Output Power and Voltage-Time Characteristics of Mono-Crystalline Photovoltaic Panel at Federal University of Agriculture, Abeokuta (FUNAAB), Alabata, Ogun State, Nigeria Under FUNAAB Weather Condition

Kifilideen L. Osanyinpeju[1*], Adewole A. Aderinlewo [1], Olayide R. Adetunji [2], Emmanuel S.A. Ajisegiri [1]

[1]Agricultural and Bio-Resources Engineering Department, College of Engineering, Federal University of Agriculture Abeokuta

[2]Mechanical Engineering Department, College of Engineering, Federal University of Agriculture Abeokuta

*Corresponding Author: *amkifilideenosanyinpeju@gmail.com*, *prof_4us@yahoo.com*

Abstract: Solar energy is gaining more attention than ever before due to its potential ability to provide the world energy needed at a sufficient and reliable rate. Putting more focus on its optimum harvesting and utilization can eventually solve the problem of energy shortage by balancing up the energy demand of the nation. Adequate information on the output voltage of the solar panel to cope with the output current during the daytime is essential to be able to predict accurately the estimated amount of energy that can be tapped from the solar panel. This study carried out investigation on the output power and voltage-time characteristics of mono-crystalline photovoltaic panels at Federal University of Agriculture, Abeokuta (FUNAAB); a location at the outskirt of Abeokuta, Ogun State, in South West Nigeria weather condition. The collectors consist of six 80 W (480 W) sunshine solar panels made in Germany, 40 W digital charge controller, two of 200 AH (400AH) solar batteries and stop watch. The output voltages of the solar panels were read and recorded for a period of 21 days between 6:30 am to 7:30 pm for each day. The average maximum output power of the solar panels for the period of the 21 days was evaluated from the maximum output current and voltage. The output voltage of the solar panel was zero at 6:00 am and 7: 30 pm. As at 7:00 am the output voltage was 12.1 Volts close to the peak voltage. The average output voltage gradually increased to the peak voltage of 14.7 Volts at 1:00 pm then maintained on this voltage till 3:30pm after which it continued dropping back to zero at 7: 30 pm. The average maximum output power obtained from the panels for the 21 days was 323 W. The results of the study show that the output voltage of solar panel varies from time to time, day to day and change with weather condition of the location.

Keywords: Output power, Output Voltage, Mono-crystalline Photovoltaic panel, Solar, Charge controller.

I. INTRODUCTION

Energy plays the most vital role in the economic growth, progress, and development as well as poverty eradication and security of any nation (Oyedepo, 2012). Uninterrupted energy supply is a vital issue for all countries today (Akinwale and Ogundari, 2017). Modern energy enriches life in which no nation can survive without it. People's dependence on energy is increasing everywhere in the world. But, access to clean and safe modern energy services in an environmentally responsible manner is an

enormous challenge facing the African continent. Future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible, and environmentally friendly (George, 2006; Okeke et al., 2014; Ramadhas, 2016). Security, climate change, and public health are closely interrelated with energy (Ramchandra and Boucar, 2011; Zakariya and Kahn, 2014).

The energy crisis, which has engulfed Nigeria for almost two decades, has been enormous and has largely contributed to the incidence of poverty by paralyzing industrial and commercial activities during this period (Nnaji et al., 2010; Tyomlia et al., 2017). Since Nigeria is blessed with abundant renewable energy resources such as hydroelectric, solar, wind, tidal, and biomass, there is a need to harness these resources and chart a new energy future for Nigeria. In this regard, the government has a responsibility to make renewable energy available and affordable to all. It is quite surprising that despite the popularity of solar energy in developed countries, yet greater numbers of Nigerians are still battling to understand its (solar energy) dynamism and efficiency.

Solar energy is gaining more attention than ever before due to its potential ability to provide the world energy needed at a sufficient and reliable rate. Putting more focus on its optimum harvesting and utilization can eventually solve the problem of energy shortage by balancing up the energy demand of the nation. In Nigeria, solar energy is accessible by all and available all year round. However, many Nigerians are still ignorant of the fact that harvesting of solar energy is possible and also there is still low utilization of the solar energy compared to its production on daily basis. At the moment, solar energy is the most reliable and inexhaustible energy resource that could be used economically to meet the world's increasing energy demands and to sustain the clamour for alternative energy source for Nigeria. The energy reaching the earth from the sun far exceeds the energy requirements of the entire world's population (Farret and Simoes, 2017). Solar energy has many advantages which includes the provision of energy without noise because it has no movement in their parts, provision of energy without wastes and does not need waste material for energy production nor produce waste during producing energy (Yohanna, 2010).

More so, solar photovoltaic (PV) technology supplies electricity without combustion. It has less maintenance since nothing is consumed or worn during their operation. It can be converted to other energy (Hasua and Gibs, 1988). Furthermore, Solar energy utilization in production of electricity is totally free from environmental degradation and pollution. Solar energy from the sun is the best alternative energy source been attractive, plenty, free of charge, non-pollutant, it does not use fuel, clean, abundant, uninterrupted, inexhaustible, clean, and cheap, available everywhere, helps in lessening the greenhouse effect. No doubt solar energy would be the best alternative source of energy people would have no choice to fall back on soon to meet their energy needs.

However, the energy of solar radiation is directly utilised in mainly three forms: which are direct or photovoltaic conversion into electricity that takes place in semiconductor devices called solar cells, thermal conversion i.e. accumulation of heat in solar collectors and photochemical conversion. A good knowledge of the output voltage, output current and output power of a solar panel and how they vary with time and with dynamic environmental condition would give accurate estimate amount of energy that can be tapped from a given solar panel. This information would help in designing accurately the size of solar panel that would be required for a solar powered system. This research work investigated the output power and voltage-time characteristics of mono-cystalline photovoltaic panels at Federal University of Agriculture, Abeokuta (FUNAAB), Alabata, Ogun State, Nigeria weather condition.

II. RELATED WORK

The literature survey has been done for collecting information regarding the voltage-time characteristics of mono-crystalline photovoltaic panel.

Evbogbai et al., (2009) investigated voltage-time characteristic of a 140W, 33 V solar panel in Ambrose Alli Univeristy, Ekpoma, Nigeria. The experiment was conducted daily for a period of one week on a clear sunny day during the dry season and a cloudy and raining day during the raining season. They reported that the three is variation in the terminal voltage with time and the variation of the terminal voltage of the solar panel is time dependent which reflects the intensity of the sun at any point in time.

Olufemi et al., (2016) carried out study on photovoltaic cell output voltage variations with time and inclination angle. The examination of the PV voltage variation with time of day was done over a seven-day period using 150 W solar panel. They reported that the highest voltage was obtained at about 13: 00 – 13: 30 hours.

Moghbeli and Ellithy (2009) investigated solar energy applications with design and implementation of photovoltaic traffic light signal system for Qatar. In their work the output voltages of solar panel at different angles and different times of the day were measured. They observed that maximum voltage does not only depend on the angle, it also depends on the time of the day, which reflects the position of the sun in the sky. Between 8:00 and 14:00, the variation of the voltage is almost the same. They indicated that the time of the day has as major effect on the voltage output of the solar panel. The peak value was achieved between 10:00 and 10:30. The same thing was observed on different days as reported.

III. MATCHING OF SOLAR PANELS

The solar panels are connected in series to maximized voltage which would be relevant in area where the electricity or power generated need to be transmitted or used with the grid system. This will prevent loss of current during transmission. The voltage of the solar panel should be greater than the voltage of the battery. Current can only flow from the solar panel to the battery when the voltage of the solar panel is higher than that of the solar battery. If the solar panel voltage is too higher that of the voltage of the battery large quantity of power would be lost.

For a series connection of solar panels, the effective voltage of all the panels would be the addition of the voltage of each individual voltage of each panel while the effective current of all the solar panels would be current of the panel that is having the smallest current value. But if the solar panels are of the same type and product the effective current would just be the current of any of the panel. The effective power of the solar panels connected in series would be the summation of individual power of each of the solar panel. To prevent loss of power due to matching of solar panels, the solar panels to be matched should be of the same type, product and have the same specification. More so, the solar panels are connected in parallel to maximized current which would be relevant in area where the electricity or power generated would be stored by a solar battery or use in an off-grid system. since solar battery stores electric charge which is a product of current and time.

Furthermore, for a parallel connection of solar panels the effective current of all the panels would be the addition of the current of each individual current of each panel while the effective voltage of all the solar panel would be voltage of the panel that is having the smallest voltage value. But if the solar panels are of the same type and product the effective voltage would just be voltage of the solar panel. The effective power of solar panels connected in parallel would be the summation of individual power of each of the solar panel. To prevent loss of power due to matching of solar panels, the solar panel to be matched must be of the same type, product and have the same specification. Never the less, the effective power of the solar panels connected in parallel or series have the same value.

IV. MATERIALS AND METHODS

Materials

The materials used for this study are six of 80 W (480 W) Mono-crystalline PV panels of sunshine product made in Germany, two of 200 AH (400 AH) solar batteries, stop watch and 40 W digital charge controller. The manufacturer' s specifications of each of the six 80 W (480 W) solar panel used were P_{max} of 80 W, solar irradiance of 1000 W/m^2, cell temperature of 25 ^oC, current at maximum power point, I_{max} as 4.57A, 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 ± 5 %.

Methods

To carry out the laboratory investigation on the mono-crystalline photovoltaic panels the six 80 W (480 W) panels were installed on the roof of the Agricultural and Bio-Resources Engineering processing laboratory while the 40 W digital charge controller and two of 200 AH (400 AH) solar batteries were installed inside the laboratory. The digital charge controller was used to monitor the output voltage from the solar panels while the output power from the solar panel was computed.

Power and Voltage-Time Characteristics of Solar Panels Due To The Effect Of The Solar Intensity

The six 80W (480W) solar panel were connected in parallel during installation to maximize current. The behaviour of the output power and voltage of the solar panel because of the solar intensity was monitored and readings were taken and recorded in the laboratory throughout the period of 21 days (from 24/12/2015 to 13/12/2016) between 6:30 and 19:30 using the 40 W solar charge controller. Also, the output power of the solar panels between 6:30 and 19:30 for the period of the 21 days was determined from the output current and output voltage measured. The average of the entire reading obtained for the 21 days and readings obtained for day 2 (25/12/2015) and day 12 (04/01/2016) were used for analysis.

V. RESULTS AND DISCUSSION

Shown in Table 1 is the results of the output voltage of the solar panels on days 2 (25/12/2015) and day 12 (04/1/2016) due to variation in weather condition. The result of the study shows that the output voltage of the solar panels varies with daytime. It was observed that the solar panels had output voltage of zero at 6:30 am and 7: 30 pm for each day of the investigation period. Table 1 (day 2), it was cleared that the output voltage of the solar panels rose sharply between 6:30 am and 7:00 am and by 12:30 pm the output voltage approached its peak value. The peak was attained by 1:00 pm. The curve shows a little variation in the output voltage between 11:30 am and 4:00 pm. This trend of was attributed to climatic and weather conditions which to a large extent affected the intensity of the sun that fell on the solar panel. It was observed that the output voltage of the solar panels follows the same trend throughout the period of investigation. This is because of the period in which the study place which were months of December and early January. There was no rain which great effect on the sunshine hours and sun intensity could have bringing a great variation in the output voltage of the solar panels. Most of the days of study the time of peak output voltage were maintained between 1:00 pm to 3:30 pm. In a similar voltage-time characteristic of a solar panel in Ambrose Alli Unversity, Ekpoma, Nigeria, Evbogbai et al. (2009) also found that the output voltage of solar panel depends on time of the day. It was reported that the output voltage obtained rose sharply between 6:00 and 7:00 am by 7:30 am, it approaches its peak value. They further stated that the output voltage had little variation between 7:30 am and 6:00 pm. Amajama (2016) observed that the output voltage of a solar cell rose rapidly to a maximum value and remains steady throughout, despite increase in solar illuminance (or intensity).

Olufemi et al., (2016) carried out study on photovoltaic cell output voltage variations with time and inclination angle. The examination of the PV voltage variation with time of day was done over a seven-day period using 150 W solar panel. They reported that the highest voltage was obtained at about 13: 00 – 13: 30 hours.

Moghbeli and Ellithy, (2009) investigated solar energy applications with design and implementation of photovoltaic traffic light signal system for Qatar. In their work the output voltages of solar panel at different angles and different times of the day were measured. They observed that maximum voltage does not only depend on the angle, it also depends on the time of the day, which reflects the position of the sun in the sky. Between 8:00 and 14:00, the variation of the voltage is almost the same. They indicated that the time of the day has as major effect on the voltage output of the solar panel. The peak value is achieved between 10:00 and 10:30. The same thing was observed on different days as reported.

Table 1. The output voltage of the solar panels at days 2 (25/12/2015) and 12 (04/1/2016) due to th variation in weather condition.

Days 2 (25/12/2015)			Day 12 (04/1/2016)		
S/N	Daytime	Output Voltage	S/N	Daytime	Output Voltage
1	6:30	0	1	6:30	0
2	7:00	11.7	2	7:00	12
3	7:30	12.4	3	7:30	12.3
4	8:00	12.9	4	8:00	12.8
5	8:30	13.2	5	8:30	12.9
6	9:00	13.5	6	9:00	13.1
7	9:30	13.7	7	9:30	13.4
8	10:00	13.9	8	10:00	13.6
9	10:30	14.1	9	10:30	13.9
10	11:00	14.3	10	11:00	14.1
11	11:30	14.5	11	11:30	14.2
12	12:00noon	14.6	12	12:00noon	14.4
13	12:30	14.7	13	12:30	14.5
14	13:00	14.8	14	13:00	14.6
15	13:30	14.8	15	13:30	14.7
16	14:00	14.8	16	14:00	14.7
17	14:30	14.8	17	14:30	14.6
18	15:00	14.8	18	15:00	14.7
19	15:30	14.6	19	15:30	14.6
20	16:00	14.5	20	16:00	14.5
21	16:30	14.3	21	16:30	14.3
22	17:00	14	22	17:00	14
23	17:30	13.6	23	17:30	13.6
24	18:00	13.1	24	18:00	13.1
25	18:30	9.6	25	18:30	12.7
26	19:00	0.3	26	19:00	0.4
27	19:30	0	27	19:30	0

Comparing their results with this study, it was deduced that the variation of the output voltage during the day time from place to place followed the same pattern but the time at which the peak voltage occurred varied. This variation was linked to the climatic change from place to place.

Table 2 shows the average output voltage, average output current and average output power for the period of the 21 days. Figure 3-5 indicates the average output current, average output power, average output voltage of the mono-crystalline PV panel for the period of the 21 days against daytime. The

result shows that the average output current varies with the daytime due to the variation of the solar intensity. At 6:00 am the output current from the solar panel was zero which latter had a value of 0.5 Amps at 7:00 am then increases gradually with the daytime to peak value of 21.4 Amps at 1:00 pm afterward it decreases with increases in daytime more, so the output current then dropped from the peak value to a value of 0.1 Amps at 6:00 pm. Finally, the output current gave output value of zero at 7:00 pm. Throughout the period of investigation it was observed that the time of peak output current from the solar panels varies from day to day which may be due to variation in the time of solar noon from day to day. Amajama (2016) in his own work also observed that the output current rose steadily with increase in solar illuminance or intensity.

The results in Table 2 also shows that the average output voltage had a value of zero at 6:30 am which suddenly increased to 12.1 Volts at 7:00 am then gradually increased to a peak value of 14.7 volts at 1:00 pm which maintained the value till 3: 30 pm then gradually dropped to a value of 0.6 volts at 7:00 pm. The average output voltage was zero at 7: 30 pm. The peak average output voltage occurred between 1:00 pm and 3:30 pm.

The average output power at daytime of the solar panels for the period of the incubation period increase steadily with daytime and attained maximum value at 1:00 pm. It was zero at 6:30 am and 7:00 pm. The average peak output power obtained was 314.58 W which was closed to the maximum output power (335 W) achieved during the field investigation of the performance of the six solar panels. The result indicates that the output power from photovoltaic solar panel is not constant but varies with time of the day, day from day which is in accordance with the report of Calabro (2009) and Mousazadeh et al. (2009).

This study revealed that a good knowledge of the output voltage, output current and output power of a solar panel and how they varies with time and with dynamic environmental condition would give accurate estimate of energy that can be tapped from a given solar panel. Such information would help in designing accurately the size of solar panel that would be required for a solar powered system.

Table 2. The average output voltage, average output current and average output power for the period of the 21 days.

S/N	Daytime	Average Output Voltage	Average Output Current	Average Output Power
1	6:30	0	0	0
2	7:00	12.1	0.5	6.05
3	7:30	12.6	1.3	16.38
4	8:00	12.9	2.7	34.83
5	8:30	13.1	3.9	51.09
6	9:00	13.2	5.2	68.64
7	9:30	13.4	6.6	88.44
8	10:00	13.6	9.3	126.48
9	10:30	13.9	12.5	173.75
10	11:00	14.1	15.3	215.73
11	11:30	14.3	17	243.1
12	12:00noon	14.4	19.2	276.48
13	12:30	14.6	20	292
14	13:00	14.7	21.4	314.58
15	13:30	14.7	21.4	314.58
16	14:00	14.7	21.3	313.11
17	14:30	14.7	20.3	298.41
18	15:00	14.7	19.2	282.24
19	15:30	14.7	17.7	260.19
20	16:00	14.5	15.6	226.2

21	16:30	14.3	12.9	184.47
22	17:00	14.1	9.1	128.31
23	17:30	13.7	5.1	69.87
24	18:00	13.2	1.9	25.08
25	18:30	12.1	0.1	1.21
26	19:00	0.6	0	0
27	19:30	0	0	0

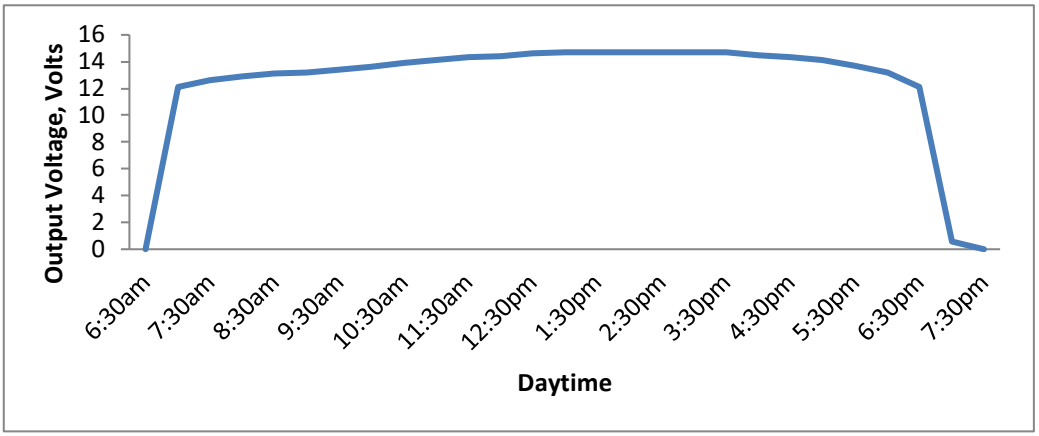

Figure 1. The average output voltage the mono-crystalline PV panel for the period of the 21 days against daytime.

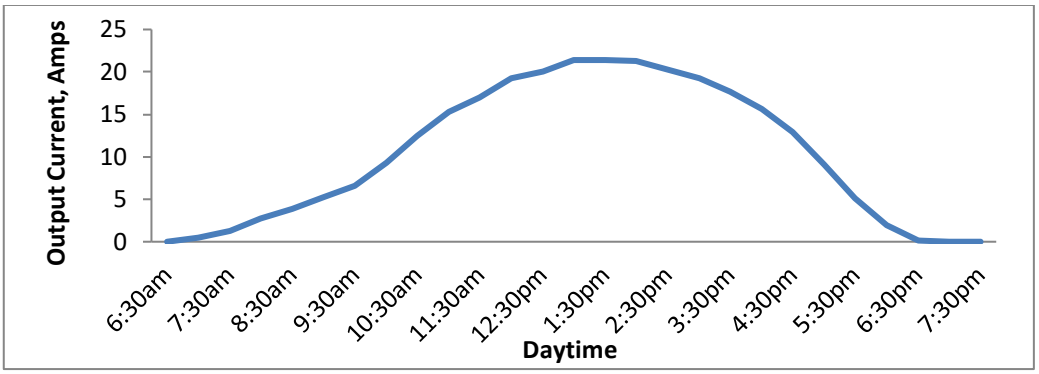

Figure 2. The average output current of the mono-crystalline PV panel for the period of the 21 days against daytime.

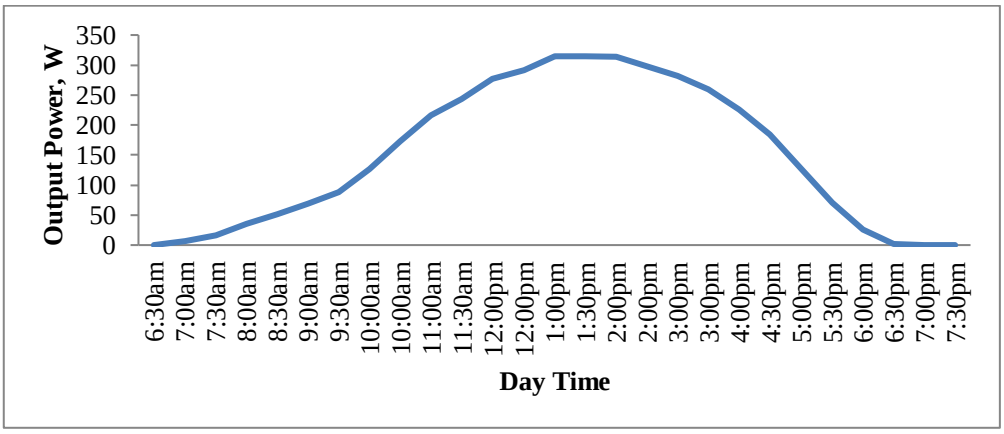

Figure 3. The average output power of the mono-crystalline PV panel for the period of the 21 days against daytime

Figures 1-3 indicates the average output current, average output power, average output voltage of the mono-crystalline PV panel for the period of the 21 days against daytime. Figures 2 and 3 also show that the output current and output power of a solar power follows the same trend which was in conformity with findings of Amajama (2016). The Amajama (2016) in his own work, also ascertain the linear relationship between the output power and output current. It can be deduced based on this observation that the output power of the solar panel is directly proportional to the solar intensity since it has been reported that output current is directly proportional to solar intensity.

Figure 4 shows the regression line and correlation between the output current and output voltage of the mono-crystalline PV panel. The coefficient of determination (R square-value) which predicted how the data fit into the regression line between the output current and output voltage of the mono-crystalline PV panel obtained from the figure was 0.361 while the R-value of the linear relationship between the output current and output voltage of the mono-crystalline PV panel obtained was 0.6011. The obtained R-value revealed that there is moderate positive linear relationship between the output current and output voltage of the mono-crystalline PV panel.

Meanwhile, Figure 5 shows the regression line and the correlation between the output power and output voltage of the mono-crystalline PV panel. The coefficient of determination (R square-value) between the output power and output voltage of the mono-crystalline PV panel obtained from the figure was 0.348 while the R-value of the linear relationship between the output current and output voltage of the mono-crystalline PV panel obtained was 0.5900. The obtained R-value indicates that there is moderate positive linear relationship between the output current and output voltage of the mono-crystalline PV panel.

Figure 6 presents the regression line and the correlation (linear relationship) between the output power and output current of the mono-crystalline PV panel. Also, a first order model was obtained from the Figure 42 to predict the output power as a function of the output current for the mono-crystalline PV panels. The model was shown in (1). The model predicted the observed data well with a coefficient of determination (R square-value) of 0.9990 as shown in the same Figure 42 within the ranges of the experimental study.

$$P = 14.72\ I - 3.888 \quad (1)$$

Where

P = the output power of the solar panel, W

I = the output current of the solar panels, Amps

The R-value of the linear relationship between the output current and output voltage of the mono-crystalline PV panel obtained was 0.9996. The obtained R-value implies that there is strong positive linear relationship between the output current and output power of the mono-crystalline PV panel. However, it can be clearly deduced that the output current and output power from the mono-crystalline are directly proportional to each other.

Table 3 shows the daily maximum output power and time of maximum power of the solar panels for the period of the 21 days. The results show that the time of maximum output current tally with the time of the maximum output power which also shows that output current and output power of solar panel are strongly correlated. The maximum output power from the six 80 W (480 W) obtained in the laboratory for the period of the 21 days ranging from 302 to 339 W. Also, the maximum average output power gotten for the period of the 21 days was 323 W which represents 67.3% of the output power stated by the manufacturer which was obtained that STC.

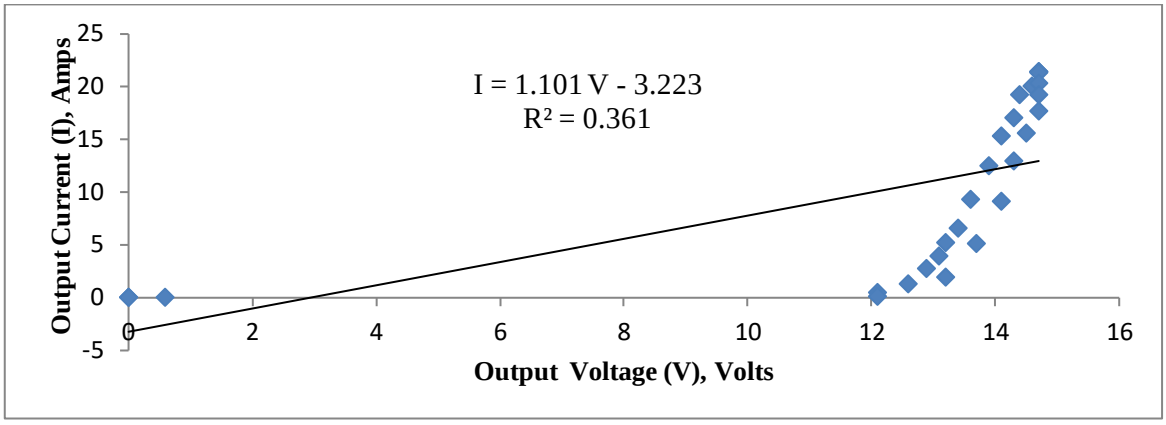

Figure 4. The regression line and the correlation between the output current and output voltage of the mono-crystalline PV panel.

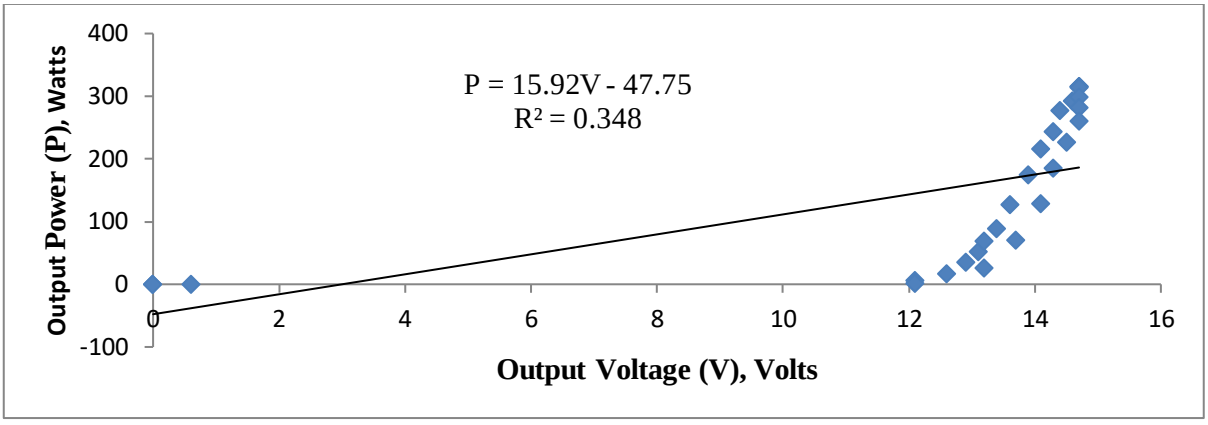

Figure 5. The regression line and the correlation between the output power and output voltage of the mono-crystalline PV panel.

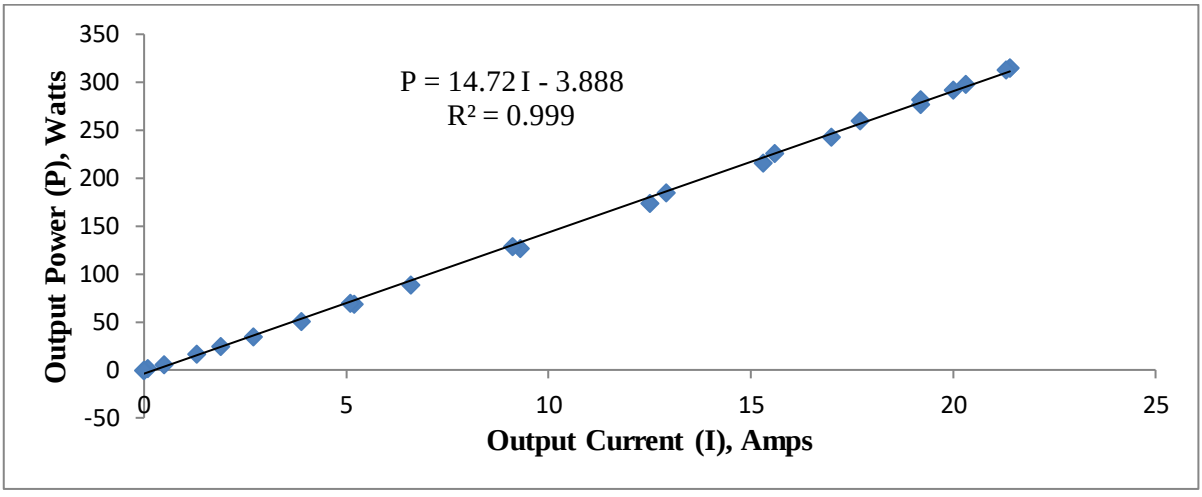

Figure 6. The regression line and the correlation between the output power and output current of the mono-crystalline PV panel.

Table 3: table showing the daily maximum output power and time of maximum power of the solar panels for the period of the 21 days.

Day	Date	Time of Maximum Output current	Time of Maximum Output Power	Maximum Output Power
1	(24/12/2015)	14:00	14:00	322
2	(25/12/2015)	14:00	14:00	337
3	(26/12/2015)	14:00	14:00	314
4	(27/12/2015)	14:00	14:00	327
5	(28/12/2015)	14:00	14:00	334
6	(29/12/2015)	14:30	14:30	320
7	(30/12/2015)	13:30	13:30	332
8	(31/12/2015)	13:30	13:30	339
9	(1/1/2016)	14:30	14:30	318
10	(2/1/2016)	13:00	13:00	318
11	(3/1/2016)	13:00	13:00	353
12	(4/1/2016)	13:30	13:30	316
13	(5/1/2016)	14:00	14:00	311
14	(6/1/2016)	13:30	13:30	302
15	(7/1/2016)	13:00	13:00	329
16	(8/1/2016)	13:00	13:00	313
17	(9/1/2016)	13:30	13:30	329
18	(10/1/2016)	14:00	14:30	317
19	(11/1/2016)	13:30	13:30	317
20	(12/1/2016)	14:30	14:30	313
21	(13/1/2016)	14:00	14:00	323

Plate 1: The view of the installed 40 W digital charge controller, 400 AH solar battery and six 80 W (480W) mono-crystalline photovoltaic solar panels.

VI. CONCLUSION

The research work investigated the output power and output voltage-time characteristics of mono-crystalline photovoltaic panel in the laboratory for a period of 21 days. The study was carried out in FUNAAB dynamic weather condition. The average maximum output power obtained from the solar panels for the period of 21 days was 323 W. The result of the research indicates that the output voltage of solar panel varies with daytime. It was observed from the results that the time of peak voltage occurred mostly from 1:00 pm to 3:30 pm for the period of the 21 days.

The results show that there is positive moderate correlation between the output voltage and output power and the correlation between output voltage and output current is positive moderate while there is strong correlation between the output power and output current. The study clearly deduced that the output current and output power from the mono-crystalline solar panel are directly proportional to each other.

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical statement: The authors declare that they have followed ethical responsibilities.

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