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PERFORMANCE EVALUATION OF REFLECTORS AND COOLING SYSTEM ON PHOTOVOLTAIC SYSTEM IN KANO NORTHWEST NIGERIA

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ABSTRACT

In the effort to improve the efficiency of a photovoltaic system, previous studies have demonstrated the potential of solar reflectors and cooling systems to enhance the performance of Photovoltaic (PV) systems. However, Result varies from Location to Location and a limited research exists on their combined effect. This study investigates the impact of reflectors and cooling on PV system performance in Kano State, Nigeria. Three Experimental setup were tested; (a solar panel without any modifications (PWM), a solar panel with reflectors sides (PWR), and a solar panel with reflectors and a cooling system (PWRC)). These Experiment were set at the optimum tilt angle of 12° in Kano State, Nigeria. The results show that panel with reflectors and panel with reflectors and cooling system both increased the amount of solar radiation (SR) received by an average of 71.06% compared to the control panel system. The surface temperature (ST) of the PWR and PWRC increased by an average of 46.25% and 28.08%, respectively, compared to the PWM. The PWR and PWRC systems increased the amount of short-circuit current (ISC) produced in the panels with an average of 50.02% and 50.03%. The open-circuit voltage (VOC) drop of the panel in the PWR and PWRC systems decreased by an average of 9.91% and 4.39%, respectively, compare to the PWM system. The power output (PO) of the PWR and PWRC systems also increased by an average of 34.89% and 42.29%, respectively, compare to the PWM system.

Keywords: Photovoltaic system, Cooling system, Panel, Solar radiation, Power output

INTRODUCTION

Nigeria is located in the western part of Africa, with a bearing of 4°north and 13°north and a land size of 9.24×105 km2, however, these country is lucky to be located within the sunshine belt that receives the global radiation that varies from 3.5kWh/ (m2day) to 7kWh/ (m2day) from the southern too far northern part of the country (Abdullahi et al., 2017). It has the average sunshine hours of 6.25- ranges from 3.5 hours in the southern part of the Nigeria to 8.0 hours in the far northern part of the Nigeria (Abdullahi et al., 2017). According to a Global Energy Network Institute report, "If solar collectors/modules were used to cover 1% of Nigeria's land space, power up to 1850 ×1023 GWh of solar electricity will be generated per year. The solar is about 100 times the current grid electricity consumption level in the country" (Bamisile et al., 2017). Photovoltaic panels generate direct current (DC) current. With DC power, electrons flow in one direction around a system (Usman, 2022).

One of the challenges regarding PV system is the low energy generation and efficiency compared to the high cost of production, finding space to increased many panel purposely to generate large amount of electricity is becoming a problem due to size of the panel and security concern. This study aim to evaluate the performance of a reflectors and cooling system on a photovoltaic system in Kano state Nigeria.

Many researchers have made effort to improve the efficiency of PV panel by using reflective materials in other to increase the concentration of solar energy without even increasing the number of cells used (Bamisile et al., 2017). In the study of (Huq* et al., 2000) investigated the effect of flat reflectors on the performance of PV modules. During an experiment in Bangladesh, 40-Watt solar panels were compared with various types of solar reflectors, including panels with a shiny aluminum reflector, mirror reflector, and tiles reflector. The results showed that a shiny aluminum reflector led to a 30% increase in power output and a 7°C increase in system temperature (ST) compared to a simple panel. With mirror reflectors, power output increased by 33% and surface temperature increased by 6°-10° compared to the simple panel. With white tiles reflectors, power output increased by 16.12%, and surface temperature increased by 2-3% compared to the simple panel.

Rakino et al. (2019) reported that passive cooling system for increasing efficiency of panel PO. Water and a straight fin heat sink (SFHS) was used as the cooling medium, water passes through aluminum beam cuboid that was attached at the bottom of the panel (50W) and the SFHS are then attached to the cuboids to release heat to the air. This decrease the surface temperature of the panel by 21.66% in comparative with an ordinary panel. It was found that the VOC increase by 21.49% compare to the normal panel, hence PO increase by 40%.

Wang et al. (2020) reported on their study of the experimental and optical performances of a solar CPV device using a linear Fresnel reflector concentration, where by Monte Carlo Ray Tracing (MCRT) software is used to undergo simulation of solar concentration processes and a test rig of the linear Fresnel concentrator is developed. the finding shows that the test result of solar cell conversion efficiency under non concentration condition are 17.9% and 17.1% while for concentration condition are 14.7% and 13.6% which are both less than the parabolic v trough concentration test condition of (12.3% and 10.7%).

Rajagopal & Yadav (2020) reported in their study on cooling Techniques for Performance Improvement of PV Systems. Two types of cooling systems that include active and passive cooling systems. The active cooling systems yield better performance than that of the passive, this increase electrical efficiency with the maximum of 22% and reduces the panel temperature with maximum of 30°C. In the order hand, cooling systems that fall in the passive category, enhance electrical efficiency to 15.5% and we may see a reduction of 20 °C in the panel surface temperature. (Nader et al., 2020), on their study Assessment of Existing Photovoltaic System with Cooling and Cleaning System: Case Study at Al-Khobar City. The results found that for the Al-Khobar region, Eastern Province, Kingdom of Saudi Arabia, the Efficiency of the solar panels after cleaning was increased from 6% to an average of 12% at nominal temperature of 27 o C. moreover, the average power output was increased by 35% during the day Time. (Abizar & Nurtanto, 2021), on their studies to determines the effect of passive cooling for optimization of solar panel output. Where by two of solar panel (50W) with reflectors with and without cooling where used in Indonesia. It was found that the effect of cooling system increases the power output with average of 59.63 watt much greater than without cooling system that yield 47.68. It was also find out that both the panel with reflector produced greater average power output 25.07% than that of a simple panel. (Kim et al., 2021), on their study of an Optimal Design Strategy of a Solar Reflector Combining PV Panels to Improve Electricity Output: A Case Study in Calgary, Canada. Where polish aluminum was used as a solar reflector on a monocrystalline solar panel. Power output increased by 5.5% to 9.2% at the lower tilt angle and 12.1 to 21.1% at the higher tilt angles, when allowed to be tilt flexible at 15.5°. For 30° and 45° the average power output 4-8% , but when allowed to be flexible tilt angles the average power was found to be 17-23%. For 60° and 75° the average increase in power output is found to be 9-12%, but when allowing flexibility of the tilt angle the average power output is found to be 17.23%. The aim to this paper to determine the power output and operating temperature of a setup of a solar PV panel with reflector and cooling system.

MATERIALS AND METHOD

Three polycrystalline PV panels of 10W were used in the latitude of Kano State. The panels electrical characteristics at the standard test condition is in table 1 below. The experimental samples were kept in an open space at centered city of Kano state. Reflective foil with 98% reflectivity was used

Table 1: Electric data specification of the module

panel types	Polycrystalline
Maximum power (W)	10
DC open circuit voltage (V)	21.8
DC max power current (V)	17.3
Operating Temperature (º C)	25
Panel size (L*W*H)mm	350*300*25
Life span (Years)	25

Design of Solar Reflector

Considering a panel with tilt angle of β with two reflectors attached to it as shown in figure 1 below.

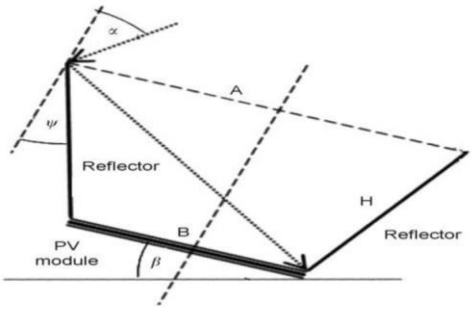

Figure 1: Free body diagram of panel with two reflectors

From the given equations (Burkhard et al., 1978)

$$C = \frac{D}{D_O} = \frac{\sin((2N+1)\alpha+\gamma)}{\sin(\alpha+\gamma)} \quad (1)$$

And

$$\frac{L}{D_O} = \frac{\sin((2N+1)\alpha+\gamma) - \sin(\alpha+\gamma)}{2\sin(\alpha+\gamma)\sin\alpha} \quad (2)$$

At γ = 0 (radiation falling normal to the aperture area), Chosen concentration ratio equals to 2, α equal to 30º and γ = 0 (radiation falling normal to the aperture area), D_O=30 cm.

The optimum length of reflector equals to 35cm

Design of Cooling System

An S-shape copper pipe is fixed at the bottom of the solar panel as shown below, these allow water to pass through it and exchange heat with the panel as shown in plate 1 below. Two valves were used to control the flow of water through the pipe. Other materials such as seal tape, tunnel, and gum were used to make sure it was well fixed and operate efficiently.

Plate 1: The Panel without modification (PWM)

Measuring Instruments

The measuring instruments used in the experiment are as follows:

i. Electronic data logger: this is an electronic device that was used to collect data each and every one minute of Temperatures, radiation, voltage and current.
ii. Thermocouple k type: was used to measure the panel temperature and water temperature
iii. Dynalab radiation pyranometer: was used to measure solar radiation falling on a panel
iv. DC Voltmeter and Ammeter: were used to measure voltage drop and current flow in the system

Experimental Procedure

The experimental samples of PWR, PWRC, and PWM were secured on a stand at the Oriental Hospital building in Kano State, Nigeria, as depicted in Plate 2. The samples were positioned at 50 cm intervals from one another. An electronic data logger, powered by a separate two-panel setup consisting of a battery and a charge controller, was utilized to measure the ST, VOC, and ISC of each sample.

In the case of PWRC, water was allowed to flow through a rubber pipe and pass through an S-shaped copper pipe to exchange heat with the panel. The water was refilled daily throughout the duration of the experiment, which lasted for three months (from January to March).

Plate 2: Experimental samples during taking reading at oriental hospital

RESULTS AND DISCUSSION

The results in figures 2 to 4 shows the radiation of PWR, PWRC, and PWM with time. The month of March 2022 recorded the highest SR captured by both the PWR, PWRC, and PWM, followed by February 2022, and January 2022, which will be due to the change of seasons in a year. The months of January 2022, and February 2022 happen to be in the cold season where clouds, air, and dust block some amount of global radiation received in the area. The maximum SR found in the hot season, which is in the month of March 2022, captured by the PWR, PWRC, and PWM, is 731, 1250, and 1251 W/m^2day. The SR of the PWR and PWRC increased with an average of 71.06% in comparison with the PWM

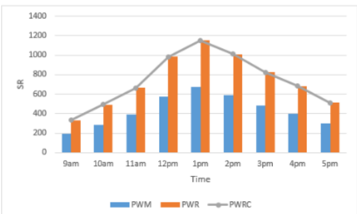

Figure 2: SR against Time in January

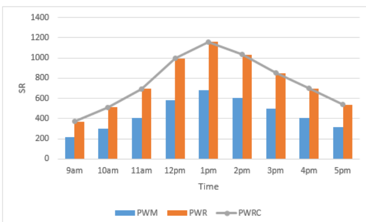

Figure 3: SR against Time in February

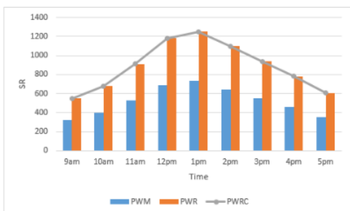

Figure 3: SR against Time in March

However, the ST of the PWR, PWRC, and PWM against SR, as described in figures 5 to 7 shows how the surface temperature of the panel relates to SR. At any point in time of a given day, peak ST is obtained where the SR is at its maximum on both PWR, PWRC, and PWM, and vise vasa. Like the SR, the month of March records the peak surface temperature, followed by February 2022, and January 2022, respectively, for both PWR, PWRC, and PWM. This shows how increased in SR directly affect the normal operating temperature.

The ST of the PWR and PWRC increased by an average of 46.25% and 28.08%, respectively, in comparison with the PWM. The maximum surface temperature obtained on PWR and PWRC was found to be 96.9°C and 79.5°C, which is higher than that of PWM, at 64.2°C.

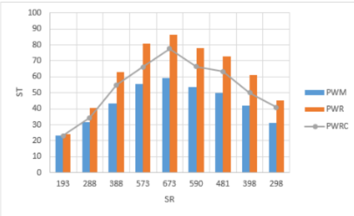

Figure 5: SR against ST in January

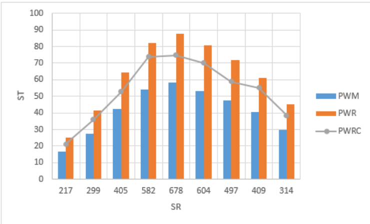

Figure 6: SR against ST in February

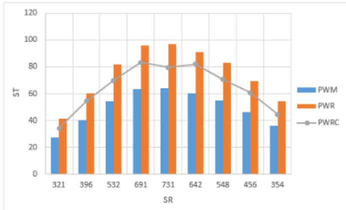

Figure 7: SR against ST in March

Considering the V_{OC}, figures 8 to 10 of V_{OC} against surface temperature shows how surface temperature affects the V_{OC} of the system. Similar research has been done on the effect of improving the performance of a panel by regulating its surface temperature with and without reflectors, as shown in the literature review. Researchers found that a rise in ST of a panel above the standard test condition of the panel decreased the V_{OC} of the system (Abdullahi et al., 2017; Abizar & Nurtanto, 2021; Elbakheit et al., 2022; Huq* et al., 2000; Wang et al., 2020) The maximum surface temperature of the PWR, PWRC, and PWM, at 96.9°C, 70.6°C, and 64.7°C, respectively, produced the minimum V_{OC} of 17.1V, 11.5V, and 16.8V. This clearly indicates that concentrating SR on a panel will not directly decrease the V_{OC} of a system if a proper and effective cooling system is used to regulate the surface temperature of a panel to its standard. The V_{OC} of the PWR and PWRC decreased by an average of 9.91% and 4.39%, respectively, in comparison with the PWM.

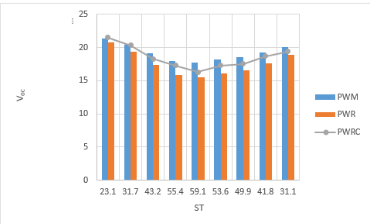

Figure 8: V_{oc} against ST in January

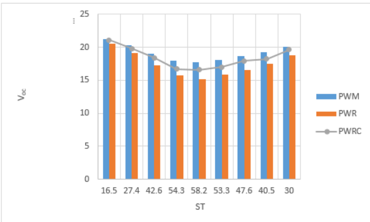

Figure 9: V_{oc} against ST in February

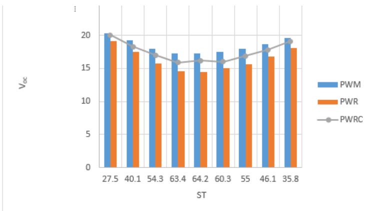

Figure 10: V_{oc} against ST in March

By analyzing the results in figures 11 to 13 of I_{SC} against SR together to observe the current flow in the PWR, PWRC, and PWM, the amount of I_{SC} flow in PWR and PWRC increased by an average of 50.02% and 50.03%, respectively, in comparison with the PWM. Despite the use of a cooling system on the PWRC, the current flow in the system is approximately equal to that of the PWR. This shows that a cooling system has no effect on the amount of current flow in a system. The maximum Isc produced on PWR and PWRC was found to be the same, at 0.71A, which is higher than that of PWM at 0.46A. Also the results show that the higher the panel captures SR, the higher the amount of current flow in the system vice versa. The minimum and maximum current produced in the systems is when the SR is at its minimum and maximum in all the months of the experiments.

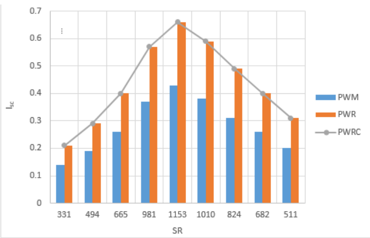

Figure 11: I_{SC} against SR in January

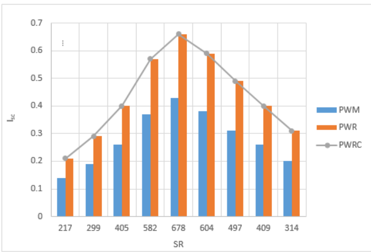

Figure 12: I_{SC} against SR in February

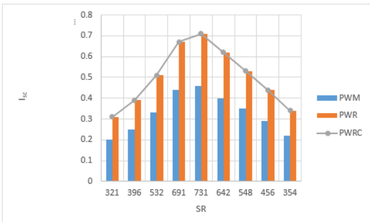

Figure 13: I_{SC} against SR in March

Since both PWR and PWRC have an impact on the V_{OC} and I_{SC}, of a solar panel, the overall power output (PO), which is the product of V_{OC} and I_{SC}, will also vary. Figures 14 to 16 illustrate the temperature against time results for PWRC, PWR, and PWM. These figures demonstrate that both PWR and PWRC enhance the PO of the solar panel. Compared to PWM, the PO of PWR and PWRC exhibited an average increase of 34.89% and 41.29%, respectively. The maximum PO achieved for PWR was 10.295W, while PWRC reached a maximum PO of 11.502W. In contrast, PWM had a maximum PO of 7.912W, which is lower than both PWR and PWRC

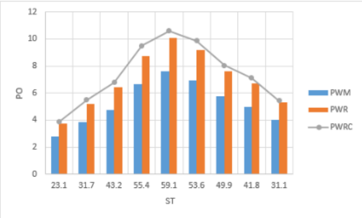

Figure 14: PO against ST in January

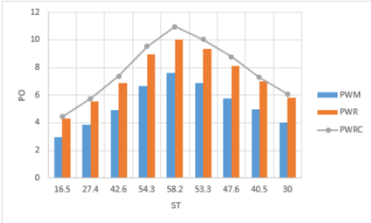

Figure 15: PO against ST in February

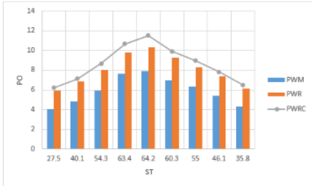

Figure 16: PO against ST in March

Despite the improvement in the power output of a panel, if the voltage drop in the system is low, it may affect many appliances. Appliances that operate at a higher voltage than the available voltage in the system may not work, and some appliances may not function well due to the designated minimum voltage required for them to work not being achieved. Moreover, even the devices that can operate at low voltage but require more than the available voltage to start will not work.

CONCLUSION

The three-month experiment aimed to determine the effect of light concentration using a reflector and the impact of cooling on the solar panel. This produced many changes in the electrical and heat parameters of the panels. The PWR and PWRC systems increased the amount of solar radiation (SR) received on the panel with an average of 71.06% compared to the PWM system. The experimental and simulation results decreased the surface temperature (ST) of the panels. The ST of the PWR and PWRC (experimental) systems increased by an average of 46.25% and 28.08% compared to the PWM system. The PWR and PWRC systems increased the amount of short-circuit current (ISC) produced in the panels with an average of 50.02% and 50.03%, respectively, compared to the PMW. The open-circuit voltage (VOC) drop of the panel in the PWR and PWRC systems decreased by an average of 9.91% and 4.39%, respectively, compared to the PWM system. The power output (PO) of the PWR and PWRC systems also increased by an average of 34.89% and 42.29%, respectively, compared to the PWM system.

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