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PERFORMANCE EVALUATION OF SOLAR PHOTOVOLTAIC PANEL MOUNTED ON SLOPED CORRUGATED METAL SHEET ROOF IN KANO STATE NORTHWEST NIGERIA

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ABSTRACT

Installation of solar photovoltaic system on roof has advantages of proper utilization of space, help in avoiding shading effects and reduction of dust accumulation on the panels. However, electrical efficiency and lifespan of solar photovoltaic panel tends to decrease due to the increase in surface temperature above the operation temperature of the panels due to its contact with the roofing sheets. The performance of solar photovoltaic panels was experimentally investigated on corrugated metal sheet (CMS) roof at four different heights (0, 100, 200, and 300mm). Four polycrystalline silicon photovoltaic panels of 10 watts each were selected from the same manufacturer. The temperatures on the roof and on the photovoltaic panels' surfaces were measured at different solar hours. Also, the outputs of the solar panels together with the irradiance available were measured at same hours using an electronic data logger and imported to an Excel software. Irradiance variation, gap between roof and photovoltaic panels, and heating effect on panels were found to be the parameters affecting the photovoltaic system's performance. The highest temperature attained by the photovoltaic panel is when it was directly mounted on the roof as 76.5°C while the other photovoltaic panels mounted at a gap height of 100mm, 200mm and 300mm attained the highest temperature of 71.8°C, 69,6°C and 68.0°C respectively. The panels' extra heat was originating from CMS roof vicinity. Output powers from the panels were unequal throughout the experiment whilst exhibited similar behavior. The panels' temperature dropped by 4.7 – 8.5°C while output power increased by an average of 1.19, 3.05 and 4.65% when the gap extended from 0 – 300mm.

Keywords: Photovoltaic System, Corrugated Metal Sheet Roof, Photovoltaic Panel, Solar Radiation, Power Output

INTRODUCTION

Energy is an important factor for economic, industrial and social development. Energy is an integral part of our lives and it has to be available and accessible, because the humans' activities at domestic and industrial levels depends largely on it. It's among the objectives of energy system to provide energy services to humans, ranging from domestic cooling, heating, and lighting to industrial processes such as manufacturing and construction (Abdullahi, 2015). currently, the most useful and available renewable energy resources worldwide are those delivered through solar, wind, hydropower, biomass, geothermal, ocean tides and waves (Panwar et al., 2011; Deichmann et al., 2011; Ellabban & Blaabjerg, 2014; Nickson et al., 2019). Solar energy is the most promising, non-exhaustible and most exploitable in the most part of the world compares to the other renewable energy sources due to its advantages of high potential applications in remote area, having no or less maintenance cost, and enormous quality of solar energy received per hour (Abdullahi et al., 2017), but the main issue in the developing of solar technology is the low efficiency which leads to high cost (Tukur, 2014; Ogheneruona et al., 2021).

Photovoltaics is a process of converting radiant energy, especially light, into electricity using semiconductors that exhibit the photovoltaic effect. A practical example of photovoltaic power generation is the solar photovoltaic panel. The efficiency of a solar photovoltaic panel is affected by irradiation and panel surface temperature. As the solar radiation rises, so does the cell temperature, and as a result, the cell materials lose their efficiency (Zaidi, 2018; Nickson et al., 2019; Amelia et al., 2016; Chander et al., 2015; Kaldellis et al., 2014; Tyagi et al., 2013;). Solar radiation is the key driving force in ecological process and is often an important ecological parameter (Abdurrahman et al., 2019). Under standard test conditions (irradiance of 1000 W/m², air mass of 1.5, and a temperature of 25°C), the conversion efficiency of the photovoltaic panel is reported to decrease by about 0.40% to 0.50%/^{0}C. (Nickson et al., 2019; Natarajan et al., 2011).

Nigeria is a sub-Saharan African country situated between latitudes 4°N and 14°N and longitudes 2°E and 15°E, with a total area of 9.23 x 10^{11} m^2 and a population of over 120 million according to the 2006 National Census with electricity supply mostly below 4,000 MW (Abdullahi, 2015). Since the introduction of electricity in Lagos in 1896, its demand has been increasing with the population growth, while its development has been slow (Oji et al., 2012). Only 10% of rural households and 30% of the total population have access to electricity (Onabote et al., 2021; Charles, 2014) forcing most households (70-80%) (Abdullahi, 2015) to rely on wood for their energy needs. Kano state (located at 12.05°N, 8.52°E) has high solar radiation, reaching up to a maximum of 26.78 MJ/m2.day (7.44 kWh/m2.day) (Abdullahi, 2015), and benefits from high average daylight and sunshine hours. Despite the energy challenges facing this agricultural state, the penetration of solar technology is still at an infant stage due to the problems mentioned above. Nowadays, most photovoltaic panels are being installed on sloped CMS roof for maximum capture of solar radiation. Installation of solar photovoltaic system on roof has advantages of proper utilization of space, help in avoiding shading effects and reduction of dust accumulation on the panels. However, electrical efficiency and lifespan of solar photovoltaic panel tends to decrease due to the increase in surface temperature above the operation temperature of the panels due to its contact with the roofing sheets. Currently, there is no report on the best height for the installation of photovoltaic systems on CMS roof in Kano State.

The effect of temperature coefficients on monocrystalline silicon photovoltaic module installed in Kumasi, Ghana by cooling the module to a temperature between 10°C – 15°C in a cooling chamber, covered with cardboard paper before the outdoor electrical testing using Dayster I-V curve tracer was investigated by (Takyi & Nyarko, 2020). The result shows that as temperature increases, output power (P_{max}), and open circuit voltage (V_{OC}) also decreases, whilst short circuit current (I_{SC}) increases slightly. A research on outdoor performance analysis of polycrystalline silicon solar panel mounted on sloped CMS roof by selecting three different polycrystalline silicon panels of 100watts from different manufacturers in local market was conducted by (Nickson et al., 2019). It was observed that the highest temperature attained by the photovoltaic panel when it was directly mounted on the roof was 74.5^0C. By varying the gap between photovoltaic panels and the roof at irradiance of 820±10W/m^2, it was found that the photovoltaics' temperature dropped by 5 – 9^0C while output power increased by 5 – 11% when the gap expanded from 0 – 500mm. (Lim et al., 2013) investigated the effect of temperature on PV panel output and concluded that output decreases by 0.469 %/°C with the temperature variation when other factors are controlled. The aim of this research is to evaluate the performance of solar photovoltaic panels mounted on sloped CMS roof in Kano state Northwest Nigeria.

MATERIALS AND METHODS

Materials

Four polycrystalline silicon solar photovoltaic panels of the same manufacturer were used, corrugated metal roofing sheet (Zinc) 720 x 2200mm, roofing stand (hollow section mild steel) and photovoltaic panels holder (angle iron) were used to developed the roof on the ground to accommodate the panels, current, voltage and temperature sensors were attached to the panels with aid of masking tape and gum.

Measuring Instrument

i. **Radiation Pyranometer:** This device is used for measuring available solar radiation and was used to calibrate the light radiation detector (LRD) in the electronic data logger for accurate measurements. It was found that there is not much variation in solar radiation between these two devices for all of the panels that were set up.
ii. **Digital multimeter:** This device is used for measuring both current and voltage in a circuit and it was used to calibrate the current and voltage sensors in the electronic data logger to ensure accurate measurements. Negligible variation was noted between these devices.
iii. **Electronic Data logger:** This device is used to record all experimental readings. It is composed of an Arduino with six terminals to which thermistors, light radiation detectors, current sensors, voltage sensors, and a memory card are connected and programmed to record readings every minute from 9am to 5pm for a period of three months, from January 2022 to March 2022.

Experimental Procedure

Four panels' holders were constructed at different heights of installation (0, 100, 200, and 300 mm) to hold the panels on the sloped corrugated metal sheet (CMS) roof. The sloped CMS roof (720 x 2200 mm) was fixed to a stand made of hollow section mild steel. The solar photovoltaic panels, with specifications mentioned in Table 1 below, were mounted on the sloped CMS roof at a tilt angle of inclination equivalent to the latitude of Kano State (12.05°N) facing south to analyze their performance. An Electronic Data logger composed of measuring instruments such as thermistor, current sensor, voltage sensor, light radiation detector, etc., was connected to each photovoltaic panel using gum and masking tape, and readings of temperatures, voltages, currents, and solar radiations of each photovoltaic panel were recorded every minute from 9am to 5pm to the Electronic Data logger on a memory card for a period of three months (January 2022 to March 2022). The data was later imported into an Excel software on a personal computer from the memory card, and hourly averages were calculated. The data was analyzed, and graphs were plotted for different variables in Excel. The graphs of the variables were compared and used for discussion. The mean days of these months were considered for analysis of the data taken because mean day is a particular day of the month in which solar energy and its characteristics was best for that month, these mean days are 17th January, 2022, 16th February, 2022 and 16th March, 2022 respectively.

Table 1: Photovoltaic Panel Specification

Module types	Poly crystalline
Max power (W)	10
DC open circuit voltage (V)	21.8
DC max power current (V)	17.3
DC short circuit current (A)	0.64
Normal operating temperature (°C)	25
Panel size (L*W*H) mm	350*300*25
Life span (Years)	25

Plate 1: Experimental Setup

RESULTS AND DISCUSSION

The results in figures 1 to 3 show solar radiation (SR) against surface temperature (ST) for the photovoltaic panels mounted on the CMS roof at 0, 100, 200 and 300mm. It can be observed that as the SR increases, the ST of the photovoltaic panels also increases. This is because solar energy is composed of both lights, known as photons, and heat. The heat part of solar energy increases the photovoltaic panel's ST, which affects its performance coinciding with findings reported by (Nickson et al., 2019); with the growth of irradiance roof temperature and panel temperature were increased to 62^0C and 74.5^0C. It was also observed that the variation in the solar radiation captured on the surfaces of the photovoltaic panels was not significant, mostly 1 to 3 W/m^2 throughout the experiment. Furthermore, the highest solar radiation was obtained in March 2022, reaching 731W/m^2 at 12pm, while the lowest solar radiation was obtained in January 2022, at 235W/m^2 at 9am.

In addition, it was noted that the SR increased by an average of 0.23%, 0.46%, and 1.69% with an increase in the height of installation from 100mm to 200mm, and then to 300mm. This indicates that increasing the distance of installation does not have any effect on the SR captured by the photovoltaic panels. Furthermore, the highest roof temperature was recorded in March 2022 at 60.40°C. The highest panel surface temperatures were also achieved in March 2022 at 76.50°C, 71.80°C, 69.60°C, and 68.00°C as the height increased from 0mm to 300mm. The lowest panel temperature was attained in January 2022 on the panel mounted at 300mm from the roof, at 24.10°C.

The ST decreased by an average of 7.5%, 10.91%, and 13.19% when the photovoltaic panels were mounted at 100mm, 200mm, and 300mm from the CMS roof. This indicates that the ST of the panels decreased gradually as the height from the roof increased. The panel mounted at 300mm had the lowest ST, with the highest percentage decrease throughout the experiment, due to the cooling effect by convection between the photovoltaic panels and the CMS roof. This result indicates that the panel mounted directly on the roof experienced heat transfer by conduction from the roof vicinity. Similar observations was reported by (Kaldellis et al., 2014); that panels operates at different range of temperature whereas 70 °C was encountered and this remained due to poor cooling. Hence the increased ST affects the output performance of the photovoltaic panels compared to those mounted at a certain height from the roof.

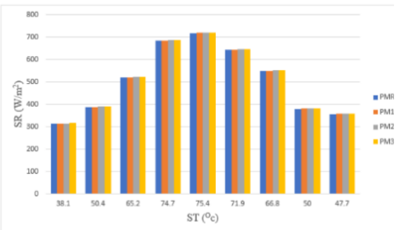

Figure 1: January, 2022 SR against ST

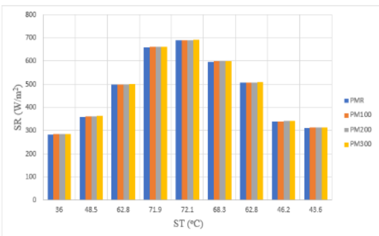

Figure 2: February, 2022 SR against ST

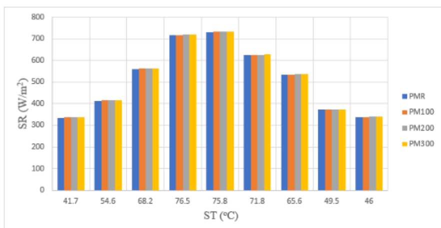

Figure 3: March, 2022 SR against ST

It can be observed from figures 4 to 6, which show open circuit voltage (V_{OC}) against ST, that the V_{OC} decreased with an increase in ST of the photovoltaic panels and increased with a decrease in ST. This indicates that V_{OC} is directly proportional to the ST of the photovoltaic panels and is affected by the rise of ST above the standard test condition of photovoltaic panels, as proved by many research works on photovoltaic systems. One of the reasons why open circuit voltage decreases when the surface temperature increases is that, when solar energy is incident on the surface of the photovoltaic panel, the electrons in the valence band gain sufficient thermal energy to jump to the conduction band. As the number of electrons in the conduction band increases, so does the conductivity of the material, and its resistivity decreases. From Ohm's law, voltage is directly proportional to resistance. Therefore, as the resistivity of the material decreases, its V_{OC} also decreases. An increase of V_{OC} was noted as the height of installation of the photovoltaic panels from the CMS roof increased. This implies that there was cooling by convection between the photovoltaic panels and the CMS roof, which decreased the ST of the mounted photovoltaic panels. Furthermore, the V_{OC} increased by an average of 1.8, 2.74, and 3.36% as the panel height of installation increased by 100, 200, and 300mm.

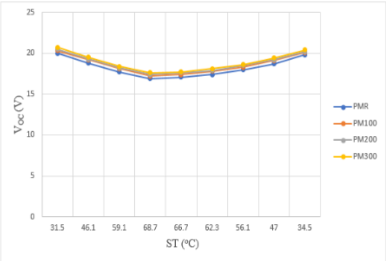

Figure 4: January, 2021 V_{OC} against ST

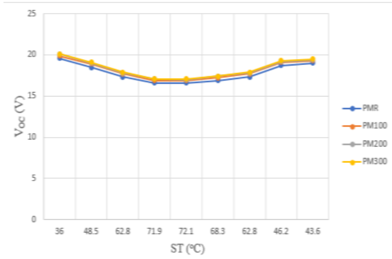

Figure 5: October, 2021 V_{OC} against ST

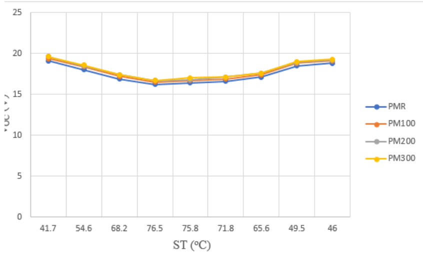

Figure 6: March, 2021 V_{OC} against ST

It can be discerned from figures 7 to 9 of short circuit current (I_{SC}) against SR that I_{SC} increases with an increase in SR captured by the photovoltaic panels. Likewise, a slight increase in I_{SC} was spotted as the ST of the photovoltaic panel increases. This designates that a rise of ST of the photovoltaic panel above the standard test condition does not affect the I_{SC} of the photovoltaic panels. Additionally, I_{SC} is directly proportional to the captured SR. It was also noticed that I_{SC} increased by an average of 0.15%, 0.44%, and 0.69% as the photovoltaic panels' height of installation from the CMS roof increases by 100, 200, and 300mm. This shows that increasing the installation height and the cooling by convection do not have any significant impact on the I_{SC}. The minimum and maximum SR produced the minimum and maximum I_{SC} recorded in all the months of the experimental research.

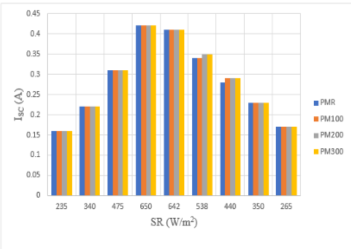

Figure 7: January, 2022 I_{SC} against SR

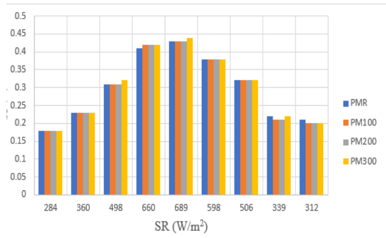

Figure 8: February, 2022 I_{SC} against SR

Figure 9: March, 2022 I_{SC} against SR

Figures 10 to 12 show that power output (PO) increases with time from before noon up to noon and then decreases in the afternoon throughout all the months of the experimental research. However, the rise of ST of the photovoltaic panels affected the expected PO because V_{OC} is directly proportional to PO and is affected by the rise of ST of the photovoltaic panels as similarly reported by (Chander et al., 2015; Tyagi et al., 2013) who revealed that with increased panel temperature; the short circuit currents increased whilst open circuit voltages, output power as well as efficiency declined. Furthermore, PO increased by an average of 1.19%, 3.05%, and 4.65% when the panels were mounted at a height of 100, 200, and 300mm from the CMS roof. These percentages indicate that the PO increases as the height of installation from the CMS roof increases. This is because the ST of the photovoltaic panels decreases with the increase of the height of installation, allowing cooling by convection to take place.

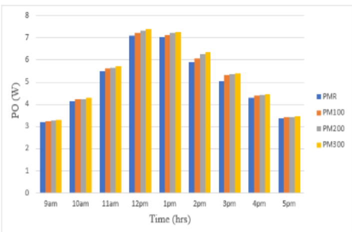

Figure 10: January, 2022 PO against Time

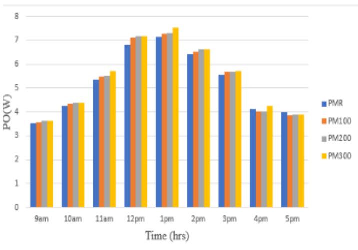

Figure 11: February, 2022 PO against Time

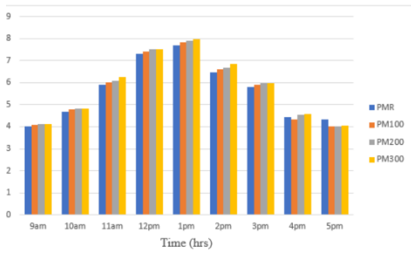

Figure 12: March, 2022 PO against Time

Cost Implication

The cost of the structure that supports the panel at the height of installation should be taken into consideration when deciding on the best height for installing photovoltaic panels. It is important to compare the cost of the structure with the power output improvement resulting from increasing the height of installation.

In order to evaluate this, table 2 below show the power output against the cost and the height of installation against the cost, respectively. It can be observed from the figures that as the height of installation increases, the power output also increases. However, as the height of installation increases, so does the cost of the added structure (photovoltaic panel's holder) on the CMS roof.

During the research study, the power output was improved by an average of 4.65% when the height of installation was increased to 300mm, which was found to be the best height of installation. Additionally, the surface temperature of the photovoltaic panel was decreased by 8.5°C with the increase in installation height.

Although an added structure comes with a cost, the total cost for the added structure, including both material and labor, was found to be only N950. This cost is relatively low compared to the significant improvement in power output and the reduction of the photovoltaic panel surface temperature.

The reduction in surface temperature can have a positive impact on the life span of the photovoltaic panels. Elevated temperature is known to contribute to degradation, wear, and tear of photovoltaic panels, which can reduce their useful life. By reducing the impact of elevated temperature, the life span of the photovoltaic panels can be increased.

Moreover, the improvement of power output by almost 5% is significant and can increase the useful performance of the photovoltaic panel. Therefore, the added structure is worth it, as it not only improves the power output of the panels but also reduces the negative impact of elevated temperature, ultimately contributing to an extended life span of the panels.

Table 2: Cost Implication of increasing Height of Installation on the Power Output

Height (mm)	Increased percentage of Power output (%)	Cost of panel's holder(N)
100	1.19	550
200	3.05	750
300	4.65	950

CONCLUSION

The three-month experiment research aimed to evaluate the performance of solar photovoltaic panel mounted on sloped CMS roof by varying the installation height has shown variations in the photovoltaic panel electrical parameters. Surface temperature of the photovoltaic panels increases with the increase of solar radiation, the highest roof temperature and panel ST was obtained in March, 2022 as 60.4^0C and 76.5^0C and the ST of the photovoltaic panel was decreased by an average of 7.5, 10.91 and 13.19% when the photovoltaic panels are mounted at 100mm, 200mm and 300mm from the roof. It was perceived that the variation of solar radiations capture by the photovoltaic panels is not significant, mostly 1 to $3W/m^2$ throughout the period of the experiment. The highest solar radiation was obtained in March, 2022 as $731W/m^2$ and the lowest was obtained in January, 2022 as $235W/m^2$ and also the solar radiation was increased with an average of 0.23, 0.46 and 1.69% with the increase of height of installation to 100mm, 200m and 300mm. Open circuit voltage was decreasing with the increase of ST. An increase of V_{OC} was noted as the height of the photovoltaic panels from the roof increases. Furthermore, open circuit voltage was increased by an average of 1.8, 2.74 and 3.36% as the height of installation increases from 0mm to 300mm. Short circuit current was increasing with increase of solar radiation and it slightly increases as the ST increases. The short circuit current was increased by an average of 0.15, 0.44 and 0.69% as the height of installation increases to 100mm, 200mm and 300mm. The expected power output was decreasing as the photovoltaic panels surface temperature rises. The power output was increased by an average of 1.19, 3.05 and 4.65% as the height of installation increases to 100mm, 200mm and 300mm.

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