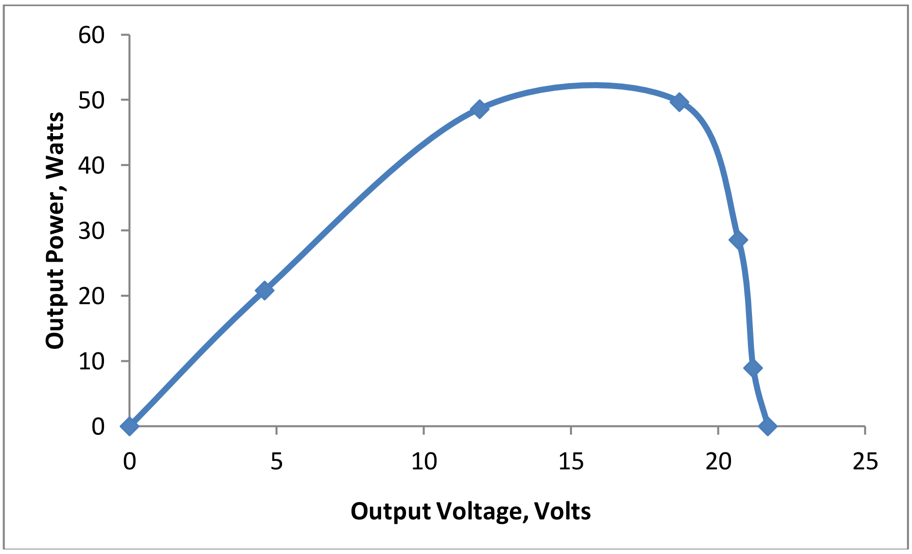

Figure 8. P-V curves for the mono-crystalline panel 2

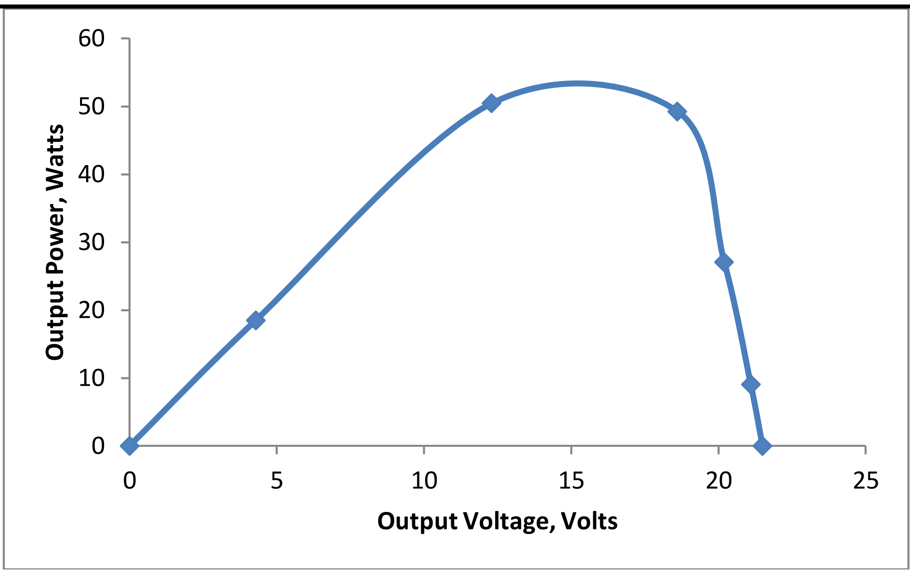

Figure 9. P-V curves for the mono-crystalline PV panel 3

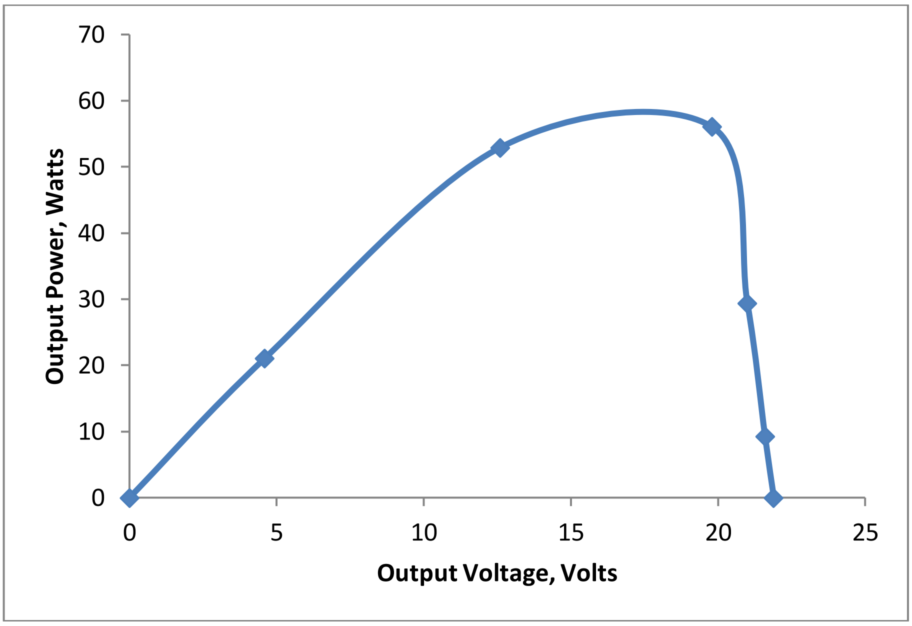

Figure 10. P- V curves for the mono-crystalline PV panel 4

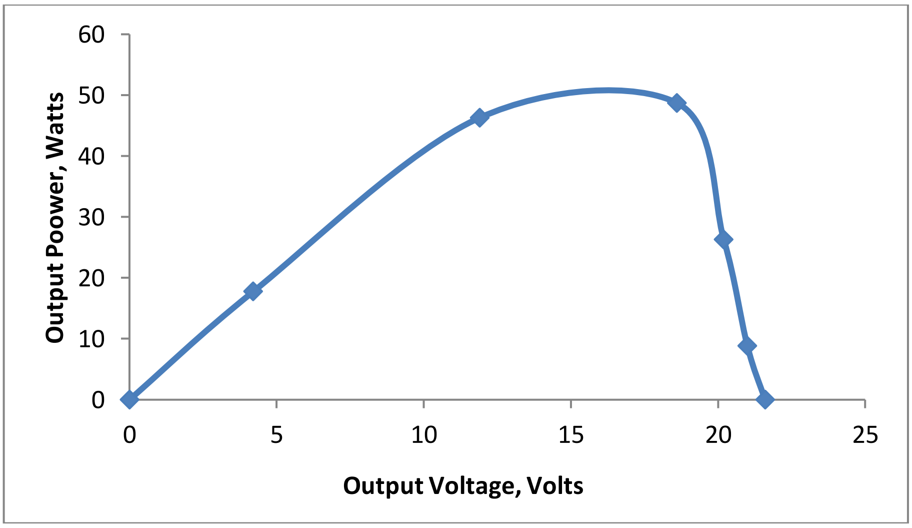

Figure 11. P-V curves for the mono-crystalline PV panel 5

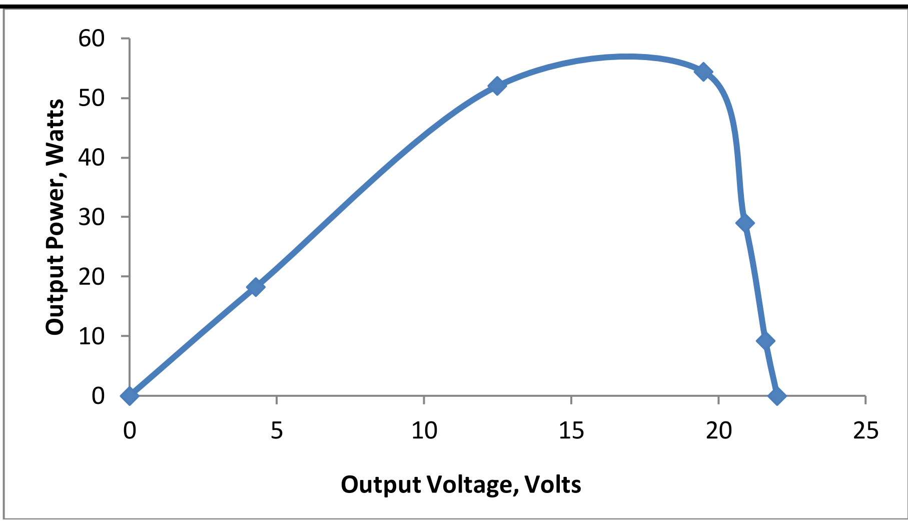

Figure 12. P-V curves for the mono-crystalline PV panel 6

Table 2 presents the fill factor of the solar panels. Fill factor (FF) is the indicator of the quality of a solar cell. The results shows that each of the solar panels has fill factor less than the calculated manufacturer's fill factor. The values of the fill factor of the six solar panels are 0.57, 0.55, 0.57, 0.58, 0.6 and 0.62 while the calculated manufacturer's fill factor was 0.71. Typical commercial crystalline silicon solar cells have a fill factor between 0.7 and 0.85 (Danielsson, 2009; Saadah *et al.,* 2016). The calculated manufacturer's fill factor fell between this range. El-Shaer *et al.* (2008) found the fill factor of mono-crystalline and poly-crystalline modules as 68% and 44%, respectively.

Table 2. The fill factor of the six Mono-crystalline PV panels.

Solar Panel S/N	Open Circuit Voltage (Volts)	Short Circuit Current (Amps)	Current at Max Power Point, Imp (Amps)	Voltage at Max Power Point, Imp (Volts)	Fill Factor	Calculated Manfacturer's Fill Factor
1	22.0	4.41	3.6	15.5	0.57	0.71
2	21.7	4.53	3.4	15.9	0.55	0.71
3	21.5	4.35	3.5	15.2	0.57	0.71
4	21.9	4.64	3.4	17.5	0.58	0.71
5	21.6	4.13	3.3	16.1	0.60	0.71
6	22.0	4.39	3.6	16.5	0.62	0.71

Table 3 shows the conversion (module) efficiencies of the six 80 W (480 W) solar panels at 1000 W/m^2 irradiance. The conversion efficiency was used to measure the quality of the mono-crystalline solar panel. More so, the field conversion efficiency of the six solar panels obtained range from 9.44 to 10.56% while the calculated manufacturer conversion efficiency for each of the six solar panels was 14.22%. The result indicates that the conversion efficiency of each of the solar panel did not tally with the calculated manufacture's conversion efficiency. The manufacturer specification was not enough to predict the performance of solar panel at installation site.

Nevertheless, the standard test condition (1000 W/m^2 irradiance, 25^{o}C cell temperature and 1.5 Air mass) in which the manufacturer obtained the specification for the solar panels was not the same condition the solar panels were subjected to at the installation site. Mansur *et al.* (2011); Jakhrani *et al.* (2011) revealed that photovoltaic performance or efficiency is greatly influenced by irradiance weather temperature and weather temperature (or cell (operating) temperature; cell temperature is dependent on weather temperature. Furthermore, According to Jakhrani *et al.* (2011); Ugwuoke and Okeke (2012) the values of the performance parameter obtained from one locality may be different from another locality due to variation in weather condition from place to place. Ugwuoke and Okeke (2012) obtained 9.61% conversion efficiency for a mono-crystalline PV module at 1000 W/m^2 irradiance. Conversion efficiency of mono-crystalline solar panel in Singapore as presented by Jiang and Wong (2005), found the maximum efficiency to be 8.12%. Also, average efficiency of a mono-crystalline panel in Brazil was found to be 9.40% (Norgueira *et al.,* 2015). In turkey, the average conversion efficiency of the mono-crystalline solar panel as found by Tascioglu *et al.* (2016) was 6.65%. Chikate and Sadawarte (2015) revealed that solar panel as a technology usually has conversion efficiency of 6% - 20 % in commercial use. Environment Canada (2012) stated that efficiency of mono-crystalline silicon PV module range between 14% and 20%. The calculated manufacturer's conversion efficiency of the six mono-crystalline solar panels fell within this range.

Table 3. The conversion (module) efficiencies of the six 80 W (480 W) solar panels.

Solar Panel S/N	Maximum power rating (W)	Solar irradiance, E (W/m^2)	Surface area (m^2)	Efficiency %	Calculated Manufacturer's Efficiency %
1	55.8	1000	0.5625	9.92	14.22
2	54.1	1000	0.5625	9.62	14.22
3	53.2	1000	0.5625	9.46	14.22
4	59.4	1000	0.5625	10.56	14.22
5	53.1	1000	0.5625	9.44	14.22
6	59.4	1000	0.5625	10.56	14.22

CONCLUSION

The performance evaluation was carried on the six 80 W (480 W) mono-crystalline photovoltaic panels in FUNAAB, Alabata Ogun State, Nigeria environmental condition. The electrical performance parameter evaluated were current at maximum power point, voltage at maximum power point, short circuit current, open circuit voltage, maximum power output, conversion (module) efficiency, normalized output power efficiency and fill factor. The results of the study showed that none of the electrical performance parameter of the solar panels evaluated on the field has value as the one stated by the manufacturer. This reveals that the condition in which the manufacturer obtained the technical data for the solar panels does not represent the real operating condition of the solar panels are subjected to at site of installation.

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