Behavioural pattern of solar filter enhanced photovoltaics in mangrove swamp

ABSTRACT

Not all wavelengths incident on a solar cell enhances the efficiency of the cell. Some wavelengths only cause electrons to twist and vibrate in their bonds which heats up the cell and inevitably hinder its efficiency. To tackle this problem, solar cells need to be exposed to distinct wavelengths of light so as to ascertain those wavelengths that adversely affect its efficiency. This study is aimed at experimentally investigating the effect of solar power and solar flux on photovoltaic (PV) modules enhanced with solar filters. The objective includes to ascertain which filter triggered higher power and efficiency from PV modules. In achieving the objectives, color filters were employed for wavelength selection, an intelligent photovoltaic maximum power point tracker was employed to determine the maximum voltage, current and efficiency of the PV module at a particular level of solar power and solar flux, while solar power and solar flux meters were employed to track the amount of the transmitted solar power and solar flux reaching the surface of the PV module. The experimental measurements were conducted in outdoor real-time conditions with varying levels of solar power and solar flux. The results revealed points of voltage increase and points of voltage stability, and also revealed filters that attained voltage stability with relatively lower levels of solar power (400 W/m^2 for orange and blue filter) and solar flux (45 Klx for lemon filter). The results also reveal the module attaining a higher efficiency under the red filter as solar flux increases. In terms of solar power, the red filter and the natural spectrum led in power generation, but the natural spectrum triggered a higher efficiency from the module as solar power increases. This study proved that the nature and wavelength of the radiation reaching a photovoltaic module influences its behavior and efficiency.

Keywords: Solar Power, Solar Flux, Solar Filter, PV Module, Efficiency

1. INTRODUCTION

As humans become more sophisticated they have made energy to become an integral part of their daily lives, therefore its supply should be sustainable and safe [1]. Energy has now become the leading pillar for any country aspiring to increase its socio-economic and technical-industrial development. This is why the consumption of electrical energy in the world has been increasing for the last decade [2].

As the population of the world increases so is its energy requirements which puts enormous pressure on the conventional energy sources, hence the need for alternative energy sources which is capable of providing energy in a reliable manner. The clear and feasible alternative of a clean energy source which is capable of providing energy security for the future, couple with its abundance nature is the sun's energy [3].

The solar energy that reaches the surface of the earth originates from the energy of the sun. It is a renewable form of energy which is now among the fastest growing energy in the world couple with the fact that it is clean, noiseless, secure, pollution free and readily available during days of the year [4]. Technological development and effective methods of converting solar energy into electrical energy have been given serious attention due to global climate change coupled with the potential depletion of fossil reserves [5-6]. Fossil fuel contributes roughly 80% of the total energy consumed in the world today which also contributes significantly to global climate change [7]. Recently, solar energy has proven to be the easiest and readily available source of energy couple with its potential towards reducing the profound long-term threat of global carbon dioxide emission and climate change [8-9]. Application of renewable energy technology in converting other forms of energy into electrical energy is of immense value due to its minimal impact on environmental degradation [10]. Utilizing photovoltaic technologies for energy conversion possess triggers very little environmental challenges in comparison to conventional power generation sources such as fossil fuels [11]. Solar energy has been seen as feasible way out toward energy and global challenges [12]. At the moment the efficiency of photovoltaic system is approximated to lie between 7 and 40% [13-14]. The issues with PV efficiency is that energy is lost due to variations in sunlight, orientation, partial shading, pollen, and bird droplets [15]. Rigorous efforts are constantly made to improve efficiency and narrow the gap between photovoltaics and conventional methods of generating power such as steam and gas turbine power generators [16].

Photovoltaic system setup includes features such as module technology; charge controller technology, battery type and inverter topology. Irrespective of the above mentioned features, photovoltaic systems still encounter environmental factors (shading, temperature variations, dust accumulation, aging and availability/nature of radiation) which affect their overall performance [17]. Variations in climate play a vital role in sunlight availability which triggers variations in air temperature and inevitably panel temperature which ultimately affect the performance efficiency of the photovoltaic module. The emergence of solar tracking technology has to come to aid photovoltaic systems in capturing maximum solar irradiance which ultimately increases its power output as well as efficiency [18]. The nature of radiation being absorbed by a photovoltaic cell is among the factors that influence the performance efficiency of photovoltaic modules worldwide since solar flux and solar radiation are a determining factor when it comes to unraveling the potential of solar energy as a source of renewable energy [19].

When solar radiation reaches the surface of a photovoltaic module one of the three scenarios is bound to happen which is either the radiation may be absorbed, reflected or may pass through it. If the absorbed radiation possesses relatively low energy, the electrons will be force to vibrate within its mean position (bond) and unable to break free, they will give up the absorbed energy as heat in the process of falling back to their original lower energy level [20]. The heat released by the electrons inevitably increases the overall cell temperature which adversely affects its performance efficiency [20].

Africa as a whole and Nigeria in particular is blessed with an abundance of sunshine throughout the year, which is supposed to be one of the major reason why it should be an ideal environment for the effective performance of photovoltaics. But since the average daytime temperature of Nigeria is far above the standard test temperature of photovoltaic modules coupled with the fact that the performance efficiency of photovoltaic modules decreases by about 0.40%-0.50% for each degree rise in temperature [21], then it is of utmost importance that different methods have to be explored to enhanced the photovoltaic module in harvesting and converting the available solar radiation. Photovoltaic modules are designed and tested at STC, but when they are employed for domestic use in a particular area or atmosphere, environmental issues like solar power, solar flux and also the nature of radiation plays a vital role in influencing its performance efficiency. Since the intensity and the nature of radiation is changing then it follows that the energy produced by photovoltaic cells will also be changing. Meteorological parameters including solar power and solar flux are accepted as dependable renewable energy sources [22]. Among all the major meteorological parameters, only solar power, solar flux and nature of radiation have been considered for the present study.

In as much as the upgrading of PV cell design and fabrication is very important, the improvement of the overall performance of PV systems also carries the same importance [23]. Shading is a serious issue which hinders the performance of PV systems and so its effect cannot be ignored. Shading reduces the available solar radiation as well as the efficiency of PV systems, so a clear understanding of its effect on PV systems performance is very important because such knowledge can enable upgrading of its design, fabrication and efficiency [24]. Even if only a very small part of your PV module or array is shaded, its impact on the entire system can be huge. Unlike solar photovoltaic/thermal (PV/T) system in which if 5% of the module is shaded you lose just around 5% of the power produced. With PV systems, depending on the situation, even if only 5% of the PV module is shaded, you can lose up to 80% of power produced [25]. For this reason, it is pertinent that your PV module remains free from shade throughout daytime.

Shade comprises of two categories: hard shade and soft shade. Hard shade is an obstruction such as fallen leaves, bird droppings or a tree branch sitting on top of the glass that can completely obstruct light from reaching the solar cells. While a soft shade is a distant obstruction such as the diffused or dispersed shadow of a tree, adjacent building, towers, telephone poles or clouds which significantly reduces the amount of radiation reaching the solar cells [25]. When a PV module is soft shaded, there is always a significant reduction in energy produced. When it is hard shaded and partially covered, the energy produced will decrease to the same level as the affected cells: if the cells are hard shaded and completely covered, a complete power shutdown may be experienced.

The solar filters applied to the PV module for this study is neither viewed as a hard shade nor soft shade. When compared to hard shade, it does not completely stop radiation from reaching the cells. When compared to soft shade, though it decreases the amount of incident radiation, the decrease is intentional as it is a result of blocking, filtering or selecting a particular wavelength. Unlike soft shades that decreases the intensity of all the wavelengths incident on it in equal proportion, the solar filter grant access to the selected wavelength while offering great resistance (blocking or absorbing) to other wavelengths.

Kazem et al. [26] carried out detailed investigation on the effect of hard shade on the performance of polycrystalline PV modules. They revealed that huge amount of power loss was experienced when cells combined in parallel were covered by shade, while a relatively lower amount of power was lost when the shade only hover around cells connected in series.

Sai Krishna and Moger [27] worked on Reconfiguration strategies for reducing partial shading effects in photovoltaic arrays. They disclosed that the power generated by a PV module or array decreases considerably due to non-uniform irradiance. They further disclosed that the drop in the generated power is not directly proportional to the shaded area but depends on the shading pattern and array configuration.

El-Shaer et al. [28] studied the effect light intensity has on crystalline silicon modules and reported that the current parameter is the most influenced parameter of all the parameters of silicon modules. Joshi et al. [29] also reported that the red color of light significantly influences present-day photovoltaic technology. They also reported that the energy available on the surface of the PV/T system lies between the wavelengths of orange and red light. Ogherohwo et al. [30] still reported that the red color of light led to the production of more electricity from solar photovoltaic panel and recommended that the efficiency of photovoltaics might be enhanced if photovoltaics could be exposed to only red light. While Ali et al. [31] analyzed how the performance of a photovoltaic cell is influenced by the visible color spectrum and reported that the red color of light profoundly affects modern photovoltaic technology. The study also reveals that the energy of a PV system lies between the yellow and green color of light. Kazem and Chaichan [32] carried out a study on how the output parameters of a PV panel is influenced by colored filters and reported that the PV attained its highest efficiency when exposed to the natural spectrum. Tobnaghi and Naderi [33] concluded that solar cell performances are highly influenced by solar radiation. Rani et al. [34] revealed that the power output of a solar cell increases as the solar irradiance reaching the cells increases. Touati et al. [35] still reported that the power obtained from both monocrystalline and amorphous PV technologies increases linearly with the amount of radiation received.

Various studies exist on the effect of solar power and solar flux on the performance of photovoltaics, but a huge part of the information available is only valid for a specific location and does not cover photovoltaics enhanced with solar filters. Generally, there is little information on the effect of solar power and solar flux on photovoltaics for specific location in the mangrove swamp regions of Nigeria that can be effectively utilized for the design and sizing of photovoltaic modules. Solar filters are capable of ensuring that only a particular wavelength falls on the photovoltaic module, which enables the module to respond to a particular wavelength and also enable researchers in knowing which wavelength comes to heat up the module and decrease its performance efficiency or increase it.

The novelty of this study lies with the thorough investigation of the behavioral pattern of PV modules enhanced with solar filters in the mangrove swamp of Nigeria. While The study is aimed at experimentally investigating how the efficiency of PV modules could be optimized by enhancing PV modules with solar filters. While the objectives of the study have to do with revealing the behavioral pattern of solar filter enhanced photovoltaics in mangrove swamps of Nigeria and the level of efficiency attained by the PV module under each filter. In achieving its objectives, the study used filters whose wavelength can be found in the visible spectrum and also incorporated some color filters whose wavelengths are not in the standard wavelengths found in the visible spectrum. This study provides information which may enable users in manipulating the system in harvesting more current or voltage from photovoltaic modules.

2. MATERIALS AND METHODS

2.1 Materials Used in This Study

A monocrystalline photovoltaic module of the model AF-100 W manufactured by Africell solar with rated maximum power of 100 W was used in the study (D) as shown in figure 1: electrical characteristics of the module is shown in table 1. Figure 1 also displays other materials employed in the study which includes; a digital solar power meter of the model SM206 for monitoring the solar power (B), while a digital solar flux light meter of the model HS1010A was also utilized for the careful observation of the solar flux (C). Different colored filters were employed for wavelength selection (E), while a digital high precision photovoltaic smart panel maximum power point tracker (MPPT) tester of the model WS400A was used to determine the maximum power generated by the photovoltaic module (A).

TABLE 1: PV module technical characteristics

Electrical Specification	**Value**
Maximum Power	100 W
Current at Maximum Power	5.49 A
Voltage at Maximum Power	18.2 V
Short Circuit Current	6.59 A
Open-circuit Voltage	21.8 V
Number of cells	33
Nominal Operating Cell Temperature	47±2
Module dimension	1340 mm*540 mm*25 mm

Figure 1: materials used for the experimental setup

2.2 Experimental Setup

the experiment was carried out in an outdoor environment at the Cross River University of Technology (CRUTECH), Calabar (latitude $4^0 55' 43.6379''$ N and Longitude $8^0 19' 52.2361''$). The photovoltaic module was installed horizontally flat facing the sun on a platform 6m above sea level. Connecting cables were connected from the output of the photovoltaic module to the input of the photovoltaic smart panel MPP tracker from which the maximum power points where tracked and determined as can be seen from figure 2.

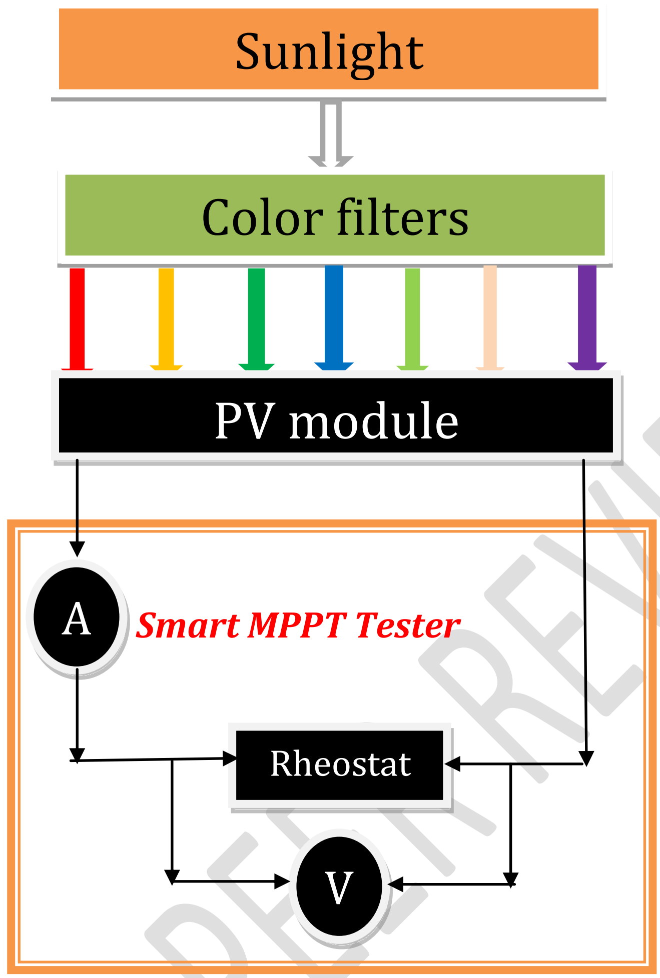


Figure 2: PV module experimental setup

2.3 Measurement procedure

Data was acquired from the photovoltaic module at an interval of 30 minutes from 8am to 4:30 pm for a period of 4months. During data acquisition, measurements were first taken without the filters, before each colored filter was placed one at a time. For each colored filter applied to the photovoltaic module, the transmitted solar power, solar flux and the maximum power that the PV module can deliver at that level of solar power and solar flux was measured.

Speaking of transmittance, the transmitted radiation (solar power and solar flux) was measured beneath the solar filters, which enabled us to ascertain the true value (amount) of radiation reaching the surface of the photovoltaic module. Other work related to this study measures the incident radiation reaching the surface of the solar filter and estimates the transmitted radiation via the formula for transmittance by considering the thickness of the filters. However, in our study, since the transmitted radiation is directly measured, the thickness of the filters is inconsequential, hence not captured in Table 1.

The transmittance property of the solar filter deteriorates with time due to constant usage, so physical inspection of the filters is done daily before measurement commences. Heat (high temperature of the PV module) causes irregularity in the thickness of the filters. Once this irregularity is observed the filter is replaced with a new one to ensure constant (same level or amount) transmitted radiation throughout the surface of the PV module.

2.4 Data processing and measurements

The experiment was conducted in real outdoor condition under varying levels of solar power and solar flux at a particular time every day. The transmitted solar power and solar flux were measured and recorded for each colored filter applied. The instantaneous voltage V_{mp} and Current I_{mp} at maximum power under a particular real-time 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 MPP tracker. The efficiency of the PV module is greatly influenced by several parameters including design and maintenance of the module and solar power (G), and may be determined by (1) as shown by [36], while the normalized power output efficiency was computed by (2) as shown by [37].

$$\eta = \frac{P_{max}}{G \times A} \quad (1)$$

$$\eta_P = \frac{P_{mea}}{P_{max}} \times 100 \quad (2)$$

Where A is the surface area of the PV module, while P_{max} and P_{mea} are the maximum power of the PV module at STC and that measured respectively.

2.5 Study location

Calabar which is our chosen mangrove swamp lies on latitude $4^0$57’06” N and longitude 8°19'19"E. It has an elevation of 32m above sea level and is the capital of Cross River State located in southern Nigeria. The dominant climate is a rare type of climate known as the tropical monsoon climate. It experiences precipitations almost throughout the entire year excluding the core months of the dry season which occurs in two short periods of January to March and October to December during a calendar year [38]. Rainfall is substantial in most months with the short dry season having little effect. In Calabar, it is hot and oppressive throughout the year, the raining season also known as the wet season is overcast, while the dry season is mostly cloudy. Throughout the year, the temperature ranges between 64^0F (17.78^0C) to 92^0F (33.33^0C) and rarely goes above 96^0F (35.56^0C) or below 58^0F (14.44^0C) [39]. The average percentage of the sky covered by clouds varies throughout the year. The part of the year with clear skies starts around November 25 and ends around February 15 with December being the clearest. While the part of the year with cloudier (unclear) skies starts around February 15 to November 25 with April being the cloudiest; in which 89% of the time the sky is cloudiest [39]. The length of daytime in Calabar varies very little throughout the year, staying within 24 minutes of 12 hours throughout. The longest day is June 21, with 12 hours, 25 minutes of daylight; the shortest day is December 21 with 11 hours, 50 minutes of daylight [39]. Calabar experiences significant seasonal variation in its average hourly wind speed. From May 23 to October 15 (4.7 months) is the windier part of the year with an average wind speed of more than 5.8 miles per hour, with August as the windiest month with an average hourly speed of 7.5 miles per hour. The calmer part of the year begins from October 15 to May 23 (7.3 months) with an average wind speed of less than 5.8 miles per hour, with December as the calmest month with an average hourly wind speed of 4.2 miles per hour [39]. The hottest month in Calabar is January, with a mean high temperature of 95.4^0F (35.2^0C) and a mean low temperature of 74.8^0F (23.8^0C), while the coldest month is August, with a mean high temperature of 82.9^0F (28.3^0C). However, the highest and lowest recorded temperature so far is 102^0F (38.9^0C) and 66^0F (18.9^0C) which were recorded in the months of January and April respectively [40]. The least humid month is January with a mean relative humidity of 69%, while July through September are the most humid months with a mean relative humidity of 87%. In regard to rainfall, December and July are the months having the least (13.5 days) and most rainfall (29.9 days) respectively [40]. In regard to sunshine hours, December (9.5 hours) is the month with the most sunshine, while August (4 hours) is the month with the least sunshine [40].

3. RESULTS AND DISCUSSION

This section presents data acquired from experimental measurement and analysis, it is divided into two parts. The first part is about the influence of solar power on the electrical parameters and efficiency of the filter enhanced PV module under different wavelengths of light which is displayed in figure 3. In the second part, analysis of results is given regarding how the electrical parameters and efficiency of the filter enhanced PV module under different wavelengths of light is influenced by solar flux shown in figure 4.

Table 2 and table 3 displays the summary of the transmitted solar power and solar flux reaching the photovoltaic module under the solar filters respectively. Table 4 to table 7 displays the summary of output electrical characteristics of the photovoltaic module under the solar filters.

Table 2: Uncertainty analysis of transmitted solar power (W/m^2) reaching PV module surface

Statistics	No filter	Red	Orange	Lemon	Green	Blue	Peach	Violet
Minimum	44.47	68.93	73.97	69.37	61.73	67.63	66.37	65.07
Maximum	1115	702.9	816.1	838.2	773.65	810.8	782.05	968.97
Mean	535.01	428.84	525.85	425.15	452.2	430.09	454.8	456.32
Median	541.55	396.9	511.9	459.2	462.7	328.8	427.4	501.88
Variance	80217.82	37931.89	96335	43007.59	43639.85	63528.93	53610.99	53146.88
Standard deviation	283.23	194.76	310.38	207.38	208.9	252.05	231.54	230.54
Standard error	64.98	44.68	71.21	47.58	47.92	57.82	53.12	52.89

Table 3: Uncertainty analysis of transmitted solar flux (Klux) reaching PV module surface

Statistics	No filter	Red	Orange	Lemon	Green	Blue	Peach	Violet
Minimum	5.78	6.07	7.73	7.47	7.63	7.53	6.93	7.03
Maximum	119.68	63.05	82.93	86.68	85.83	76.2	73.7	95.3
Mean	64.35	39.36	49.16	45.81	49.75	44.61	46.41	45.09
Median	69.33	33.83	51.12	46.45	52.6	37.2	46.53	52.3
Variance	1001.4	307.81	508.98	559.04	510	516.56	490.23	524.98
Standard deviation	31.65	17.55	22.56	23.64	22.58	22.73	22.14	22.91
Standard error	7.26	4.03	5.18	5.42	5.18	5.21	5.09	5.26

Table 4: Uncertainty analysis of voltage (V) generated by PV module

Statistics	No filter	Red	Orange	Lemon	Green	Blue	Peach	Violet
Minimum	11.39	11.18	11.12	11.14	11.12	11.19	11.13	11.13
Maximum	17.79	17.05	17.56	17.3	17.13	17.41	17.37	17.19
Mean	15.94	15.41	15.31	15.22	15.16	15.06	15.27	15.1
Median	16.52	15.67	15.79	15.57	15.76	15.45	15.54	15.41
Variance	3.98	1.93	3.58	2.98	3.56	2.93	3.65	3.27
Standard deviation	1.996	1.39	1.89	1.73	1.89	1.71	1.91	1.81
Standard error	0.46	0.32	0.44	0.4	0.44	0.39	0.44	0.42

Table 5: Uncertainty analysis of current (A) generated by PV module

Statistics	No filter	Red	Orange	Lemon	Green	Blue	Peach	Violet
Minimum	0.31	0.27	0.27	0.28	0.25	0.26	0.26	0.25
Maximum	3.46	3.75	3.66	2.98	2.99	2.78	2.94	3.05
Mean	2.1	1.71	1.78	1.59	1.62	1.57	1.69	1.54
Median	2.25	1.58	1.89	1.57	1.7	1.55	1.72	1.34
Variance	1.05	0.63	0.77	0.63	0.55	0.64	0.7	0.66
Standard deviation	1.03	0.79	0.88	0.79	0.74	0.8	0.84	0.81
Standard error	0.24	0.18	0.2	0.18	0.17	0.18	0.19	0.19

Table 6: Uncertainty analysis of power (W) produced by PV module

Statistics	No filter	Red	Orange	Lemon	Green	Blue	Peach	Violet
Minimum	3.48	2.98	3.04	3.08	2.79	2.92	2.92	2.8

Maximum	61.52	58.73	65.64	49.61	49.28	43.45	47.92	52.4
Mean	35.24	26.94	28.62	25.27	25.72	24.73	27.13	24.51
Median	36.55	24.72	30.65	25.73	25.55	22.21	26.34	21.92
Variance	364.45	172.44	255.15	196.34	165.76	190.63	219.56	207
Standard deviation	19.09	13.13	15.97	14.01	12.88	13.81	14.82	14.39
Standard error	4.38	3.01	3.66	3.21	2.95	3.17	3.4	3.3

Table 7: Uncertainty analysis of efficiency (%) level reached by PV module

Statistics	**No filter**	**Red**	**Orange**	**Lemon**	**Green**	**Blue**	**Peach**	**Violet**
Minimum	3%	3%	3%	3%	3%	3%	3%	3%
Maximum	62%	60%	66%	50%	49%	43%	48%	52%
Mean	35%	27%	29%	25%	26%	25%	27%	25%
Median	37%	25%	31%	26%	26%	22%	26%	22%
Variance	4%	2%	3%	2%	2%	2%	2%	2%
Standard deviation	19.09	13%	16%	14%	13%	14%	15%	14%
Standard error	4.38%	3%	3.66%	3.21%	2.95%	3.17%	3.40%	3.30%

3.1 Influence of solar power on the electrical parameters of filter enhanced PV module

Figure 3a displays the voltage response pattern of the solar filter enhanced PV module with varying levels of solar power. From the figure it is observed that without the application of the filters there is an increase in voltage between 0 to 500 W/m^2 of solar power. At 500 W/m^2 the output voltage rises close to the voltage at maximum power, and above 500 W/m^2 the voltage remains fairly stable irrespective of the solar power received by the module. However, with the application of the red filter, an increase in voltage was observed from 0 to 700 W/m^2 before achieving stability in voltage close to V_{mp}. With the application of the orange filter stability in voltage was quickly reached at about 400 W/m^2, although the stable voltage reached was not very close to the V_{mp}. While with the lemon filter, a rise in voltage was observed up to 600 W/m^2 before achieving stability. The green filter enabled stability in voltage to be attained at about 550 W/m^2, while with the blue filter stability in voltage was achieved with a relatively lower solar power of about 400 W/m^2, but the stable voltage was relatively not close to the $V_{mp.}$ With the PV module under the peach filter an increase in voltage was observed to about 710 W/m^2 before achieving stability, while with the violet filter voltage stability was observed to occur at about 600 W/m^2. The figure further reveals that during the rising section of the voltage the lemon and green filter produced the highest voltage while the peach and blue filter produced the least voltage. However, in the stable section a higher voltage was generated without the application of filters.

Figure 3b reveals the current generated by the PV module under distinct wavelengths of light with respect to solar power. From the figure it is observed that with the PV module exposed to distinct wavelengths of light, the generated current increases linearly as the solar power reaching the PV module increases which agrees with earlier studies by [19]. The figure further reveals a higher amount of current generated with the red filter followed by the results obtained without the application of filters, while the peach and violet filter generated the least voltage with the lemon and green filter lying in between. This result agrees with previous work by [35] which reported that the red color of light led to the production of more electricity from solar photovoltaic panel.

Figure 3c shows the power output from the PV module with and without the application of the filters with respect to solar power. From the figure it is observed that the power output of the module with and without the filters increases linearly with solar power which agrees with studies by [35] which reported that the power obtained from both monocrystalline PV technologies increases linearly with the amount of radiation received. The figure also reveals some interesting results as we would have expected a higher amount of power to be generated with the red filter given that a relatively higher amount of current was generated with the red filter as evident in figure 3b, but the figure revealed otherwise, revealing a higher amount of power produced without the application of the filter as evident from the trendline. Moreover, the higher amount of power generated without the filters is due to the fact that a higher amount of voltage was achieved from the module without the filter as observed in figure 3a. Also figure 3c further shows the least amount of power output generated with the orange filter while the lemon, blue and red filter produced a relatively higher power when compared to the filters applied.

Figure 3d depicts the efficiency of the PV module in the presence and absence of the filters with respect to solar power. From the figure it is observed that the efficiency of the PV module increases linearly as solar power increases which still agrees with work by [19]. The figure also discloses the module been least efficient with the orange filter and more efficient without the filters. However, among the filters used the lemon filter still enabled the module to attained a relatively higher efficiency. The efficiency attained by the module with and without the filters is simply due to the level of output power generated as evident in figure 3c.

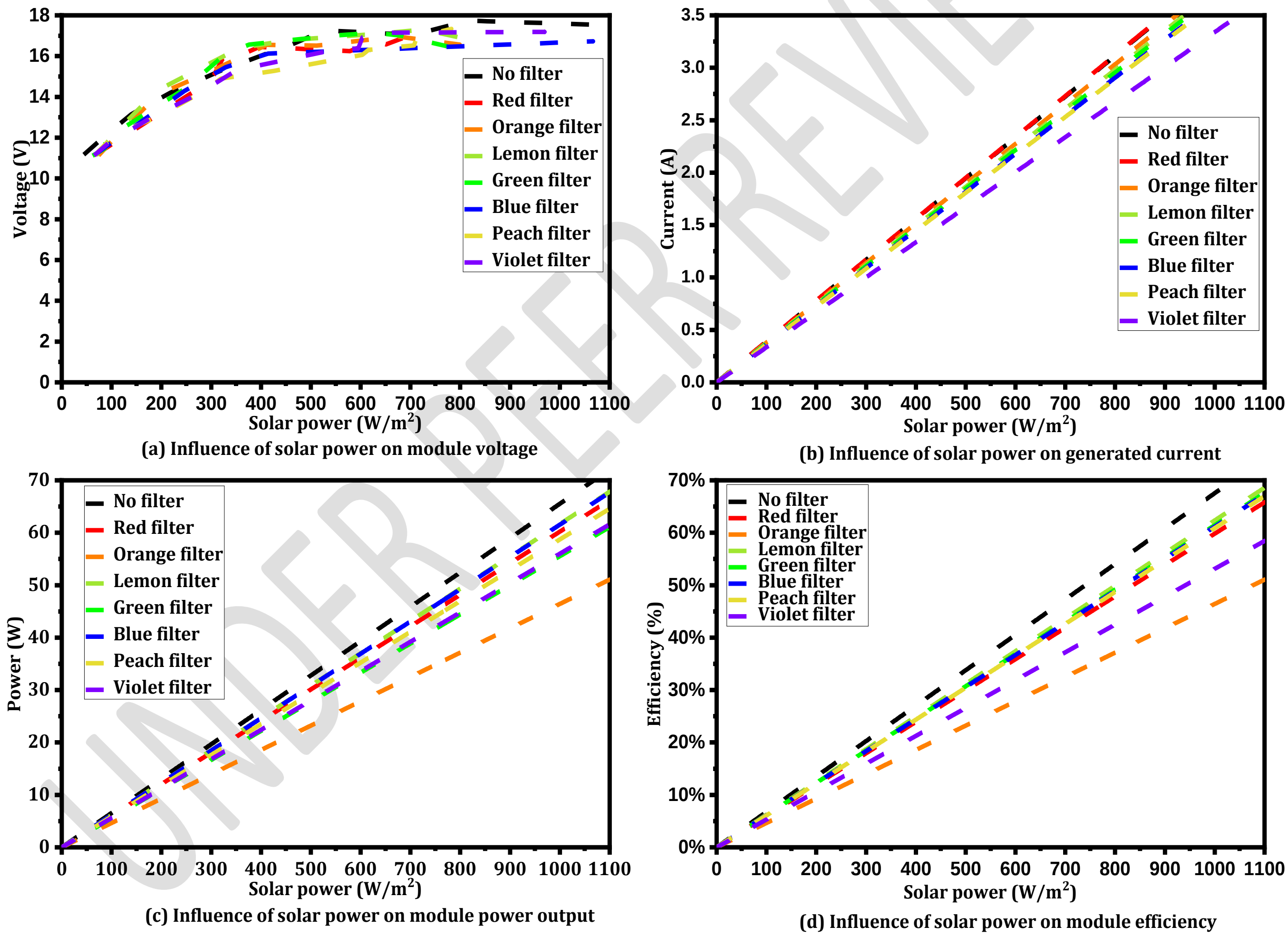


Figure 3: Influence of solar power on the electrical parameters of filter enhanced PV module

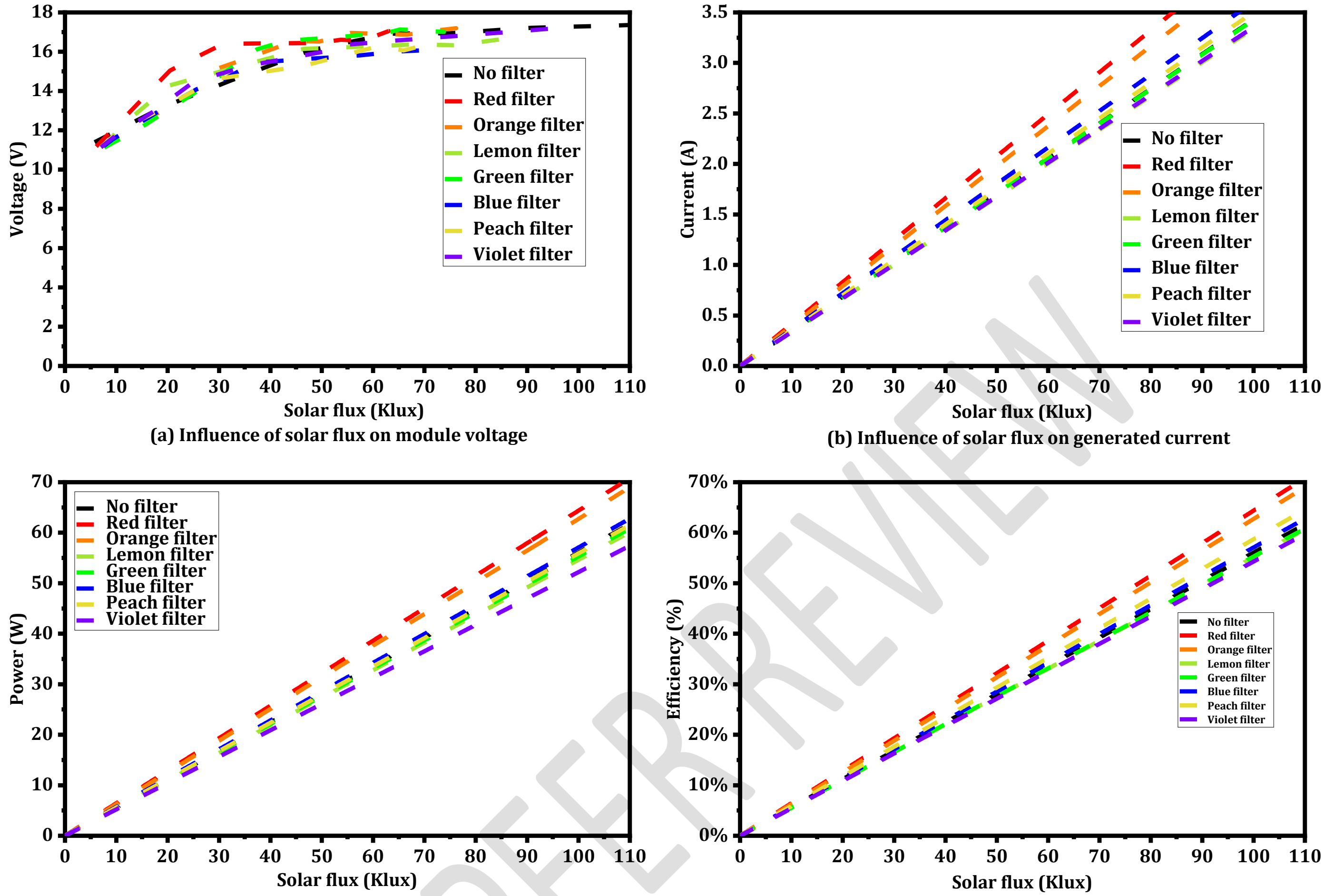
3.2 Influence of solar flux on the electrical parameters of filter enhanced PV module

Figure 4a displays the voltage response pattern of the solar filter enhanced PV module with varying levels of solar flux. From the figure it is observed that without the application of the filters there is an increase in voltage between 0 to about 90 Klx. Above 90 Klx the voltage approaches the V_{mp} and remains fairly stable. Under the red filter an increase in voltage was observed up to about 65 Klx, above 65 Klx the voltage remains fairly stable and close to the V_{mp}. With the orange filter an increase in voltage was observed up to 70 Klx before a fair stability in voltage was attained. However, with the lemon filter stability in voltage was detected with a fairy low solar flux of about 45 Klx, although the fairly stable voltage reached was not closed to the V_{mp}. With the PV module under the green filter a fairly stable voltage which was close to the V_{mp} was observed at about 60 Klx. Under the blue filter, a fairly stable voltage not close to V_{mp} was attained at about 75 Klx. With the peach filter stability in voltage was also achieved at 60 Klx but the fairly stable voltage was still not close to the V_{mp}. While under the violet filter an increase in voltage was observed up to about 95 Klx before attaining fair stability which was also close to the V_{mp}. Irrespective of the level of solar flux in which stability was attained, a common behavioral pattern was observed; first an increase in voltage is observed before fair stability is achieved. Moreover, figure 4a also reveals poor voltage performance from the lemon, peach and blue filter. While red, orange and green filter gave better voltage performance.

Figure 4b depicts the current produced by the PV module under distinct wavelengths of light with respect to solar flux. The figure reveals that with the PV module exposed to distinct wavelengths of light, the current produced increases linearly with solar flux which conforms with earlier studies by [19]. The figure further depicts a higher amount of current generated with the red filter followed by the orange filter, while the lemon and violet filter generated the least current. This result also conforms with previous work by [36] which reported that the red color of light profoundly affects modern photovoltaic technology.

Figure 4c portrays the power generated by the PV module under distinct wavelengths of light with respect to solar flux. The figure reveals the power output of the module under distinct wavelengths increasing linearly with solar flux which also agrees with studies by [19]. Furthermore, the figure also reveals higher amount of power produced by the red filter, followed by the orange, while the lemon and violet filter produced the least power. The higher amount of power generated with the red filter follows from the fact that a higher amount of voltage and current was generated with the red filter as evident in figure 4a and figure 4b respectively, which still agrees with work by [36].

Figure 4d depicts the efficiency of the PV module under the different filters with respect to solar flux, which reveals the efficiency of the PV module increasing linearly with solar flux. Furthermore, it is observed that the PV module is more efficient under the red filter followed by the orange filter, with violet coming least. Moreover, it is of no surprise that the PV module is more efficient under the red filter given that a higher amount of power was generated with it as evident in figure 4c.



(a) Influence of solar flux on module voltage

(b) Influence of solar flux on generated current

(c) Influence of solar flux on module power output

(d) Influence of solar flux on module efficiency

Figure 4: Influence of solar flux on the electrical parameters of filter enhanced PV module

4. CONCLUSION

An experimental study of the behavioral pattern of monocrystalline photovoltaic enhanced with solar filter was conducted in the mangrove swamp of Calabar in Cross River State, Nigeria. Solar filters with distinct wavelengths were used to enhance the PV module. The outdoor experimental investigation of the monocrystalline module behavior under different wavelengths of light was conducted; influence of the solar filters on the module was determined by measuring the electrical operating parameters as well as tracking the maximum power and efficiency of the module under different wavelengths with the same operating environmental condition (i.e. temperature and humidity). The transmitted solar power and solar flux through the filters was used to investigate the behavioral pattern of the module. After careful and thorough analysis, it was observed that the module responds to the filters in a similar way. The study unveils that as the transmitted solar power and solar flux reaching the module rises, first the voltage increases before attaining a fairly stable voltage which may or may not be close to the V_{mp}. However, the ripples observed across the fairly stable region of the voltage is due to variations in the module temperature. A slight increase in temperature is accompanied by a slight drop in voltage and vice versa. The study shows an increase in current, power and efficiency as the transmitted solar power and solar flux reaching the module through each filter increases. The study also reveals some interesting results as it shows that the module produces more current, power and efficiency under the red filter as solar flux increases. While in terms of solar power, the red filter and the natural spectrum led in the production of current, with the natural spectrum triggering a higher efficiency from the module as solar power increases. This study proved that the nature and wavelength of the radiation reaching a photovoltaic module influences its efficiency.

ABBREVIATIONS

PV: Photovoltaic
V_{mp}: Voltage at maximum power
I_{mp}: Current at maximum power
MPPT: Maximum power point tracker
STC: Standard test condition

REFERENCES

1 Njok AO, Archibong EA, Fischer GA. "Diurnal analysis of the performance of photovoltaic systems under the Guinea Savannah Atmosphere in Ogoja, Cross River State, Nigeria." Physical Science International journal. 2023;27(1):1-15.

2 Heyine MS, Yahya AM, Daher DH, Gaillard L, Menezo C, Mahmoud AK. "Performance evaluation of 50MWp solar plant under different conditions." International Journal of Power Electronics and Drive Systems. 2022;32(1):561-575.

3 Bhattacharya T, Chakraborty AK, Pal K. ''Effects of ambient temperature and wind speed on performance of Monocrystalline solar photovoltaic module in Tripura, India.'' Journal of Solar Energy. 2014; 2014:5 pages, Article ID 817078.

4 Njok AO, Ogbulezie JC, Panjwani MK, Larik RM. ''Investigation of monthly variations in the efficiencies of photovoltaics due to sunrise and sunset times.'' Indonesian Journal of Electrical Engineering and Computer Sciences. 2020;18(1):310–317.

5 Andrea Y, Pogrebnaya T, Kichonge B. ''Effect of Industrial Dust Deposition on Photovoltaic Module Performance: Experimental Measurements in the Tropical Region.'' International Journal of Photoenergy. 2019; 2019:10 pages, Article ID 1892148.

6 Balal A, Abedi M, Shahabi F. "Optimized generated power of a solar PV system using an intelligent tracking technique." International Journal of Power Electronics and Drive Systems. 2021;12(4):2580-2592.

7 Joseph B, Pogrebnaya T, Kichonge B. "Semitransparent building-integrated photovoltaic: review on energy performance, challenges, and future potential." International Journal of Photoenergy. 2019;2019: 17 pages, Article ID 5214150.

8 Kamarudin MN, Rozali SMD, Jamri MS. "Active cooling photovoltaic wit IoT facility," International Journal of Power Electronics and Drive Systems." 2021;12(3):1494-1504.

9 Ahmad EZ, Sopian K, Ibrahim A, Gan CK, Ab Razak MS. "Experimental investigation of passively cooled photovoltaic modules on the power output performance." International Journal of Power Electronics and Drive Systems. 2022;32(1): 520-527.

10 Torres JPN, Nashih SK, Fernandes CAF, Leite JC. "The effect of shading on photovoltaic solar panels." Energy Systems. 2018;9(1):195–208.

11 Su B, Han W, Chen Y, Wang Z, Qu W, Jin H. "Performance optimization of a solar assisted CCHP based on biogas reforming." Energy Conversion and Management. 2018; 171:604–617.

12 Ogbulezie JC, Njok AO, Panjwani MK, Panjwani SK. ''The impact of high temperature and irradiance source on the efficiency of polycrystalline photovoltaic (PV) panels in a controlled environment.'' International Journal of Electrical and Computer Engineering. 2020;10(4): 3942–3947.

13 Debbarma M, Sudhakar K, Baredar P. "Comparison of BIPV and BIPVT: a review." Resource Efficient Technologies. 2017; 3(3):263–271.

14 Green MA, Hishikawa Y, Dunlop ED, Levi DH, Hohl-Ebinger J, Ho-Baillie AWY. "Solar cell efficiency tables." Progress in Photovoltaics: Research and Applications. 2018;26(7):427–436.

15 Hashim HF, Kareem MM, Al-Azzawi WK, Ali AH. "Improving the performance of photovoltaic module during partial shading using ANN." International Journal of Power Electronics and Drive Systems. 2021; 12(4):2435-2442.

16 Njok AO, Ogbulezie JC. ''The effect of relative humidity and temperature on polycrystalline solar panels installed close to a river.'' Physical Science International Journal. 2018; 20(4):1–11.

17 Adıgüzel E, Özer E, Akgündoğdu A, Yılmaz AE. "Prediction of dust particle size effect on efficiency of photovoltaic modules with ANFIS: an experimental study in Aegean region, Turkey." Solar Energy. 2019; 177:690–702.

18 Hammoumi AE, Motahhir S, Ghzizal AE, Chalh A, Derouich A. "A simple and low-cost active dual-axis solar tracker." Energy Science & Engineering. 2018; 6(5): 607–620.

19 Njok AO, Kamgba FA, Panjwani MK, Mangi FH. ''the influence of solar power and solar flux on the efficiency of polycrystalline photovoltaics installed close to a river.'' Indonesian Journal of Electrical Engineering and Computer Sciences. 2020; 17(2):988–996.

20 Njok AO, Iloke JI, Panjwani MK, Panjwani SK. ''the impact of colored filters on the performance of polycrystalline photovoltaic panel in an uncontrolled environment." International Journal of Electrical and Computer Engineering. 2020;10(4):3927–3935.

21 Natarajan S, Mallick T, Katz M, Weingaertner S. "Numerical investigations of solar cell temperature for photovoltaic concentrator system and without passive cooling arrangements." International Journal of Thermal Sciences. 2011;50(2):2514-2521.

22 Abdelkader MR, Al-Salaymeh A, Al-Hamamre Z, Firas S. "A comparative analysis of the performance of Monocrystalline and multicrystalline PV cells in semi-arid climate conditions: the case of Jordan." Jordan Journal of Mechanical and Industrial Engineering. 2010; 4:543–552.

23 Chou CS, Guo MG, Liu KH, Chen YS. "Preparation of TiO2 particles and their applications in the light scattering layer of a dye-sensitized solar cell." Applied Energy. 2012; 92:223–224.

24 Koutroulis E, Blaabjerg F. "A new technique for tracking the global maximum power point of PV arrays operating under partial-shading conditions." IEEE Photovoltaics. 2012;2(2):84–190.

25 Boxwell M. "Solar Electricity Handbook: A simple, practical guide to solar energy – designing and installing photovoltaic solar electric systems (6th ed.)." *United Kingdom: Greenstream Publishing*, pp. 409, 2012.

26 Kazem HA, Chaichan MT, Alwaeli AH, Mani K. "Effect of Shadows on the Performance of Solar Photovoltaic," In: Sayigh, A. (eds) Mediterranean Green Buildings & Renewable Energy. Springer, Cham. 2017:379-385. https://doi.org/10.1007/978-3-319-30746-6_27.

27 Sai Krishna g, Moger T. "Reconfiguration strategies for reducing partial shading effects in photovoltaic arrays: State of the art," Solar Energy. 2019; 182:429-452. https://doi.org/10.1016/j.solener.2019.02.057.

28 El-Shaer A, Tadros MT, Khalifa MA. "Effect of light intensity and temperature on crystalline silicon solar modules parameters." Journal of Emerging Technology and Advanced Engineering. 2014; 4:311-318
.

29 Joshi SA, Dincer B, Reddy BV. "Effect of color of light on the PV/T system performance." International Journal of Energy Research. 2011; 36(5):572-578.

30 Ogherohwo EP, Barnabas B, Alafiatayo AO. "Investigating the Wavelength of Light and Its Effects on the Performance of a Solar Photovoltaic Module." International Journal of Innovative Research in Computer Science & Technology. 2015; 3:61-65.

31 Ali SM, Arjyadhara P, Prabeer KD, Batala KR. "Analysis of color spectrum on the performance of photovoltaic cell." International Journal of Renewable Energy. 2013; 8(1):25-30.

32 Kazem HA, Chaichan MT. "The impact of using solar coloured filters to cover the PV panel in its outcomes." Scholars Bulletin. 2016; 2:464-469.

33 Tobnaghi DV, Naderi D. "The effect of solar radiation and temperature on solar cells performance." Extensive Journal of Applied Sciences. 2015; 3:39-43.

34 Rani SP, Giridhar SM, Prasad SR. "Effect of temperature and irradiance on solar module performance." IOSR Journal of Electrical and Electronics Engineering. 2018;13(2):36-40.

35 Touati F, Massoud A, Hamad JA, Saeed SA. "Effects of environmental and climatic conditions on PV efficiency in Qatar." In International Conference on Renewable Energies and Power Quality (ICREPQâ€™ 13). 2013.

36 Ali H, Zafar M, Bashir M, Nasir M, Ali M, Siddiqui A. "Effect of dust deposition on the performance of photovoltaic modules in Taxila, Pakistan." Thermal Science. 2017; 21(2):915–923.

37 Muhammad AB, Hafiz MA, Shahid K, Muzaffar A, Aysha MS. "Comparison of performance measurements of photovoltaic modules during winter months in Taxila, Pakistan." International Journal of Photoenergy. 2014; 2014:1-8.

38 Kamgba FA, Edet CO, Njok AO. "Effects of some Meteorological Parameters on Wind Energy Potential in Calabar, Nigeria." Asian Journal of Physical and Chemical Sciences. 2017; 4(1):1-7.

39 Njok AO, Akonjom NA, Ogbulezie JC. "Design and performance evaluation of systems with automatic dust wiper in a natural dusty environment." Asian Journal of Physical and Chemical Sciences. 2022; 10(4):1-15.

40 Njok AO, Kamgba FA. "Monocrystalline Photovoltaic Panel Response Pattern to Relative Humidity and Temperature under Distinct Wavelengths in Mangrove Swamp Environment in Calabar, Cross River States, Nigeria." Journal of Applied Sciences and Environmental Management. 2023;27(8):1825-1837.