Original Research Article

Design and Performance Evaluation of Photovoltaic systems with Automatic Dust Wiper in a Natural Dusty Environment

ABSTRACT

The accumulation of dust on solar panels affects the transmittance of solar panel glazing which leads to the degradation of performance efficiency due to low levels of irradiance reaching the cell. In this work, the response of polycrystalline silicon solar panels toward dust in a natural dusty environment was experimentally investigated at a location in Calabar close to the Calabar river. The experimental measurements were carried out in real-time outdoor conditions where human activities take place. An automatic dust wiping/cleaning mechanism to ensure the panel surface was kept clean was deployed in the study. An intelligent maximum power point (MPP) tracker for tracking the maximum power points of the panels were also utilized for this work. Results obtained revealed that the accumulation of dust on polycrystalline solar panels adversely affects power output and efficiency. From the results, it was also revealed that the average panel temperature of the photovoltaic system with the automatic dust wiping mechanism was 5.30^{0}C lower than the panel without the automatic dust wiping mechanism. This lower panel temperature of the solar panel with the automatic dust wiping mechanism led to an increase of 16%, 32.5%, 43.40% and 43.37% in average voltage, average current, average power and average efficiency respectively over the dusty panel. It was demonstrated that solar panel efficiency plummets as panel temperature rises due to heat dissipation caused by the accumulation of dust.

Keywords: Dust, shade, automatic dust-wiping mechanism, maximum power point, solar panel, efficiency

1. INTRODUCTION

The photovoltaic (PV) cell is one of the most amazing mechanisms developed by man for the generation of electricity. Connecting the PV cells in series and parallel make up a solar panel which can be carefully assembled with other components to make up a photovoltaic system. The birth of the PV system for the generation of electricity was made possible through the PV effect; discovered by Alexandre E. Becquerel in 1839 [1-3]. At present, PV systems are now ranked as the most favourable and reliable source of energy in the middle east and Africa due to the abundant solar irradiation of the regions [4]. Due to the remarkable and steady improvements in PV technology, PV systems are no more confined to street lighting or household applications since it has been shown that they can be used to generate power on large scales in the range of mega and gigawatt [5]. PV systems possess many advantages (long-lasting, almost maintenance-free, minimum operational control and generating maximum electricity during periods of peak load demand) which makes them eye-catching for both small and large-scale investments [6-7].

The working principle of the PV system envelops features including charge controller topology, battery technology, solar panel technology and inverter design. Regardless of these remarkable features, PV systems are constantly influenced by atmospheric factors including temperature variations, ageing, wind, shading and dust [8-10]. The emergence of solar tracking technology enabled solar panels and PV systems in capturing maximum solar radiation which ultimately enhanced the power output and efficiency [11-12]. Notwithstanding the enormous benefits and improvements that solar tracking technology adds to PV systems, temperature, dust and shade still affect their performance efficiency [13-15].

Particles with sizes less than 500 μm are classified as dust, and their deposition, composition and morphology depends on the characteristics of the location [16-18]. Dust is normally measured in micrometers and comprises of minute particles of various elements and sizes, which are transported by air currents and formed by the disintegration of solids into tiny pieces through crushing, grinding or impact among other ways [19-20]. Some particles cause crowding in the dust layer which results in adhesion to surfaces due to ionic charges, which ultimately causes significant increase in effort required to remove dust particles from surfaces [21-22]. The size of particles and the density of dust on the surface of solar panel influences the plummet in the performance of solar panels [23]. The accumulation of dust on the surface of a solar panel tends to trigger a significant rise in temperature due to the affected cell heating up while acting as a barrier to the generated photocurrent [24]. This phenomenon can lead to the birthing of hot spot that have the potential to cause severe damage to the solar panel [25]. The performance and conversion efficiency of solar panels is related to the size of the dust particles deposited on it. Dust made of very fine particles have minimum interparticle separation between them which makes it very difficult for light to pass through to reach the solar panel [26]; this cause a higher drop in performance efficiency of a solar panel when compared with dust of larger particle and larger interparticle separation [27].

The output power of solar panels has been ascertained to drop by 85% due to sand, dust, algae-like substance and even small stones that accumulate on their surface, which means regular cleaning is a must if maximum performance from the panel is desired [28]. The shading, masking and coating due to deposition, accumulation and contamination can be classified into two categories: soft shade and hard shade [29]. Soft shades can be formed due to smoke, dust particles in the air hovering over the surface of the solar panel or 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. On the other hand, hard shade is an obstruction such as fallen leaves, stones, bird droppings or a tree branch laying on the panel surface that can completely obstruct light from reaching the solar cells. [30].

Gholami et al. [31] carried out an experimental study about the impact of dust accumulation on a solar panel surface after 70 days without rainfall. Their findings revealed that the surface density of the accumulated dust increased up to 6.0986 g/m^2, which triggered a 21.47% decrease in the output power. Said and Walwil [32] researched a dusty solar panel for 5 weeks without cleaning in Dhahran, Saudi Arabia. They found that the short circuit current and output power dropped by 13% and 6% respectively. Kaldellis and Kapsali [33] studied how PV system outputs are affected by different air pollutants. They disclosed that the output parameters of PV systems are severely affected by dust deposition and accumulation on PV surfaces. While Sulaiman et al. [34] researched the impact of dust on the performance of a 50 W solar panel using artificial dust (mud and talcum) and clear plastic under constant radiation sources in a laboratory. Their results portrayed a massive drop in efficiency of 50% and 18% for maximum power. Furthermore, their results show just a slight difference in the performance of the panel covered with mud and talcum. However, Darwish et al. [35] using different types of dust pollutants studied the impact each pollutant has on the performance of PV systems. They concluded that ash, silica and limestone are the pollutants that mostly influence the performance of PV systems. Mustafa et al. [36] investigated the impact of dust accumulation, bird dropping, shading effects and water drops on the performance of PV systems. From their analysis, it was revealed that dust accumulation caused the output power and efficiency to drop by 8.80% and 11.86% respectively. While about a 7.40% reduction in the output power was observed when the panel was covered with bird droppings. When the surface of the PV panels was exposed to water droplets, an improvement of at least 5.9% in the output power was observed. Jiang et al. [37] researched the impact airborne dust deposition and accumulation have on PV module performance. Data was obtained when the density of the accumulated dust reached 22 g/m^2. Analysis of the obtained data revealed a 22% decrease in the short circuit current, while a 6% reduction in the open circuit voltage was observed. Andrea et al. [38] studied the effect of industrial dust deposition on PV module performance in Arusha Tanzania. Dust utilized in the study was obtained from fertilizer, gypsum, aggregate crusher and coal mine industries. Maximum module efficiency loss was observed to be 64%, 42%, 30%, and 29% for coal, aggregate, gypsum, and organic fertilizer dust, respectively. Their results also show that PV module performance depreciated with the increase in temperature owing to heat dissipation triggered by dust accumulation.

The effect of various types of shade, dirt and dust accumulation on solar panel surfaces have been investigated. As a matter of fact, there is a plethora of obtainable literatures on the effect of dust on the performance of photovoltaics, but a huge amount of the obtainable information is only valid to for a specific location or region and does not apply to PV systems with automatic cleaning/wiping mechanism. Generally, there is a shortage of pertinent information on how the performance of PV modules are hindered by dust deposition for a specific location in Nigeria that can be employed by engineers in the design and sizing of PV systems.

Deposition and accumulation of dust on PV module surface is inevitable. Solar panels were designed and manufactured to be optimally efficient in outdoor environments with their surface free from shade, dust and dirt. Since there is difficulty that comes with the regular cleaning of solar panels, especially when they are installed on roof tops. Then the solution is to create and design a photovoltaic system that will always be free from dust and dirt irrespective of how dusty the environment might be. Thus the introduction of an automatic cleaning/wiping mechanism will not only ensure that the module surface is kept clean but also ensure that the system remains optimally efficient. The polysilicon technology is the dominant technology in the Nigerian market and is widely utilized for backup power in households and small business premises. Hence the need to develop a means so that it surface can be kept clean. Investigation on the performance of polysilicon PV systems with automatic cleaning/wiping mechanism is not yet investigated in the Nigeria's prospect.

The aim of this study is to experimentally investigate the degradation in performance efficiency of PV systems caused by the natural accumulation of dust and dirt. In achieving the objectives, an intelligent water timer coupled with relays that is linked to the dust wipers was employed. The intelligent water timer triggers the wiping mechanism once the preset times (6:30 and 13:00) for the PV module surface to be cleaned is reached. Once the preset time is reached, the cleaning/wiping mechanism activates and remains active for 90 seconds before shutting down automatically and reactivating again once the next preset times is reached. This study provides information that will enlighten user of how much energy their PV system will lost as dust and dirt keeps accumulating on solar panel surface.

2. MATERIALS AND METHODS

This section is about the materials used in the study, how they were connected and the steps followed in the course of measurement.

2.1 Materials Utilized in the Study

Two exact 130-watt polysilicon solar panels of the model AF-130W produced by Africell solar were utilized in this study: the output electrical characteristics of the module are revealed in table 1. A digital high-precision intelligent photovoltaic panel maximum power point tracker (MPPT) (model WS400A) manufactured by Elejoy was used to track and determine the maximum power generated by the photovoltaic modules as shown in figure 1a. An intelligent digital programmable water timer (model ZG004) manufactured by Zhigarden and a digital relay timer (model THC-15A) manufactured by Gangbei were also deployed and can be seen in figures 1b and 1c respectively. Water hose, water sprinklers (figure 1d) and wipers were also employed. Solar batteries (Gel battery: 12 V, 100 A) and a digital charge controller were also utilized. A digital hygrometer (model KT-908 shown in figure 1e), a digital solar power meter (model SM206) manufactured by RZ (figure 1f) and a digital non-contact infrared gun thermometer (model GM320) manufactured by Aneng (figure 1g) were deployed for the tracking of the relative humidity, irradiance and temperature respectively at the surface of the solar panel.

The digital intelligent photovoltaic panel maximum power point tracker is designed to function without an external power supply as it takes its energy from the solar panel. It is designed to track the maximum power point and open circuit voltage of a PV module in seconds. When switched to automatic MPPT detection mode, the device automatically scans and adjust the tracking interval time according to the current power value and refreshes the digital display continuously. When set to manual MPPT detection mode, the instrument starts a scan of the maximum power point and refreshes the digital display. When the open circuit voltage (V_{oc}) button is pressed, the voltage of the solar panel is displayed immediately. It boasts an accuracy of ±0.1 Watt, ±0.1 Volt and ±0.1 Amps for power, voltage and current respectively. It is capable of measuring to a maximum of 400 W, 60 V and 20 A for power, voltage and current respectively. The device is designed to protect itself from over-voltage, over-power, over-current and over-temperature due to its in-built multi-protections mechanisms. Due to the astonishing features this device possesses, it is selected for this study because of its accuracy, speed and ease of measurement when compared to the traditional way which requires an ammeter, a voltmeter and a rheostat or potentiometer to be assembled before the maximum power points could be determined.

The solar power meter is designed a multi-functional LCD. It is employed for solar radiation measurement, physical and optical experiments like measuring glass light intensity to verify glass properties. It rapidly responds to changes in irradiance and can steadily measure for a long period. It measures irradiance in Watt per square metre (W/m^2) or in British thermal unit (Btu) with a resolution of 0.1 W/m^2 or 0.1Btu. it is designed with a sampling time of 0.25s and can accurately measure in the range of 0.1 to 1999.9 W/m^2 or 0.1 to 1999.9Btu. it has a temperature error of ±0.38 W/m^2/^{0}C and ±0.12Btu/^{0}C deviation at 25^{0}C, and a drift of <±1.5%/year. Its accuracy and speed in responding to changes makes the device suitable for this work.

The hygrometer is another device designed with a multi-functional LCD. It is designed to measure temperature (^{0}C or ^{0}F) and relative humidity (%). It is highly stable with an accuracy of ±5% for relative humidity and ±1^{0}C or ±2^{0}F for temperature. It can measure temperatures in the range of -10.0 to 50.0^{0}C (14.0 to 122.0^{0}F) for indoor, and -50.0 to 70.0^{0}C (-58.0 to 158.0^{0}F) for outdoor operation. Its high stability and quick response to changes in temperature and relative humidity is the reason why it is chosen for this study.

The non-contact infrared gun thermometer can be used to measure the surface temperature of hot water pipes, hot engines parts, cooking surfaces, hot tubs, etc. It is designed with an LCD where the readings of the measurement are displayed. It is equipped with an adjustable emissivity from 0.1 to 1 which facilitates precise measurements on different surfaces such as wood, metal, clay, marble, etc. It can measure temperature in the range of -50.0 to 400.0^{0}C (-58.0 to 752.0^{0}F) with a resolution of 0.1^{0}C of 0.1^{0}F. it has an accuracy of ±1.5^0 and a distance spot ratio of 12:1. Its operating temperature is between 0 to 40.0^{0}C (32.0 to 104.0^{0}F) with a spectral response of 5 to 14 micro meter (um). The non-contact mode of measurement, its accuracy and speed of measurement as compared to the traditional way of temperature measurement that requires a thermometer to be permanently installed on the object surface before measurements can be taken is among the reasons why it is chosen for this research.

The intelligent water timer also possesses a large LCD and functions with two 1.5 V AA Alkaline batteries. The power consumption is very low which allows the timer to keep timing for over six months. If the timer is not operated within 30 seconds, the screen automatically goes into sleep state which helps to save power. It is designed with six separate watering programs for six separate irrigation modes. The frequency and duration of the watering schedule can be easily customized. The watering schedule can be set to week cycle mode (from Monday to Sunday), day cycle mode (from 1 hour to 9 days) and run time which can be from 1s to 99min 59s. The timer comes with an in-built rain sensor which automatically detect raindrops and monitors real-time rainfall with high sensitivity, then responds to pause the programmed watering schedule by halting the valve which could help save water. Immediately the rain sensor gets dry the watering timer starts running again as schedule. The timer is built with IPX5 grade waterproof which makes it more impact resistant and wear resistant than ordinary plastic. It is also equipped with a manual button which allows immediate water use without interrupting the previous setting timers. The ease with which solar panels could be easily cleaned without human presence coupled with its intelligent nature makes this device a perfect choice for this study.

The relay timer displays the timing on an LCD screen. It is a weekly 7 days' programmable digital time switch relay which can be used for AC and DC purposes. It is designed with space for lithium battery so that timing can continue when power from the solar or solar batteries is down. It has an auto time error correction of ±30 seconds/weekly and hysteresis of ≤2 seconds/day(25^{0}C). these features make the timer an ideal choice for this study.

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

Figure 1:materials used for the experimental setup

2.2 Experimental setup

The experiment was done in an outdoor environment in Calabar at a location close to the Calabar river (latitude $4^0$57′38.6161” N and Longitude $8^0$18’58.482”). The solar panels were installed at an angle of 5^0 facing the north on a platform of one metre above sea level. One solar panel was installed with the cleaning/wiping mechanism and served as the control, while the other was left unattended for dust to accumulate.

For the dusty solar panel, connecting cables were connected from its output to the input of the intelligent MPP tracker from which its maximum power points were tracked and determined as displayed in figure 2. For the panel installed with the cleaning/wiping mechanism, connecting cables were connected from its output into a two-way switch. One output of the two-way switch leads to the intelligent MPP tracker from which its maximum power points were precisely tracked and determined, while the other output enters the input of the charge controller for smooth charging of the battery as shown in figure 3. The input of the programmable timer relay was connected to the battery while the output powers the wiper which wipes the surface of the solar panel. On the other end, the input of the intelligent water timer was connected to a tap from a water tank, while the output led to the water sprinkler via a hose. Through the water sprinkler, water was directed to the surface of the solar panel.

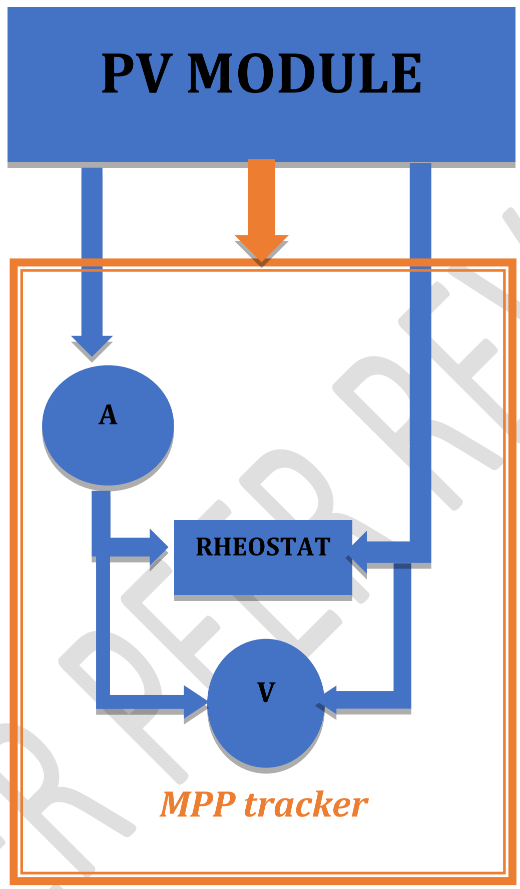

Figure 2: The experimental setup for the dusty panel

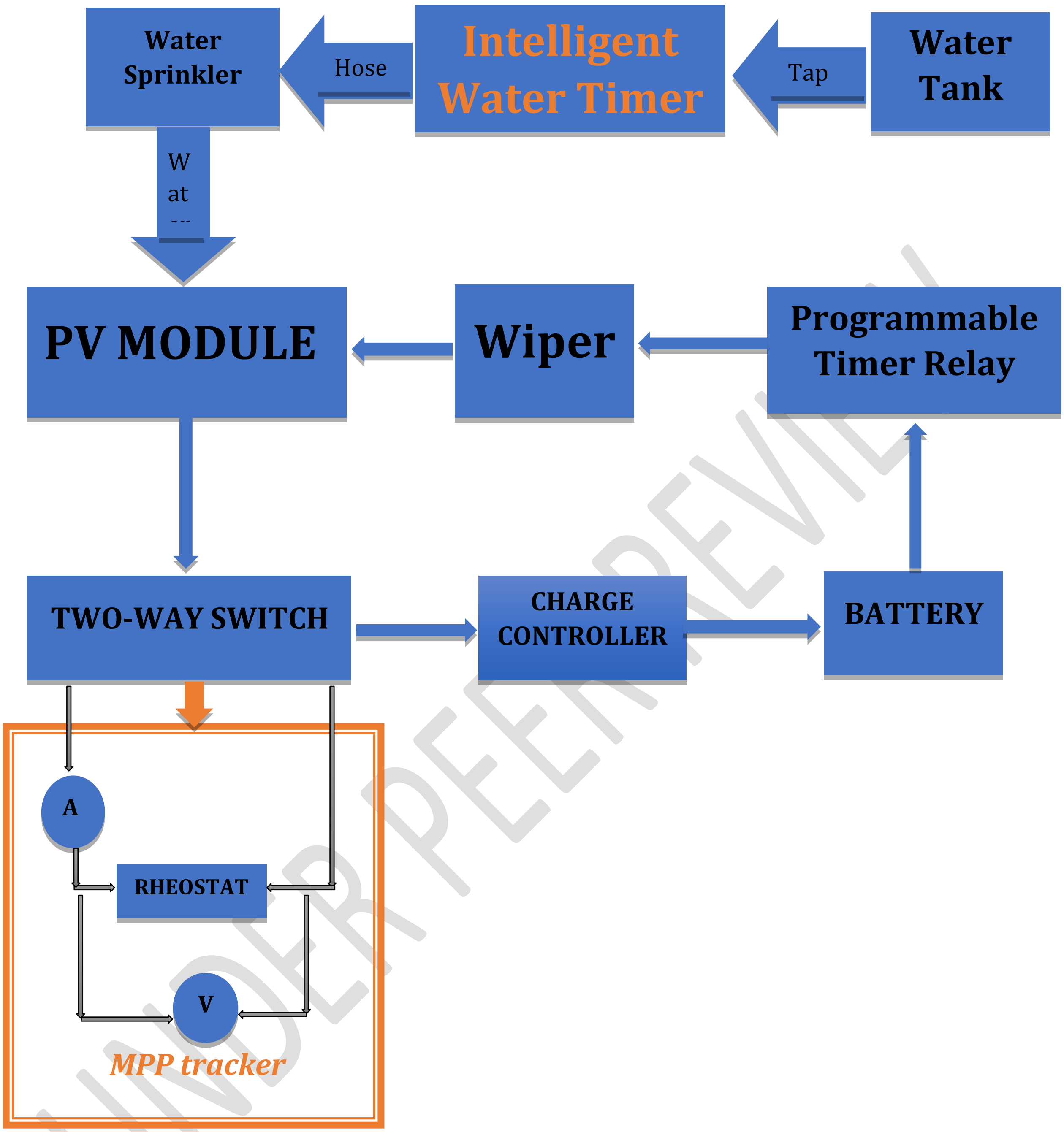

Figure 3: The experimental setup for the clean panel

2.3 Measurement procedure

Data was acquired from the solar panels at 30 minutes' interval from 6:00 to 18:00 for 16 weeks. During data acquisition, data were taken from both panels simultaneously. During data acquisition, the time of day was noted, while the power, current and voltage from the panels were ascertained with the aid of the intelligent MPP tracker. The humidity level, the surface temperature and the level of irradiance at the surface of the panels were measured through the digital hygrometer, digital infrared gun thermometer and digital solar power meter respectively.

2.4 Data processing and measurements

This study was carried out in real-time outdoor conditions with varying atmospheric parameters. With the aid of the intelligent MPP tracker, the maximum power at maximum power point P_{mp}, the open circuit voltage V_{oc}, the instantaneous current I_{mp} and voltage V_{mp} at maximum power under a particular real-time atmospheric condition were measured. The efficiency of a solar panel is significantly influenced by the current and voltage it can generate which in turn is affected by maintenance and atmospheric parameters. The V_{mp} and the V_{oc} are immensely influenced by temperature (T) which can be ascertained by (1) as revealed by [39]. Also the I_{mp} and the short circuit current I_{sc} are immensely influenced by irradiance (H) and can be ascertained via (2) also revealed by [39]. In contrast, from the data obtained, the normalized power output efficiency was computed with (3) while the solar panel efficiency at STC was confirmed with (4) as shown by [40-41].

Open circuit voltage:

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

Short circuit current:

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

Normalized power output efficiency:

$$\eta_p = \frac{P_{mea}}{P_{max}} \times 100\% \quad (3)$$

Module Efficiency:

$$\eta_{Mod} = \frac{Power\ of\ photovoltaic\ module \times 100\%}{Area\ of\ photovoltaic\ module \times 1000W/m^2} \quad (4)$$

where K and Q are Boltzmann constant and electronic charge respectively. i_0 is the saturation current while b is a constant which is influenced by the semiconductor junction properties. P_{mea} and P_{max} are measured power and power at STC respectively.

2.5 Study Area

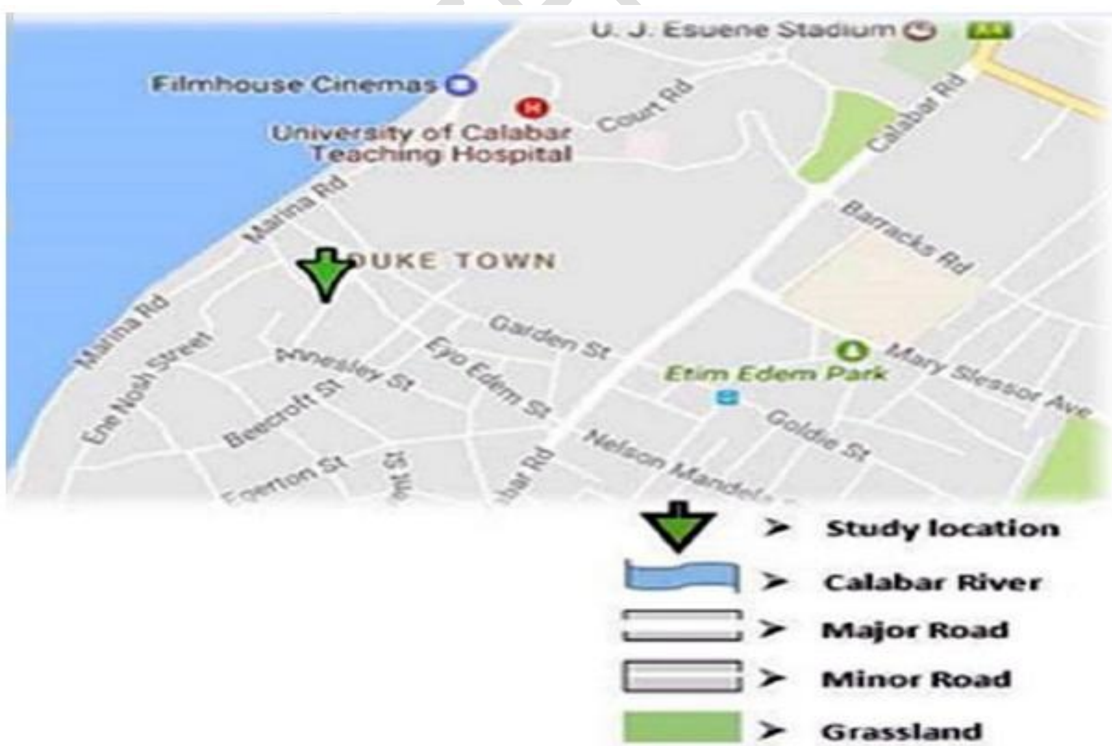

Figure 4: Map of study area

Calabar lies on Latitude 4°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 the tropical monsoon climate and 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 [42]. 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 rainy season is overcast, while the dry season is mostly cloudy. Throughout the year, the temperature ranges between 64^{0}F (17.78^{0}C) to 92^{0}F (33.33^{0}C) and rarely go above 96^{0}F (35.56^{0}C) or below 58^{0}F (14.44^{0}C) [43].

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 [43]. 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 [43].

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 [43].

The hottest month in Calabar is January, with a mean high temperature of 95.4^{0}F (35.2^{0}C) and a mean low temperature of 74.8^{0}F (23.8^{0}C), while the coldest month is August, with a mean high temperature of 82.9^{0}F (28.3^{0}C). However, the highest and lowest recorded temperature so far is 102^{0}F (38.9^{0}C) and 66^{0}F (18.9^{0}C) which were recorded in the months of January and April respectively [44].

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 [45]. 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 [45]. The location for this study is on Latitude 4^{0}57'38.6161" N and Longitude 8^{0}18'58.482" E which is less than 400 metre away from the Calabar river as displayed in figure 4.

3. RESULTS AND DISCUSSION

This section presents the results acquired from experimental measurement and analysis, it is divided into four parts. The first part discusses the variations in the atmospheric condition during data acquisition in the study area. The second part presents the analysis of the performance of the solar panels with respect to ambient temperature. In the third and fourth part, analysis is given on how both solar panels responds to varying levels of relative humidity and irradiance respectively. 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 produces instantly under a particular atmospheric condition.

Table 2 displays the summary of the atmospheric data obtained at the site, while table 3 displays the summary of the output electrical parameters of both solar panels under study.

Table 2: Uncertainty analysis of atmospheric data obtained from in-situ measurement

	Relative Humidity (%)	**Irradiance (W/m^2)**	**Ambient Temp (^{0}C)**
Statistic			
Minimum	65.53	0.00	25.27
Maximum	93.13	665.9	32.01
Mean	76.24	298.11	29.01
Median	73.07	331.3	29.31
Variance	85.74	41205	4.88
Standard Deviation	9.26	202.99	2.21
Standard Error	1.85	40.6	0.44

Table 3: Uncertainty analysis of solar panel data obtained from in-situ measurement

	Panel Temp (^{0}C)		Voltage (V)		Current (A)		Power (W)		Efficiency (%)	
Statistic	**Clean**	**Dusty**	**Clean**	**Dusty**	**Clean**	**Dusty**	**Clean**	**Dusty**	**Clean**	**Dusty**
Minimum	24.61	28.35	1.87	1.57	0	0	0	0	0%	0%
Maximum	44.95	51.78	18.35	15.41	4.81	3.24	87.70	49.65	67.46%	38.20%
Mean	34.80	40.08	17.00	14.28	2.12	1.43	38.53	21.81	29.63%	16.78%
Median	34.89	40.19	18.14	15.23	2.46	1.66	44.33	25.10	34.10%	19.31%
Variance	43.05	57.12	11.55	8.15	2.12	0.96	712.10	228.26	4.21%	1.35%
Standard Deviation	6.56	7.56	3.40	2.86	1.46	0.98	26.66	15.11	20.53%	11.62%
Standard Error	1.31	1.51	0.68	0.57	0.29	0.20	5.34	3.02	4.10%	2.32%

3.1. Variation of atmospheric parameters at the site

As displayed in figure 5a, there was constant fluctuation in the atmospheric parameters (temperature, relative humidity and irradiance) at the location of study. A constant rise in irradiance was observed in the morning and peaking at 11:00. Between 11:00 to 13:00 a decrease was observed, between 13:00 to 14:00 another increase was observed, beyond 14:00 there was constant decrease in irradiance. As for the ambient temperature of the location; it increased gradually from morning to 11:30, then attained fair stability until 16:00, then begin to decrease gradually. Also, the relative humidity was high in the morning; an increase in relative humidity was observed between 6:00 to 7:00, then begin to decrease beyond noon time to 14:30, beyond 14:30 an increase in relative humidity was experienced again; this shows that as irradiance increased, relative humidity decreased. Transient variations of atmospheric parameters are triggered by turbulences within the atmosphere.

The impact of dust on solar panel temperature is revealed in figure 5b. the figure shows that dust accumulation on solar panels enhances its operating temperatures which is undesired. This observation was made in the process of acquiring data from both panels which revealed an average panel temperature difference between the clean and dusty panel to be 5.30^{0}C as evident in table 3. Furthermore, the rise and fall in panel temperature also depends on the level of solar irradiance at the surface of the solar panel which is clearly evident in figure 5a. Our observation about the impact of dust on the solar panel operating temperature corresponds with earlier studies by [38] which reported that the operating temperature of the clean module was observed to be lower than that of the dusty one.

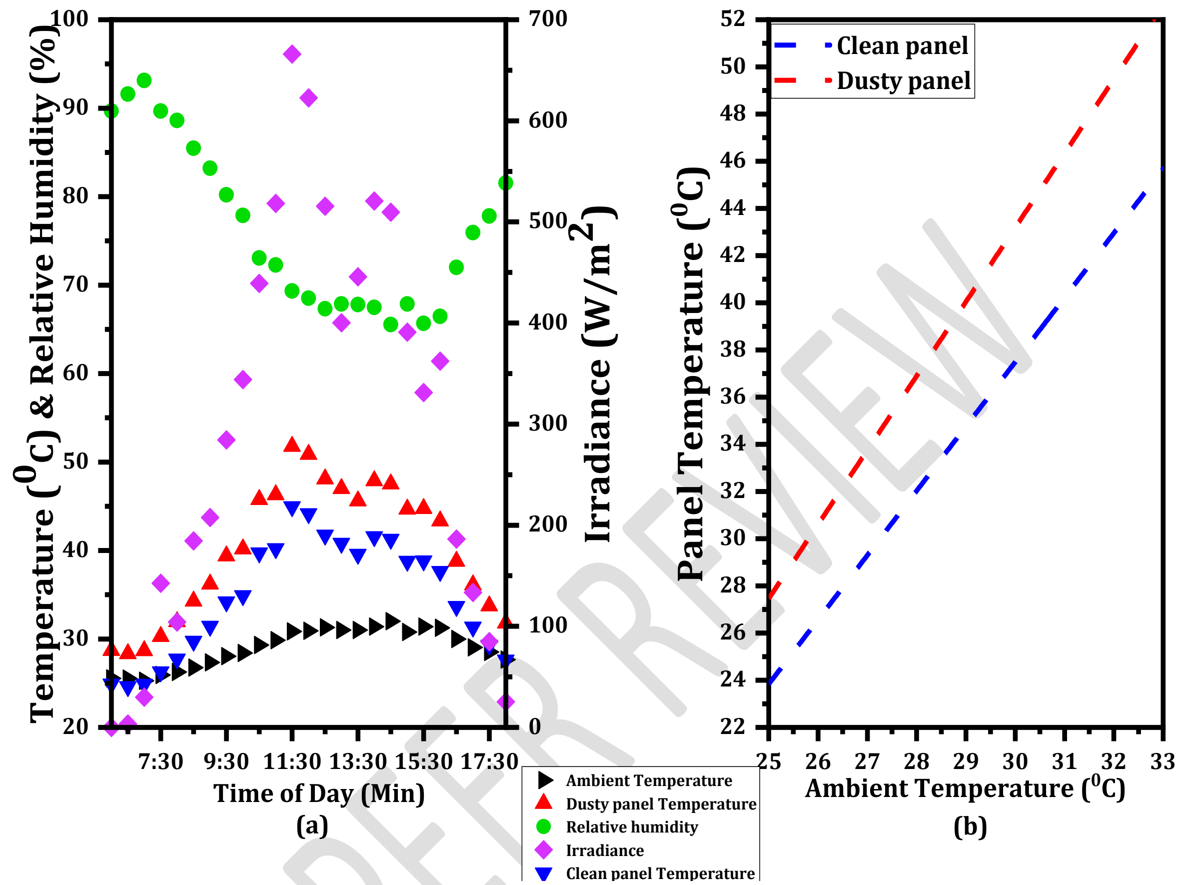

Figure 5: Climatic condition at site and panel temperatures with respect to ambient temperature

3.2. Analysis of electrical performance of both solar panel with varying temperature

The impact of dust on the output electrical parameters of the solar panels with respect to ambient temperature is displayed in figure 6. Figure 6a and figure 6b reveals a higher voltage and current performance from the clean solar panel over the dusty one respectively. The low voltage and current performance from the dusty panel is linked to its higher panel temperature (as revealed in figure 5) which is as a result of the dust on its surface absorbing heat and also obstructing air from reaching its surface to enhance cooling. The poor voltage and current performance from the dusty panel is translated to poor output power and efficiency which is evident in figure 6c and figure 6d respectively. These figures reveals that temperature rise in solar panel which is triggered by dust deposition hiders the performance efficiency of solar panels. Our results in figure 6 is in agreement with earlier researches by [13-15] which revealed that temperature, dust and shade affect the performance efficiency of solar panel.

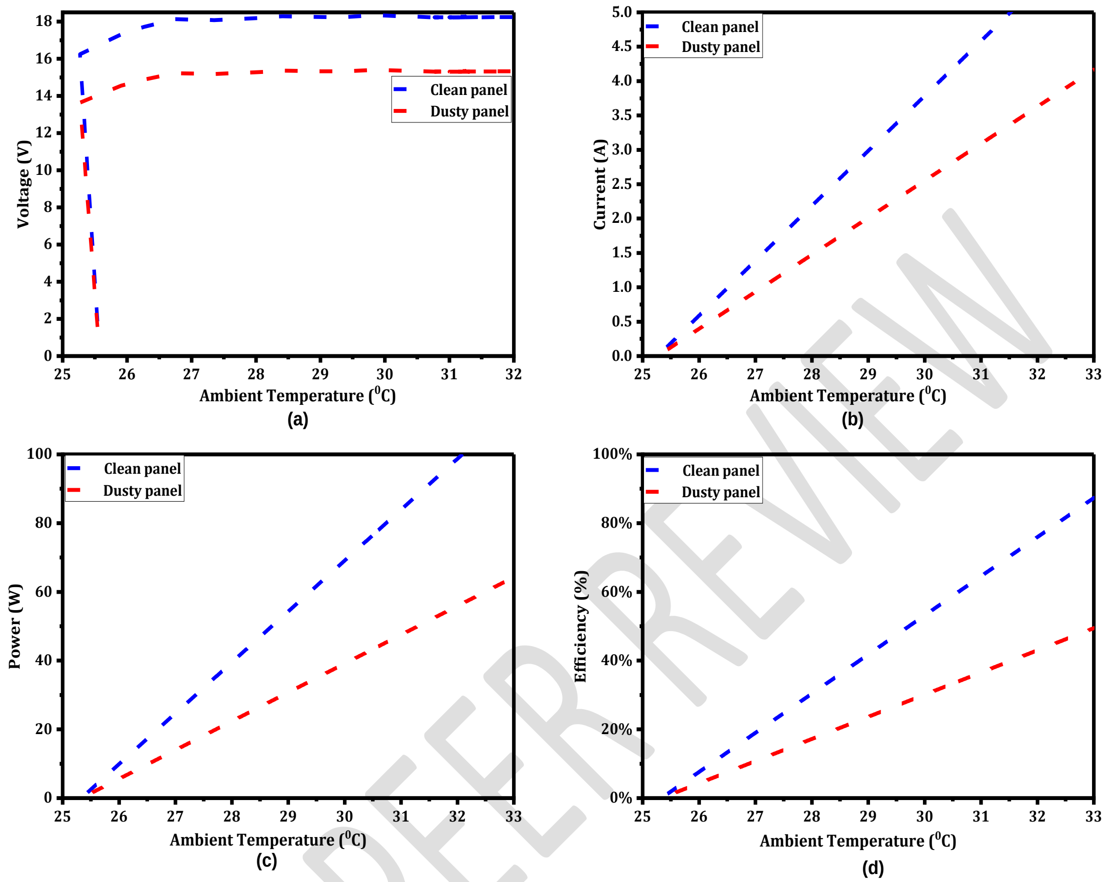

Figure 6: impact of ambient temperature on operating voltage, current, power and efficiency for clean and clean and dusty panels

3.3. Analysis of electrical performance of both solar panel with varying levels of relative humidity

The effect of relative humidity on the clean and dusty solar panel performances is shown in figure 7. From figure 7a and figure 7b respectively, it is revealed that high levels of relative humidity adversely affect the voltage and current performance of both panels. An increase in voltage was observed for both panels as the relative humidity decrease to 80%, below 80% stability in voltage was achieved while a linear increase in current was observed as the humidity level decreases. The figure further shows the dusty panel generating lower voltage and current. High level of humidity hinders solar radiation from reaching the surface of the panels, while the dust on the surface of the dusty panel further hinders the available solar radiation at it surface from going through to reach the cells, which further causes a degradation in its voltage and current performance. Figure 7c and figure 7d which displays the power output and efficiency of both panel respectively is as a result of the voltage and current performances from both panels. It depicts that for the same level of relative humidity around both panels, the lost in power by the dusty panel was up to 43.40% which is a massive lost. Our observation about the impact of dust on the solar panel output power corresponds with earlier studies by [31] which reported that dust accumulation on solar panels up to 6.0986 g/m^2 triggered a 21.47% decrease in the output power.

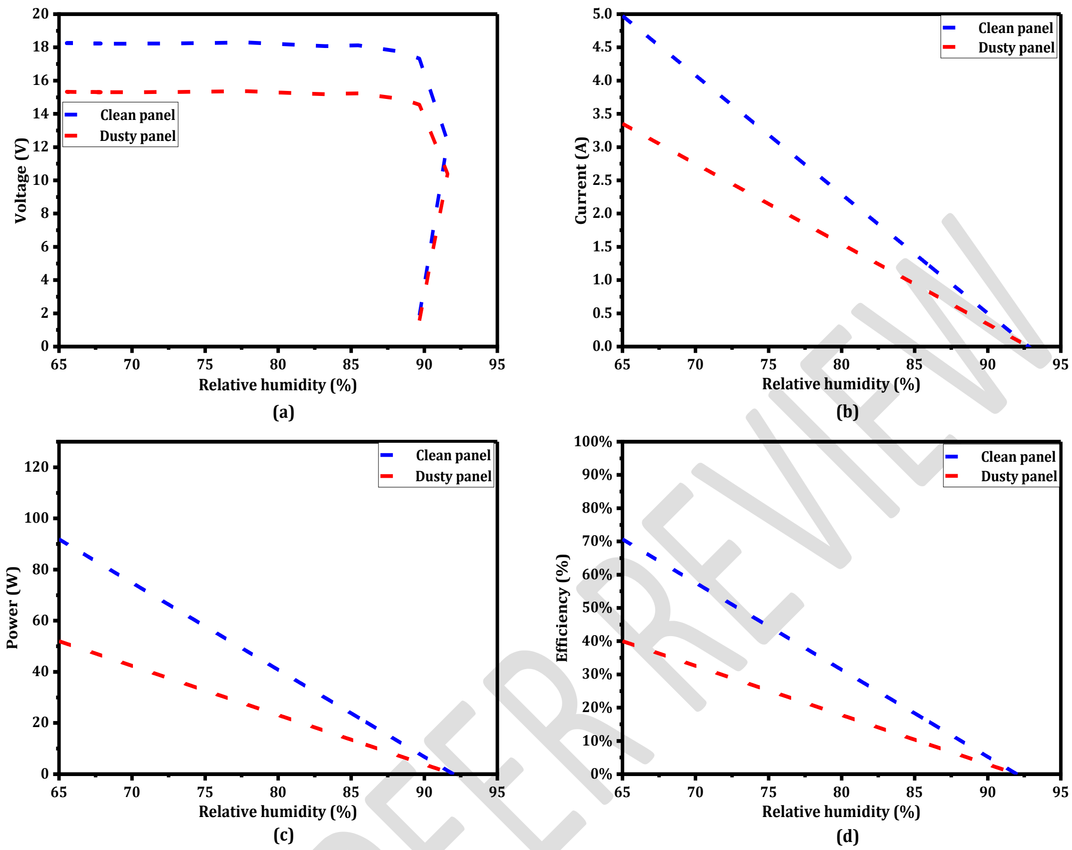

Figure 7: impact of relative humidity on operating voltage, current, power and efficiency for clean and clean and dusty panels

3.4. Analysis of electrical performance of both solar panel with varying levels of irradiance

The impact of dust on the output electrical parameters of the solar panels under the same level of irradiance is displayed in figure 8. The figure reveals an increase in voltage from both panels from 0 to 200 W/m^2, above 200 W/m^2 stability in voltage was attained, while the current, power and efficiency of both panels increases linearly as irradiance increases which conforms to earlier work by [4]. Furthermore, the figure shows low performance in voltage, current, power and efficiency from the dusty solar panel as displayed in figure 8a to figure 8d respectively which is as a result of the obstruction towards solar radiation caused by dust deposition and accumulation on the panel surface. Solar radiation is one of the most important parameter necessary for the effective operation and functionality of a solar panel. Once it is hindered from reaching the cells of a solar panel, the efficiency of the panel is drastically reduced as evident from figure 8d. The difference between the average maximum efficiency attained by the clean panel and the dusty one is 29.26% which is more than 50% efficiency lost as displayed in table 3, and this shows that for solar panel to keep functioning at its best it must be free from dust and shade at all time. Our observations about the impact of dust on solar panel output electrical parameters corresponds with earlier studies by [38] which reported they observed maximum panel efficiency loss to be 64%, 42%, 30%, and 29% for coal, aggregate, gypsum, and organic fertilizer dust, respectively.

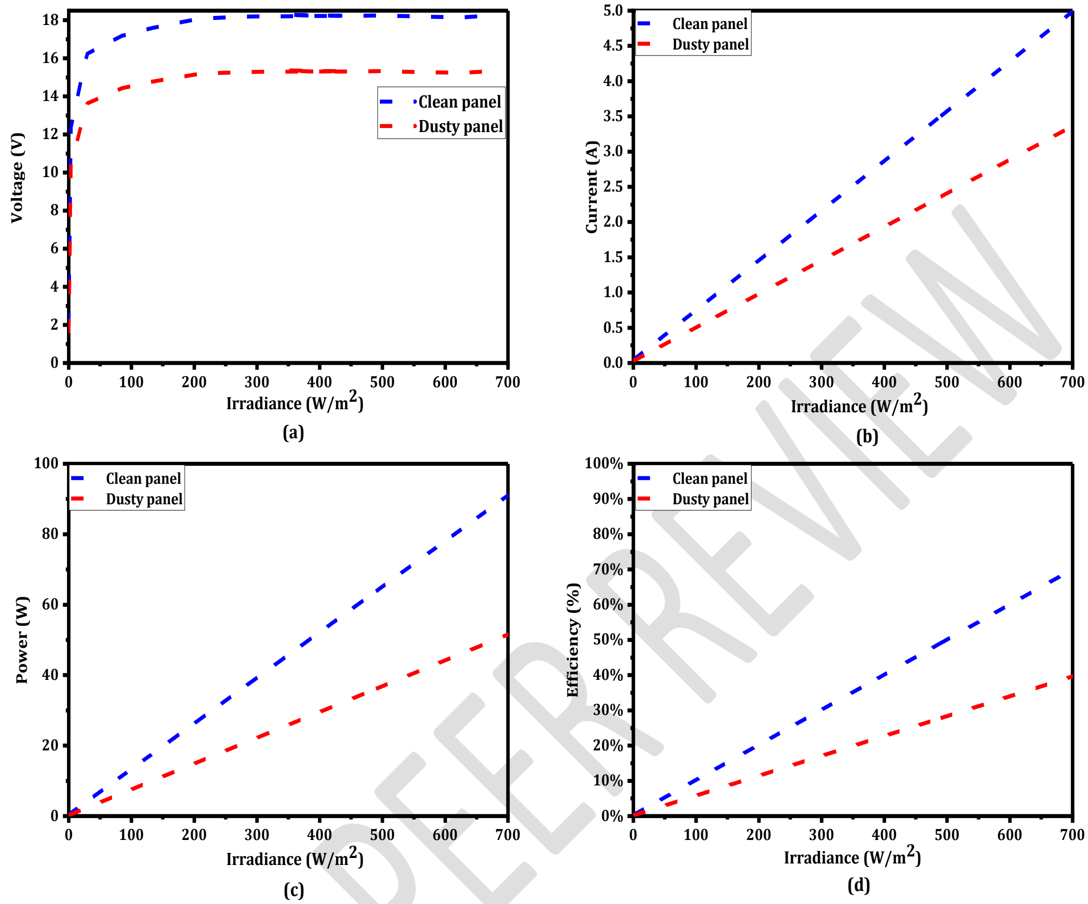

Figure 8: impact of irradiance on operating voltage, current, power and efficiency for clean and clean and dusty panels

4. CONCLUSION

A photovoltaic system with an automatic dust wiping/cleaning mechanism was designed and its impact was evaluated. Loss in performance efficiency of a polycrystalline solar panel due to dust accumulation was investigated in real-time outdoor conditions in an environment where human activity takes place. The impact of dust deposition was ascertained by subjecting both panels to the same environmental and atmospheric conditions. One panel was installed with the automatic dust-wiping mechanism while the other panel was left unattended for the dust to accumulate on it. It was observed that the photovoltaic system with the automatic dust-wiping mechanism performed better in voltage and current performance and efficiency over the dusty panel. The average panel temperature of the photovoltaic system with the automatic dust-wiping mechanism was 5.30^0C lower than the panel without the mechanism. This lower panel temperature of the solar panel with the automatic dust-wiping mechanism led to an increase of 16%, 32.5%, 43.40% and 43.37% in average voltage, average current, average power and average efficiency respectively over the dusty panel. Plummet in voltage and current output due to dust accumulation leads to a loss in power output and efficiency and consequently, huge economic loss to photovoltaic power with concern towards large-scale photovoltaic power generating plants. Solar radiation is one of the most essential parameters necessary for the effective operation and functionality of a solar panel. Once it is hindered from reaching the cells of a solar panel, the efficiency of the panel will immensely decrease. From this study, it is advisable not to mount photovoltaic systems just one metre above the ground in a dusty environment as the study reveals that just 16 weeks after the mounting of the photovoltaic system more than 40% efficiency can be lost. If a photovoltaic system must be mounted one metre above the ground it must be given considerable care and attention or an automatic dust-wiping mechanism must be installed with it, especially for large-scale photovoltaic power generating plants.

ABBREVIATIONS

I_{sc}: Short circuit current
V_{oc}: Open circuit voltage
V_{mp}: Voltage at maximum power
I_{mp}: Current at maximum power
P_{max}: Maximum power of solar panel at STC
MPP: Maximum power point
STC: Standard test condition
LCD: Liquid crystal display

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