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Effect of Meteorological Parameters on the Performance of Photovoltaics Installed under the Guinea Savannah Atmosphere in Ogoja, Cross Rivers State, Nigeria

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ABSTRACT: A thorough experimental investigation was carried out to study the effect of some meteorological parameters on the performance of photovoltaics installed under the guinea savannah atmosphere in Ogoja, Cross River State, Nigeria by in-situ measurement approach using a precision digital solar power meter, an accurate digital hygrometer, precision digital infrared gun thermometer and a digital high precision photovoltaic smart panel maximum power point tracker (MPPT) tester to track and determine the maximum power, voltage and current produced by the photovoltaic module. The result reveals that stability in voltage should be expected between relative humidity levels of 67% to 47% while erratic drop in voltage below 47% of relative humidity should be expected which hinders the PV module from attaining 100% efficiency. In addition, the temperature of the study location seems favorable as on the average the panel temperature will rarely exceed 40^0C for months besides January which makes it possible for the PV module to attain 90% efficiency. Also, with an altitude of 85m above sea level coupled with the fact that as early as 9:00am the solar power level is close to 800W/m^2 makes the location a good site for the installation of solar farm for harvesting solar energy.

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An important component of human needs as society becomes sophisticated on daily basis is energy. If Nigeria is to attain the socio-economic development it seeks, then ensuring that its population is able to obtain a cost-effective, sufficient and accessible energy is imperative. The world's demand for energy is growing daily and it is estimated to continue growing due to increasing population, industrialization and changing lifestyles (Agyekum *et al*., 2021). Nigeria has crude oil in abundance, coupled with the fact that it is among the crude oil exporting countries, yet its population has turn to renewable energy due to the constant rising cost of crude oil coupled with the problems of global warming. Renewable energy has gained so much attention among other sources of energy due to several advantage related to its use. The use of solar energy for the generation of electricity has gained attraction recently due to the plummeting cost of its components (Qaisrani *et al*., 2019). Solar energy which is a renewable source of energy is ranked among the rapidest rising source of energy in the world, due to its pollution free, noiseless and clean nature. Due to the depletion of the ozone layer and global warming, solar energy is receiving huge attention (Njok *et al*., 2020a). The photovoltaic technology which is almost maintenance free is the most established and well-known technology used for the generation of electricity globally (Shivashankar *et al*., 2016). Photovoltaic (PV) systems possesses the ability to match the electricity production of the world. In 2018, 100 GW of Photovoltaic systems were installed which enabled the total capacity of installed PV systems to exceed 505 GW worldwide (Renewables 2019). Also in 2018, china solely installed closed to 45 GW of PV systems and its total capacity rose to 176 GW (Mustafa *et al*., 2020). Photovoltaic modules are made by the combination of solar cells which are solid state devices

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that inherently possesses the ability to transform radiation (natural or artificial) into electricity. In Nigeria the photovoltaic technology overflowing its market are the crystalline and amorphous solar technology which are mainly installed for household purposes. With the cost of electricity attaining steady increase, domestic standalone PV systems could be implemented and used with a low system budget. The obvious drop in the cost of acquiring and installing PV systems means that it is possible for them to compete with electricity prices both nationally and regionally in locations with high irradiation (Mustafa *et al.*, 2020). The performance of photovoltaic cells inevitably depends on the climatic conditions which they find themselves due to the fact that they were manufactured and tested under controlled laboratory environment using standard test conditions (STC). However, these STC varies from real outdoor conditions at the location of installation which triggers performance variations due to variations in environmental conditions. Numerous investigations (Omubo-Pepple *et al.*, 2013; Kazem *et al.*, 2012; Sanusi *et al.*, 2011; Siddiqui and Bajpai, 2012; Bashir *et al.*, 2013; Kazem and Chaichan, 2015; Carr and Pryor, 2004) have been done to ascertain the effect of atmospheric conditions on photovoltaic modules. However, the performance of PV model in outdoor conditions is still not high due to the fact that photovoltaic power as well as its efficiency depends on several factors which includes temperature, humidity, solar radiation intensity, geographic location, sun position, dust accumulation and load demand. Hence the objective of this paper is to experimentally investigate the effect of some meteorological parameters on the performance of photovoltaics (PV) installed under the guinea savannah atmosphere in Ogoja, Cross Rivers State, Nigeria.

MATERIALS AND METHOD

Materials: a polycrystalline photovoltaic module was used in the study: electrical characteristics of the module is displayed in table 1. A digital high precision photovoltaic smart panel maximum power point tracker (MPPT) tester of the model WS400A was used to track and determine the maximum power, voltage and current produced by the photovoltaic module.

A digital solar power meter of the model SM206 was used for monitoring the solar power reaching the surface of the PV module, while a digital hygrometer of the model KT-908 was utilized for effective tracking of the relative humidity level at the PV module surface.

A digital infrared gun thermometer was employed to determine the PV surface temperature.

Measurement procedure: Measurements were taken at an interval of 30 minutes from 6:00am to 6:00pm for a duration of 90 days. During acquisition of data, the time of day was noted, while the voltage, current as well as power from the photovoltaic module were determined directly with the aid of the smart panel MPPT tester. The level of relative humidity at the surface of the module, the panel temperature and the amount of solar power reaching the module were measured using the digital hygrometer, digital infrared gun thermometer and digital solar power meter respectively.

Table 1: PV module technical characteristics

Electrical Specification	Value
Maximum Power	130W
Current at Maximum Power	7.18A
Voltage at Maximum Power	18.10V
Short Circuit Current	7.91A
Open-circuit Voltage	21.72V
Number of cells	36
Module dimension	1480mm*670mm*35mm
Manufacturer	Africell solar
Model	AF-130W

Experimental setup: A platform one-metre-high was built and the photovoltaic module was mounted horizontally flat on it facing the sun. Connecting cables made as short as possible were connected from the output of the photovoltaic module to the input of the photovoltaic smart panel MPPT tester from which the maximum power points where tracked and determined as shown in figure 1.

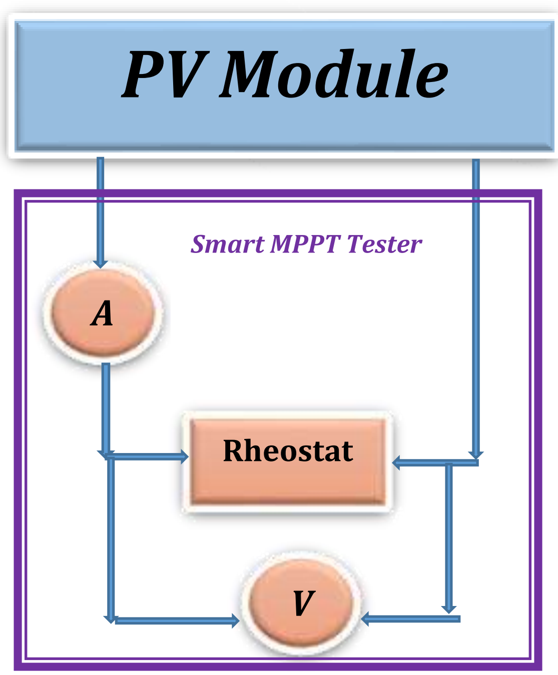

Fig 1: Experimental setup

Data processing and measurements: The study was carried out in real-time outdoor conditions with varying meteorological parameters. The open circuit voltage V_{oc}, the instantaneous voltage V_{mp} and Current I_{mp} at maximum power as well as P_{mp} under a particular real-time meteorological condition were measured directly with the aid of the smart panel MPPT tester. The efficiency of the PV module is significantly influenced by the amount of voltage and current it can generate which in turn is affected by several meteorological parameters as well as design and maintenance of the module. The V_{mp} and the V_{oc} are critically influenced by temperature (T) which can be determined by (1) as revealed by (Njok and Ewona, 2022). While the I_{mp} and the short circuit current I_{sc} are also critically influenced by the solar power (H) and can be ascertained via (2) shown by (Njok *et al*., 2020a). Also from the data obtained the PV module efficiency at STC was confirmed with (3) while the normalized power output efficiency was computed by employing (4) as shown by (Njok *et al.,* 2022)

Open circuit voltage:

$$V_{oc} = \frac{KT}{Q} ln \frac{I_{sc}}{I_0} \quad (1)$$

Short circuit current:

$$I_{sc} = bH \quad (2)$$

Module Efficiency:

$$\eta_{Mod} = \frac{Power\ of\ photovoltaic\ module \times 100\%}{Area\ of\ photovoltaic\ module \times 1000W/m^2} \quad (3)$$

Normalized power output efficiency:

$$\eta_p = \frac{P_{mea}}{P_{max}} \times 100\% \quad (4)$$

Where K is the Boltzmann constant, Q is the electronic charge, i_0 is the saturation current while b is a constant which entirely depends on the semiconductor junction properties. P_{mea} and P_{max} are measured power and power at STC respectively.

Study area: Ogoja sits on latitude $6^0$39'30.24" N and longitude $8^0$47'57.23" E. It is located in Cross River State of Southern Nigeria at an elevation of 85m above sea level. Ogoja has the tropical savanna climate prevailing, the wet season is warm, oppressive, and overcast and the dry season is hot, muggy, and partly cloudy. Over the course of the year, the temperature typically varies from 18.3°C (65°F) to 32.2°C (90°F) and is rarely below 15.56°C (60°F) or above 33.89°C (93°F) (Weathersparks.com). The average temperature for the year in Ogoja is 26.78°C (80.2°F). The warmest month, on average, is March with an average temperature of 29°C (84.2°F). The coolest month on average is July, with an average temperature of 25.5°C (77.9°F). Its mean relative humidity is 76% and the annual wind speed is 3.68m/s (Weatherbase.com). Moreover, January is the least humid month with an average relative humidity level of 29%, while August is the most humid month with an average relative humidity level of 86% (Weather-atlas.com). But the location selected for this study is the Cross River University of Technology (CRUTECH) campus at Ogoja with bearing of Latitude $6^0$37'35.4" N and longitude $8^0$46'23.1" E.

RESULTS AND DISCUSSION

This section is about the data acquired from experimental measurement and analysis, it is divided into four parts. The first part is about how the electrical parameters and the efficiency of the module respond to the humidity of the study location. In the second part, analysis of results is given regarding how the electrical parameters and the efficiency of the module is influenced by its temperature. The third part displays the analysis of the results concerning how the module responds to the level of solar power of the study location. The last part discusses the meteorological parameter at each time of day. it should be noted that the voltage, current and power used in the analysis of the results are the maximum voltage, current and power respectively that the modules generates instantaneously at a particular meteorological condition.

Influence of relative humidity on the electrical parameters of the PV module: Fig 2 is a result which explains the voltage performance of the photovoltaic module with varying relative humidity levels. The figure clearly shows that photovoltaic modules perform better with low level of relative humidity. The figure also reveals that for the study location, stability in voltage should be expected between relative humidity levels of 67% to 47%, below 47% erratic voltage performance should be expected.

Fig 3 is a result which demonstrate how the current generated by the photovoltaic module is affected by varying levels of relative humidity. The figure obviously shows a very strong negative (downhill) linear relationship between current and relative humidity. This very strong negative relationship simply reveals that the lower the level of relative humidity the more current will be generated by the photovoltaic module; which conforms to our statistical correlation. Furthermore, the lower the relative humidity, the higher the amount of solar radiation reaching the photovoltaic module.

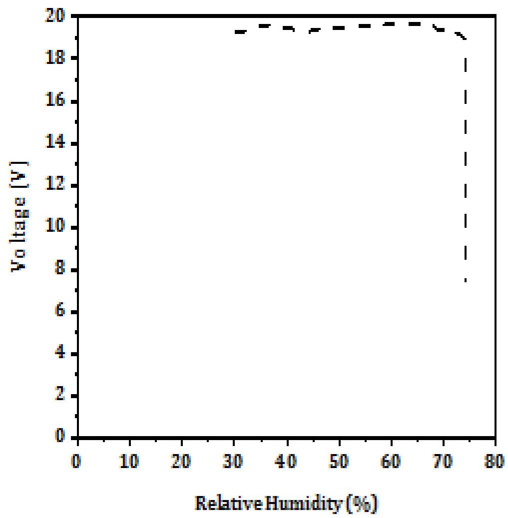

Fig 2: Voltage produced by photovoltaic module with varying relative humidity level

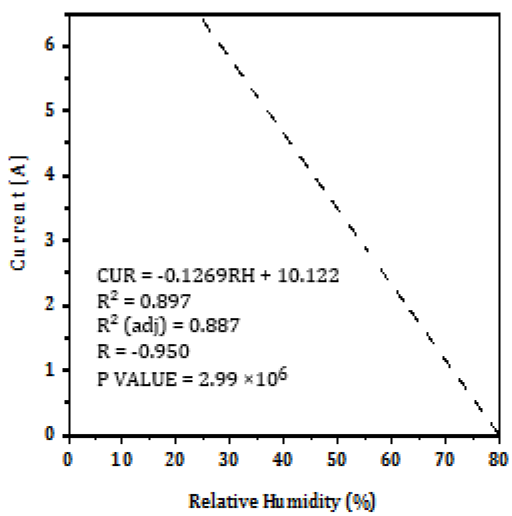

Fig 3: Current generated by photovoltaic module with varying relative humidity level

Fig 4 exhibit how the power generated by the photovoltaic module is influenced by varying levels of relative humidity. The figure reveals a very strong negative linear relationship between the output power generated and relative humidity, which help us to understand that photovoltaics performs better with low level of relative humidity which also conforms to our statistical correlation. Fig 5 which is influenced by the voltage, current and power performance of the photovoltaic module reveals how efficient the photovoltaic module is with varying levels of relative humidity. The figure displays a very strong negative linear relationship between the efficiency of the module and relative humidity which corresponds to our statistical correlation. This is as a result of the adverse effect that high relative humidity has on voltage, current and power as shown in fig 2 to fig 4 respectively. This further explains that high level of relative humidity does not enhance the efficiency of photovoltaics. Fig 2 to fig 5 is in agreement with previous studies by (Njok and Ogbulezie, 2018).

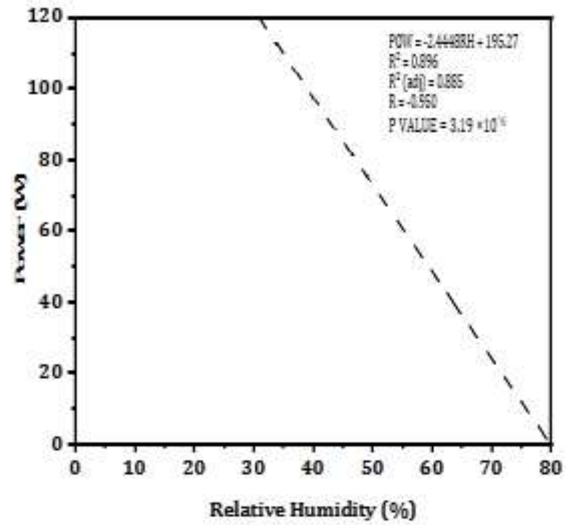

Fig 4: Power generated by photovoltaic module with varying relative humidity level

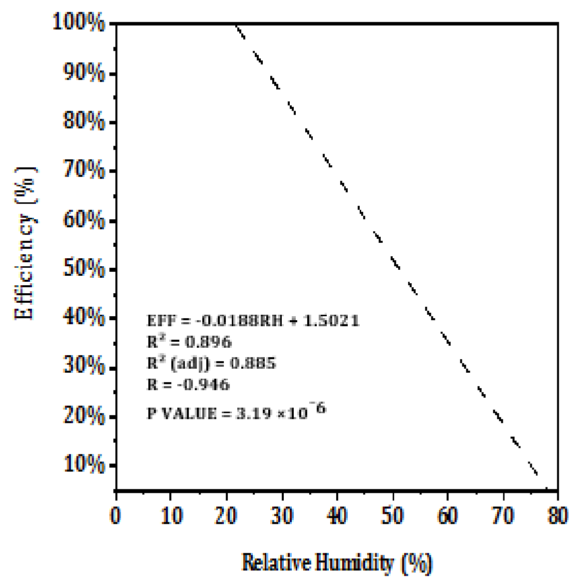

Fig 5: Efficiency of the photovoltaic module under varying relative humidity level

From the details of our study location coupled with the manufacturer specification of the PV module used, it is very evident (from Fig 3 and Fig 4) that for the PV module to give out its maximum current (7.18A) and maximum power (130W) as displayed in table 1, the relative humidity level has to drop down to a level close to 20% which is possible in the month of January. Furthermore, Fig 5 disclose that 100%

efficiency could be attained from the PV module for a relative humidity level between 23% to 25%. However, Fig 2 reveals that below 47% of relative humidity erratic voltage performance should be expected. Hence 100% efficiency from the PV module may not be possible.

Influence of temperature on the electrical parameters of the PV module: Fig 6 displays the voltage performance of the photovoltaic module as the panel temperature rise and fall. The figure reveals an increase in voltage between 25^{0}C and 35^{0}C. Between 35^{0}C to 43^{0}C a fairly stable voltage was maintained by the module. Beyond 43^{0}C unpredictable drop in voltage is experienced which indicates that high temperature does not favor voltage production from photovoltaics agrees with previous studies by (Ogbulezie *et al.*, 2020).

Fig 7 shows how the current generated by the photovoltaic module is affected as the panel temperature rises. The figure reveals a strong positive (uphill) linear relationship between current and panel temperature. This strong positive relationship explains that increase in panel temperature favors current production by the photovoltaic module which matches with our statistical correlation. Furthermore, this increase in panel temperature is seen as an increase in energy supplied to the atoms in the lattice structure which enables more electrons to be excited to a higher energy level and hence breakout from their bonds to constitute a current formed by thermal agitation, which sums up with the current generated by the photovoltaic effect. Fig 7 also agrees with earlier studies by (Ogbulezie *et al.*, 2020).

Fig 8 depicts the level of efficiency attained by the photovoltaic module as the panel temperature rises. It shows an increase in efficiency as panel temperature rises to 43^{0}C. beyond 43^{0}C the efficiency begins to plummet indicating that the maximum operating cell temperature has been exceeded. The increasing part of the result is due to the favorable effect that increasing panel temperature has on current as shown in Fig 7 while the plummeting part of the result is due to the unpredictable plunge in voltage beyond 43^{0}C as shown in Fig 6 which agrees with earlier studies by (Njok and Ogbulezie, 2018).

Details of our study location reveals that March is the hottest month and the temperature is rarely above *33.89°C (93°F)*. Also, according to Boxwell (2012) panel temperature for pole mounted photovoltaic modules can be obtained by multiplying the ambient temperature by 1.2. This implies that on the average the panel temperature will not exceed 40^{0}C for other months. Hence, 90% efficiency from PV modules could be assured.

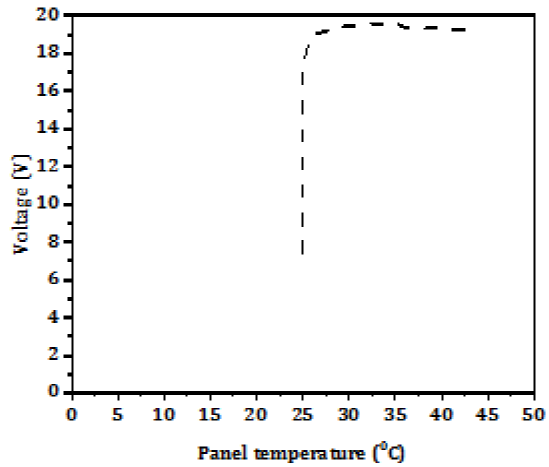

Fig 6: Voltage produced by photovoltaic module with varying panel temperature

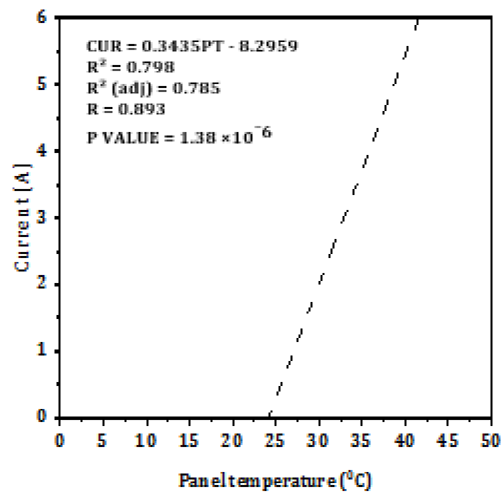

Fig 7: Current generated by photovoltaic module with varying panel temperature

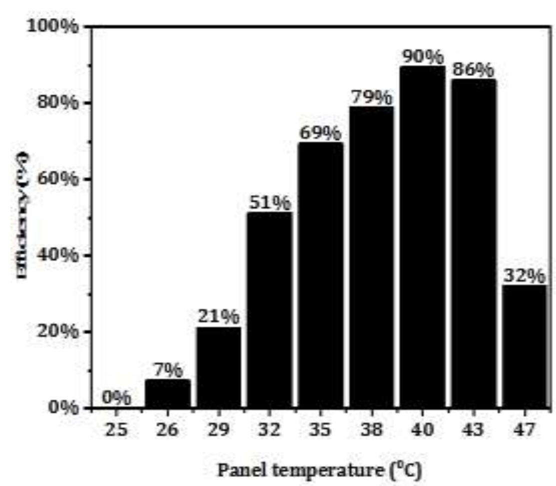

Fig 8: Efficiency of the photovoltaic module with varying panel temperature

Influence of solar power on the performance of the PV module: Fig 9 displays the voltage produced by the photovoltaic module with increasing solar power. The figure reveals that the voltage produced by the photovoltaic module increases as the solar power increases from 0 to approximately 200W/m^2. Above 200W/m^2 the voltage produced remains fairly stable and close to the maximum voltage that could be generated by the module regardless of how high the solar power reaching the photovoltaic module is. This shows that even as early as 8:30am maximum voltage could be expected from the photovoltaic module at the location of study as shown in fig 12.

Fig 10 shows the effect of solar power on the current generated by the photovoltaic module. The figure reveals a very strong positive (uphill) linear relationship between solar power and current. This very strong positive linear relationship unravels that the more the solar power reaching the photovoltaic module the greater the current generated by the photovoltaic module which corresponds to our statistical correlation, which further confirms that a linear relationship exist between the solar power reaching a photovoltaic module and the current generated by the module. Fig 11 depicts the efficiency of the photovoltaic module with increasing solar power. The figure shows a very strong positive linear relationship between the efficiency of the photovoltaic module and solar power which indicates that the higher the amount of solar power reaching the photovoltaic module the higher the efficiency attained by the module, which corresponds to our statistical correlation. This positive effect of solar power on the efficiency is as a result of the favorable effect that increasing solar power has on current as shown in fig 10. Fig 9, 10 and 11 agrees with earlier research by (Njok et al., 2020c).

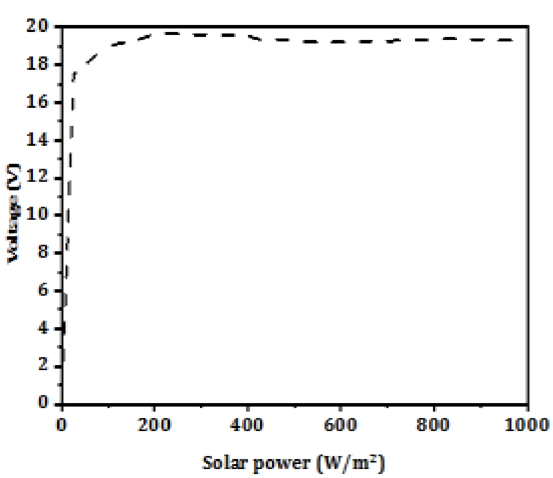

Fig 9: Voltage produced by the photovoltaic module with increasing solar power

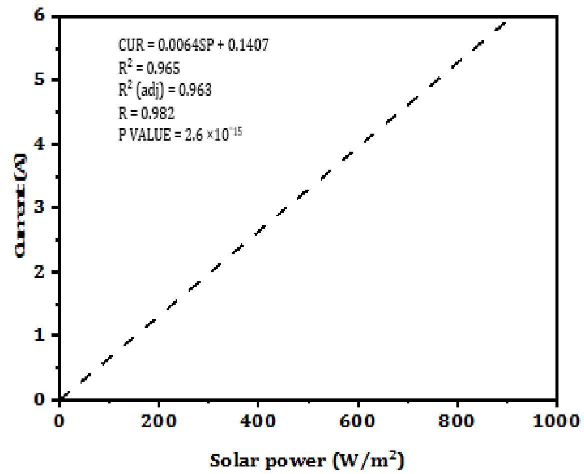

Fig 10: Current generated by the photovoltaic module with increasing solar power

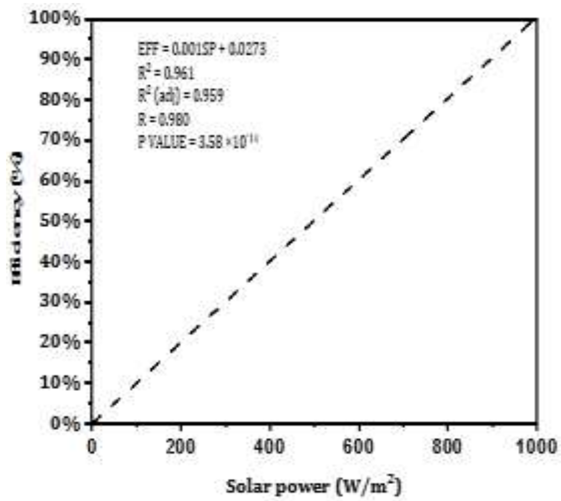

Fig 11: Efficiency of the photovoltaic module with increasing solar power

Details of our study location divulges that it is 85m above sea level which makes it relatively favorable for receiving intense solar radiation. Moreover, as early as 9:00am the solar power level is close to 800W/m^2 as evident from Fig 12 which implies that the PV module efficiency should be at a level above 70% as portrayed in Fig 11.

Diurnal analysis of meteorological parameters at study location: Fig 12 displays the variation in the meteorological parameters throughout daytime for the study location. It reveals that the highest level of solar power should be expected at 12 noon which implies that the maximum efficiency of PV modules should be expected at this time. It also reveals that as early as 8:30am the solar power will be above 200W/m^2 which is the level of solar power required by the photovoltaic module to generate voltage close to the maximum module voltage. The figure also reveals that the highest panel temperature and lowest relative humidity level should be expected at 1:00pm which indicates the panel temperature might exceed the maximum operating cell temperature at this time. Hence drop in efficiency should be expected.

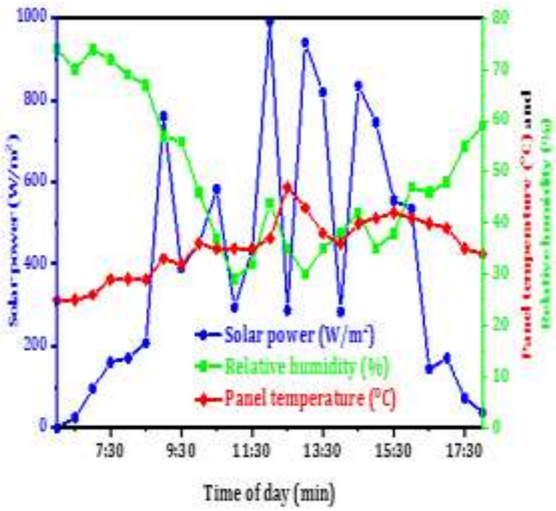

Fig 12: Meteorological parameter at each time of day

Conclusions: For the PV module to give out its maximum current and power, the relative humidity level has to drop down to a level close to 20% which is possible in the month of January. But due to the erratic drop in voltage below 47%, 100% efficiency from the PV module may be out of reach. However, results also revealed that on the average the panel temperature will rarely exceed 40^0C for months besides January. Hence, 90% efficiency from PV modules could be assured. Moreover, with an altitude of 85m above sea level which makes it relatively favorable for receiving intense solar radiation, makes the location a good site for the installation of solar farms.

Abbreviations

PV: Photovoltaic
V_{mp}: Voltage at maximum power
I_{mp}: Current at maximum power
P_{mp}: Power at maximum power
P_{mea}: Measured power
P_{max}: Power at STC
MPPT: Maximum power point tracker
STC: Standard test condition
POW: Power
CUR: Current
EFF: Efficiency
SP: Solar power
RH: Relative humidity
PT: Panel temperature

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