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Evaluation of the Performance of Photovoltaic System under different Wavelengths from Artificial Light in a Controlled Environment

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ABSTRACT: Photovoltaics cell behave in a unique way when light falls on it. The objective of this work is to evaluate the performance of photovoltaic system under different wavelengths from artificial light in a controlled environment. Measurements were first taken from the PV module in the absence of the filters, followed by each filter been placed individually and measurement taken correspondingly. From the results obtained the PV module was most efficient when the yellow colored filter was employed and least efficient with the blue filter (revealing a difference of 2% in efficiency between them). Nevertheless, the photovoltaic module surpassed the efficiencies reached with the application of the colored filters when left open to the natural spectrum.

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Solar photovoltaic (PV) energy is a renewable source of energy which is among the fastest growing energy resource in the world, which has shown increased growth recently as researchers continue to improve its efficiency and lower cost of production (Njok *et al*., 2020a). These facts have made solar photovoltaic (PV) energy to be seen as a viable alternative for energy production coupled with the benefit of no gas emission. Blistering attention is now been given to solar energy due to the fact that monstrous focus is now on renewable energy (Kamgba et al., 2017). Exhaustive efforts are now geared toward improving PV cell efficiency, reduce the cost of PV cell production and also bridge the gap between conventional electricity methods and photovoltaics (Njok and Ogbulezie, 2018). Solar PV systems have shown exponential growth in terms of development since the early 2000s (Garfi *et al*., 2019). Unfortunately, the characteristics of solar cells greatly rely on environmental and ecological parameters like humidity, temperature, and irradiance (Kamalakkannan and Kirubakaran, 2019). Solar modules are designed, simulated, manufactured, and tested based on standard test conditions (STC): air mass of 1.5, the ambient temperature of 25^{0}C, and solar irradiance of 1000W/m^2. Consequently, it is of great importance for it to be noted that PV performance under our living environmental conditions differs from laboratory conditions (Sabri *et al*., 2018). Rawat (2017) showed that more electrical output was generated upon the exposure of a solar panel to red light. Abdulmunem *et al*., (2018) reported that the red colored filter produced the highest PV panel temperature when compared with other filters. Khokhar and Nandal (2017) carried out a thorough analysis on the performance of polycrystalline solar panels under different temperatures using colored filters. They found that upon exposure of the panel to the natural spectrum, the panel output exceeded those of the colored light. Whereas, among the colored filters used, red color produced higher electricity than other colors. Gouvea *et al*., (2017) disclosed that photovoltaic technology using crystalline silicon displays a non-uniform response to solar radiation. Joshi *et al*., (2012) concluded that present PV technology is influenced by wavelengths in the red

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band of light. Emetere and Adeyemo (2019) reported that bio-filters are very useful in enabling monocrystalline and polycrystalline PV panels to increase their voltage output above 10%. They also reported that the bio-filter was helpful in screening the harmful spectra while allowing the panels to function at an optimized state. The results of Soman and Antony (2019) displayed the power conversion efficiencies of colored photovoltaic cells, which revealed that the RGB colors and white has a relative power conversion efficiency of 70-80% and 59% respectively. Ji *et al*., (2019) discovered that vivid colors could be used as protection against moisture and ultraviolet radiation, mainly when applied in the decoration of perovskite and OPVs solar cells. Radiation reaching the earth from the sun has a varied spectrum of wavelengths. When light (natural or artificial) strikes a solar cell, there is loss of efficiency because the light is either too energetic (light that possesses high energy beyond that required for the separation of electrons from bonds) or not energetic enough (light that possesses energy not sufficient for the separation of electrons from their bonds) for the proper production of electron-hole pair. Losses associated with light having too high or too low energy arises in the process of the interaction of the light with a solar cell. At an energy level that matches that of the material used in manufacturing the solar cell, light can free electrons from their atomic bonds instead of causing the bonds only to vibrate. Each material used in the manufacturing of solar cells has its own characteristic energy at which electrons are liberated. This characteristic energy is the energy of the band gap of the material, which is the separation between the conduction and valence bands. For silicon, the energy is 1.14 electron volts, for germanium its 0.67 electron volts, for gallium arsenide its 1.43 electron volts and 2.26 electron volts for gallium phosphide (Streetman and Banerjee, 2000). For boron in the intrinsic range, the band gap energy is 1.42 electron volts (Dietz and Herrmann, 1965) and 2.05 electron volts for single-layer black phosphorus (Liang *et al*., 2014). A handful of research exist on the performance of PV systems under different wavelengths of light, but very little information is available on how they perform in a controlled environment under artificial light. Therefore, the objective of this work is to evaluate the performance of photovoltaic system under different wavelengths from artificial light in a controlled environment.

MATERIALS AND METHOD

Materials: a polycrystalline photovoltaic module (model: AF-130W) manufactured by Africell solar with rated maximum power of 130W 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 generated by the photovoltaic module. A digital solar power meter of the model SM206 was used for monitoring the solar power, while a mastech digital solar flux light meter of the model MS6616 was also utilized for the careful observation of the solar flux. A solar box fitted with artificial light made of tungsten were used to simulate the sun and our natural environment. At the same time, colored filters were employed in the process of separating the simulated spectrum into distinct wavelengths. Inside the visible portion of the spectrum, violet is positioned at the high energy end while red is position at the low energy end, as shown in table 2.

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

Experimental setup: A solar box fitted with artificial light made of tungsten was built and put in a dark room, while the PV module was positioned facing the source of light inside the solar box. Connecting cables 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 can be seen from figure 1.

Measurement procedure: Data were obtained after 60 seconds from the time the solar panel was covered with a particular colored filter, and the light source switched on. In the process of obtaining data, the colored filters were placed apiece after data had been obtained from the photovoltaic module under the natural spectrum. Before the next filter was inserted into the solar box to cover the photovoltaic module, the temperature of the module was allowed to drop to room temperature (25^0C) before proceeding with the measurement. To further elaborate on the process of obtaining data, in the interval of 60 seconds, only one measurement is done. The photovoltaic module is covered with a particular colored filter and placed inside the solar box. Then the light is switched on, and measurements are taken after 60 seconds of the module being exposed to light. At the time of each measurement the module temperature is always at 27^0C. After data have been obtained, the light source is switched off and the photovoltaic module is cooled and its temperature allowed to drop to room temperature (25^0C) before the procedure is repeated with the next colored filter.

Data processing and measurements: the experiment was conducted in a controlled environment where the solar power and solar flux were measured and held constant. The instantaneous voltage V_{mp} and Current I_{mp} at maximum power under the controlled condition were measured and recorded. The open circuit voltage V_{oc}, V_{mp}, I_{mp} and P_{max} were measured directly with the aid of the smart panel MPPT tester. With the aid of digital solar power and digital solar flux (light) meter, the amount of irradiance (448W/m^2) and flux (4880Klux) inside the solar box were measured and held constant. In order to reduce uncertainty, the experiment was redone (10 times) and the average obtained. The presented methodology enables the photovoltaic module not to be influenced by any other wavelengths but one. Comparing with methodology presented in reference by (Kazem and Chaichan, 2016) and (Njok, *et al*., 2020c), there is a time lag in changing from one color filter to another and this time lag enables the photovoltaic module to absorb radiation from the natural spectrum which may influence the photovoltaic response to the next color filter. Hence the results obtained with this methodology tends to be free of any uncertainty that may have occurred due to the presence of time lags as noticed in referenced (Kazem and Chaichan, 2016) and (Njok, *et al*., 2020c). The efficiency of the PV module is greatly influenced by several parameters including design and maintenance of the module and solar power, and may be determined by (1) as shown by (Njok, *et al*., 2020b), while the normalized power output efficiency and performance ratio was computed by (2) and (3) respectively as shown by (Ogbulezie, *et al*., 2020).

Module efficiency:

$$\eta_{\text{mod}} = \frac{Power\ of\ photovoltaic\ module \times 100\%}{Area\ of\ photovoltaic\ module \times 1000W/m^2} \quad (1)$$

Normalized power output efficiency:

$$\eta_p = \frac{p_{mea}}{p_{max}} \times 100 \quad (2)$$

Performance ratio:

$$PR = \frac{P_{mea}/P_{max}}{E_{mea}/1000} \quad (3)$$

Where E_{mea} is the measured solar power reaching the photovoltaic module inside the solar box. While P_{max} and P_{mea} are the maximum power of the PV module at STC and that measured respectively.

Table 2: Light colors with corresponding wavelength and energy

Color	Frequency (THz)	Wavelength (nm)	Photon Energy (eV)
Violet	660 – 770	390 - 455	2.73 – 3.20
Blue	610 – 660	455 – 492	2.52 – 2.73
Indigo	670 – 710	420 – 450	2.77 – 2.94
Green	520 - 610	492 – 577	2.15 – 2.52
Yellow	500 – 520	577 – 597	2.07 – 2.15
Orange	480 – 500	597 – 622	1.99 – 2.07
Red	380 – 480	622 - 780	1.57 – 1.99

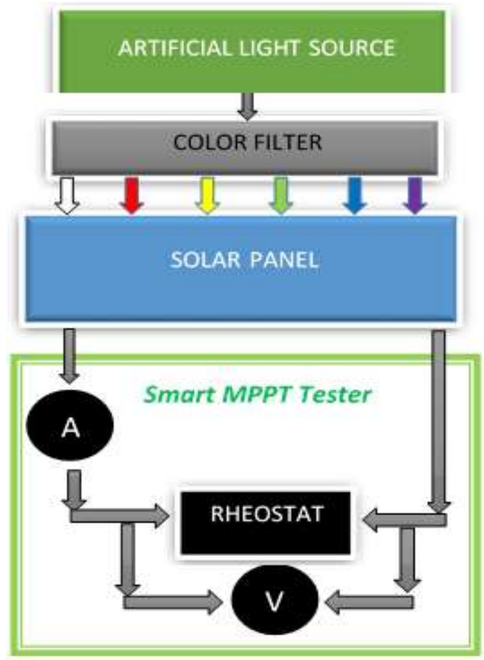

Fig 1: Experimental layout

Radiation can be pictured as a wave or as a particle called photon. The energy embedded in a single photon can be found through the relationship $E = hf$, as shown by (Young and Freedman, 2008). Where E is the energy in Joules (J), h is Planck's constant given as ($h = 6.626 \times 10^{-34}$Js), and f is the frequency of radiation in Hertz (Hz). The frequency f of a photon is related to its wavelength via $f = \frac{c}{\lambda}$. Where c is the speed of light given as (c = 2.998 $\times 10^8 \text{ms}^{-1}$). Through the above relationship, the energy that a single photon propagates with can also be computed with $E = \frac{hc}{\lambda}$, also shown by (Young and Freeman, 2008). The various wavelengths of light in the visible spectrum and their corresponding energy are shown in table 2. From table 2, it could be expected that the PV module should be more efficient under wavelengths ranging from red to yellow. This expectation is due to the energy band gaps of the materials that constitutes the PV module.

RESULTS AND DISCUSSIONS

This section displays data acquired from experimental measurement and analysis. 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 can generate under the solar power and solar flux level in the controlled environment. Figure 2 displays the voltage produced by the PV module with and without the application of the colored filters. It reveals that in the absence of the filters, the highest voltage (18.49V) was generated. However, in the presence of the filters, the highest voltage (18.30V) was generated by yellow, succeeded by violet, which was just slightly less than yellow with 18.29V. Red, green, and blue gave the same voltage of 18.26V. Figure 2 which confirms that the PV panel voltage output for the natural spectrum is the highest compared to other wavelengths, agrees with researches by (Kazem and Chaichan, 2016) and (Njok *et al*., 2020c). Figure 3 depicts the current produced by the PV module with different wavelengths of light. It is observed that yellow and green filters reached the same highest current value (1.04A), while blue produced the least current (0.90A).

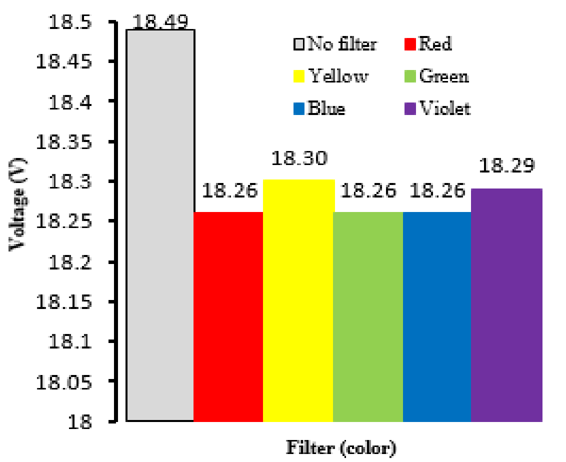

Fig 2: Voltage levels produced by the colored filters

However, without the filters, the PV module produced and exceeded current values produced by the filters, which still agrees with that by Njok et al. (Njok *et al*., 2020c). The level of efficiency of the photovoltaic module exposed to distinct wavelengths of light in the controlled environment is displayed in Figure 4.

It can be seen that the PV attained higher efficiency under the natural spectrum of the light source. However, with the application of the colored filters, the module reached its highest efficiency with the yellow filter (14.64%), and blue giving the least efficiency (12.64%); which is still in agreement with studies by Njok et al. (Njok *et al*., 2020c)**.**

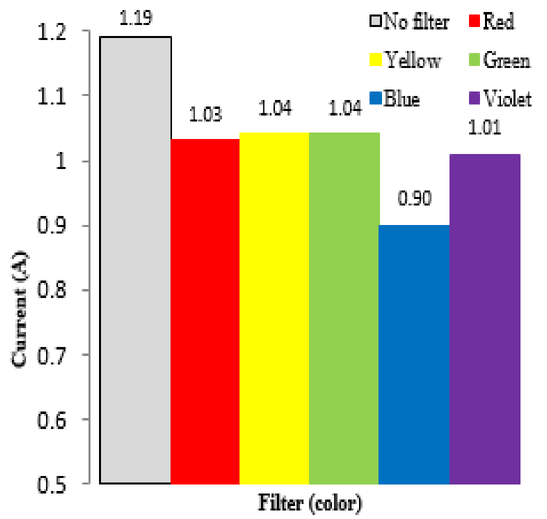

Fig 3: Current levels produced by the colored filters

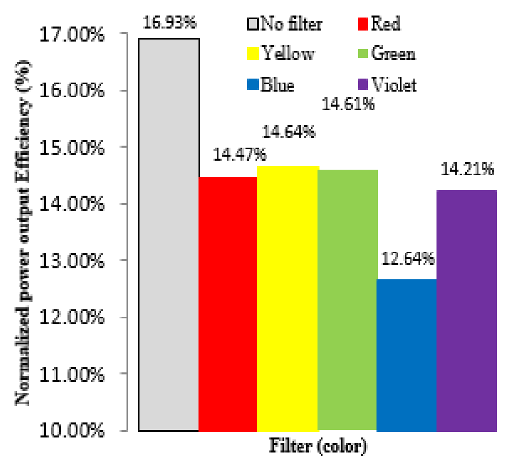

Fig 4: Efficiency reached by the photovoltaic module under the colored filters

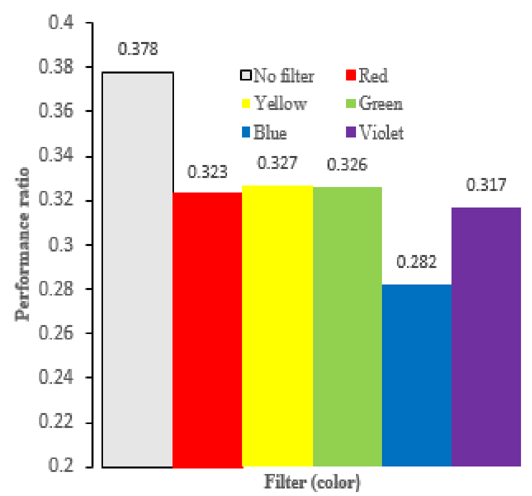

Fig 5: Performance ratio of the photovoltaic module under the colored filters

Figure 5 displays the performance of the PV module in the presence of the filters. It reveals that the PV module performs more under the yellow filter, and its least performance can be seen with the blue filter. However, under the natural spectrum, its performance exceeds those obtained with the colored filters.

Conclusions: In the controlled environment where the study was conducted, the PV module revealed better efficiency with the yellow filter, while the least efficiency of the module was observed with the blue filter (revealing a difference of 2% in efficiency between them). However, the PV module attained its highest efficiency under the natural spectrum of the light source. The result of this study reveals and further confirms that polycrystalline photovoltaic modules responds to artificial light in a way similar to when natural light from the sun falls on them.

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