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THE EFFECT OF DUST ON THE OUTPUT PERFORMANCE OF SOLAR MODULE

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ABSTRACT

This study investigates the effect of dust on the output performance of a solar module. Two 250W monocrystalline modules (control & dust) were used during the study. The experiment was performed in the University of Port Harcourt, at the Basic Unit in Abuja Campus, Rivers State, Nigeria with longitude 4.903674°N and latitude6.923759°E. The amount of current and voltage generated by both panels, under solar radiation, were recorded using a digital multimeter at an interval of 15minutes between 7am and 4pm for a period of 7days. Measurement data and graphical analyses were used to evaluate the I-V characteristics of the control and dusty modules, and also the amount of output power generated by both modules. The minimum and maximum values of the Cumulative Average Power Output (watt) obtained for the control module were 2156.16W and 5790.655W respectively. While the minimum and maximum values of the Cumulative Average Power Output (watt) obtained for the dusty module were 1743.277W and 4714.068W respectively. The percentage reduction in output power for the solar module with dust typically ranged from 5.92% to 28.78%. The results reveal that dust particle accumulation on the surface of solar module leads to a significant reduction in the current, voltage and amount of output power generated by a solar module which in turn abates its overall performance.

Contribution/Originality: This study is one of very view studies which have investigated the effect of dust on output performance of solar module. The effect of dust is thus quantified in the geographical location.

1. INTRODUCTION

A solar module also known as a solar panel is a single photovoltaic device that consists of an assemblage of connected solar cells which absorb sunlight as a source of energy to generate electricity. The solar cells or photovoltaic cells are electrical devices that convert the energy of light directly into electricity by the photovoltaic effect i.e. the generation of a potential difference at the junction of two different materials in response to electromagnetic radiation. The electricity generated in this process can be used to power equipment or to recharge a battery.

Module electrical connections of the solar cells are made in series to achieve a desired output voltage or in parallel to provide a desired current capability (amperes). The conducting wires that take the current off the modules may contain silver, copper or other non-magnetic conductive transition metals. The working mechanism of the solar cells in the module depends on three factors which are;

i. Absorption of light in order to generate the charge carriers, holes (p-type) and electrons (n-type).
ii. Separation of charge carriers.

iii. The collection of charge carriers at the respective electrodes establishing the potential difference across the p-n junction.

The generation of voltage difference noticed at the p-n junction of the cell in response to visible radiation is utilized to do the work.

Solar modules are used to convert sunlight directly into DC electrical energy. The performance of the solar module is determined by the cell type and characteristics of the silicon or material used, with the two main types being mono-crystalline and polycrystalline silicon.

Dust is a term used to describe dry solid particles suspended in the atmosphere that can range in size from a sub-micron to several tens of microns. Dust can originate from a variety of sources such as soil, salt spray, smoke from forest fires and industrial sources, volcanic eruptions, extraterrestrial sources (i.e., meteor dust), and organic materials, such as bacteria, plant pollen, animal hairs, and human skin cells. Dust may also be defined as crushed form minute particles having size less than 500µm which comes from various sources such as constructional sites, industries and dust storm (Hussain, Batra, & Pachauri, 2017).

A key parameter in describing dust particles is the particle size. The size of dust particles deposited on the surface of a solar module is known to significantly affect the amount of solar radiation reaching the surface of the solar cells. Conventionally, dust particles have a particle size that is below 75µm in diameter or are usually in the size range from about 1 to 100µm in diameter. Particle size can be measured using the measure technique of sieve analysis (which is a fractional or separation technique of particle size) amongst other techniques (Tureková, Mračková, & Marková, 2019).

All solar modules are rated by the amount of DC (direct current) power they produce under standard test conditions. The power output of a solar module represents a solar module's theoretical power production under ideal sunlight and temperature conditions. It is expressed in units of watts (W). The power output of a solar panel depends on three factors:

i. The size of the panel.
ii. The efficiency of the solar cells (i.e., the voltage and current generated by its individual cells).
iii. The amount of sunlight the panel gets.

It is calculated using the equation:

$$P = Isc \times Voc \tag{1}$$

Where:

P = Power in watts.

Voc = Open Circuit Voltage in Volts.

Isc = Short Circuit Current in Amps.

The efficiency of a solar cell is the most commonly used parameter to compare the performance of one solar module to another. It plays a major role when measuring the output performance of a solar module under the influence of external or environmental factors such as dusts. The efficiency of a solar cell can be defined as the ratio of the electrical power output and the solar irradiance input over the device area expressed as a percentage. In other words, solar cell efficiency relates to the amount of available energy from the sun that gets converted into electricity. Solar cell efficiency depends on the spectrum and intensity of the incident sunlight and the temperature of the solar cell.

$$Efficiency E = \frac{Output\ Power}{Input\ Power}\ x\ 100 \tag{2}$$

The accumulation of dust particles from the external environment on solar modules is a natural occurrence. Thus, efforts are being made by researchers to study the effect of these dust particles as regards the output performance of solar modules.

Elminir et al. (2006) studied the "Effect of dust on the transparent cover of solar collectors" and observed that the output performance of a solar module is greatly influenced by the gradual degradation of transmittance that depends on the accumulation of dust. The results obtained showed that the reduction in glass normal glass transmittance depends strongly on the dust deposition density in conjunction with tilt angle which has a profound effect on the efficiency and output performance of the solar panel. They concluded that, for moderately dusty places, weekly cleaning of the glass cover of the solar module is strictly recommended so as to retain the nominal operating efficiency and output performance of a solar module.

Sulaiman, Hussain, Leh, and Razali (2011) worked on the "Effects of Dust on the Performance of PV Panels" using artificial dust (mud and talcum) under a constant irradiance conducted in an indoor lab. The study shows that dust has an effect on the performance of solar PV panel. In their observation, the reduction in the peak power generated by the module can be up to 18% and under greater irradiation, the effect of dust became slightly reduced but not negligible. They concluded that dust particles must be removed from the surface of solar PV panels in order to ensure highest performance.

Rahman, Aminul, Zadidul, and Asraful (2012) carried out a research study on the "Effects of Natural Dust on the Performance of PV Panels in Bangladesh" and it was observed that the value of short circuit current and power decreases with respect to the amount of dust on the solar panel, thus reducing the performance of the PV panel. It was also noticed that greater irradiation does not nullify completely the effect of dust on the output efficiency of the panel. They came to a conclusion that the presence of dust on the surface of a solar module has an effect on the performance of solar PV panel and the reduction in the peak power generated can be up to 20%. Also, it was concluded that the surface of solar PV panels should be kept clean from dust particles in order to ensure highest performance.

Studies by Rao, Pillai, Mani, and Ramamurthy (2014) on the "Influence of dust deposition on photovoltaic panel performance" showed that dust deposition on PV panels has an influence on the cell operating temperatures and an increase in temperature due to the presence of dust further reduces the efficiency and performance of the panel. Their study also showed a correlation between dust deposition density and the power losses associated with dust settlement on photovoltaic panels such that the more dense the dust on the panel, the higher the decrease in the output power of the PV panel. In their study, it was concluded that dust deposition leads to a significant drop in current output, degradation of the output performance of solar panels, and the consequent drop in power output due to dust is an immense loss of electrical power.

A research study on "The Effect of dust on performance of PV panel and design cleaning system" was conducted by Hameed et al. (2019) using four 300-watt solar panels. They observed that the spread of dust in the atmosphere and its accumulation on the surface of the solar modules generates a barrier on it, reducing its ability to absorb photons falling on it and hence, leads to a reduction in both the short circuit current and the output power. It was also observed that the accumulation of 4grams per square meter reduces the conversion efficiency of solar energy by 4%. Thus, the efficiency of the solar module is reduced by a certain percentage, leading to loss of solar energy. They concluded that the accumulation of dust on the solar panel surface has an essential effect on the panel's output power such that with increasing amount of dust particles, there is significant decrease in the output power and performance of the solar panel.

This paper thus reports the effect of dust particles on the output performance of solar module in this geographical location to affirm the claims and reports of other researchers.

2. MATERIALS AND METHODS

The employed materials for the study are :

1. Two 250W solar modules - which are Sunpower solar module products having the following specifications Figure 1:

i. Maximum Power/Pmax(W) 250W
ii. Maximum Power/Tolerance +3%
iii. Open-circuit Voltage/VOC (V) 37.60V
iv. Open-circuit Current/ISC (A) 8.75A
v. Maximum Power Voltage/Vimp 31.20V
vi. Maximum Power Current/Imp (A) 8.02A

2. Two Digital multimeters - which are UNITY digital multimeters DT9205A product having the following specifications Figure 2:

i. 3 and Half digits, 7segment, 35mm Large LCD display
ii. Large LCD display
iii. Maximum Value display 1999
iv. Out of range indication (Displays 1)
v. Symbols for High Voltage
vi. Low Battery indication
vii. Range Selected Display
viii. 2 to 3mm thick Yellow protective jacket cover (removable)
ix. Recessed display to protect from damage
x. Bright/Clear Easily visible display at all angles (wide and up/down angles also).

The DT9205A digital multimeter also has the following measuring range:

i. AC Voltage (V): 2V, 20V, 200V, 750V.
ii. DV Voltage (V): 200mV, 2V, 20V, 200V, 1000V.
iii. AC Current (A): 2mA, 200mA, 20A.
iv. DC Current (A): 20µA, 2mA, 200mA, 20A.
v. Resistance (Ohm): 200Ω, 2kΩ, 20kΩ, 200kΩ, 2MΩ, 200MΩ, 200MΩ.
vi. Capacitance (F): 20nF, 2µF, 20µF, 200µF.

2.1. Experimental Set-Up

The experiment was performed in the University of Port Harcourt, at the Basic Unit in Abuja Campus, Rivers State, Nigeria with longitude 4.903674°N and latitude 6.923759°E. Two monocrystalline PV panels of 250W each were mounted and inclined at an angle of 15° to the horizontal in a manner suitable for both panels to harness full solar radiation (Amusan, Chukwuocha, & Edah, 2012). The PV panels (control & dusty panel) having two terminals (positive and negative) were connected to the positive and negative terminals of the multimeter which was used to take current and voltage values at intervals of 15 minutes Figure 3.

The methodology includes:

i. Incline the solar panels at angle of about 15° on the ground mount.
ii. Record Open Circuit Voltage, Voc from the terminal of the inclined solar panels (control & dust).
iii. Record Short Circuit Current, Isc from the terminal of the inclined solar panels (control & dust).
iv. Calculate the Output power, Pdc from (ii) and (iii).
v. Record the weather conditions at instant of measurements.
vi. Tabulate the readings starting from 7:00am to 4:00pm at interval of 15minutes.
vii. Tabulate Average power, Pdc for each day for both control and dusty panels.
viii. Plot Isc–Voc graph for each day for both control and dusty panels.
ix. Plot graph of power, Pdc against time of the day for both control and dusty panels.
x. Plot Voc (control) and Voc (solid dirt) against time of the day
xi. Determine % loss in output voltage from (x).

xii. Determine % loss in output power from (ix).

Figure-1. Employed 250w solar panel.

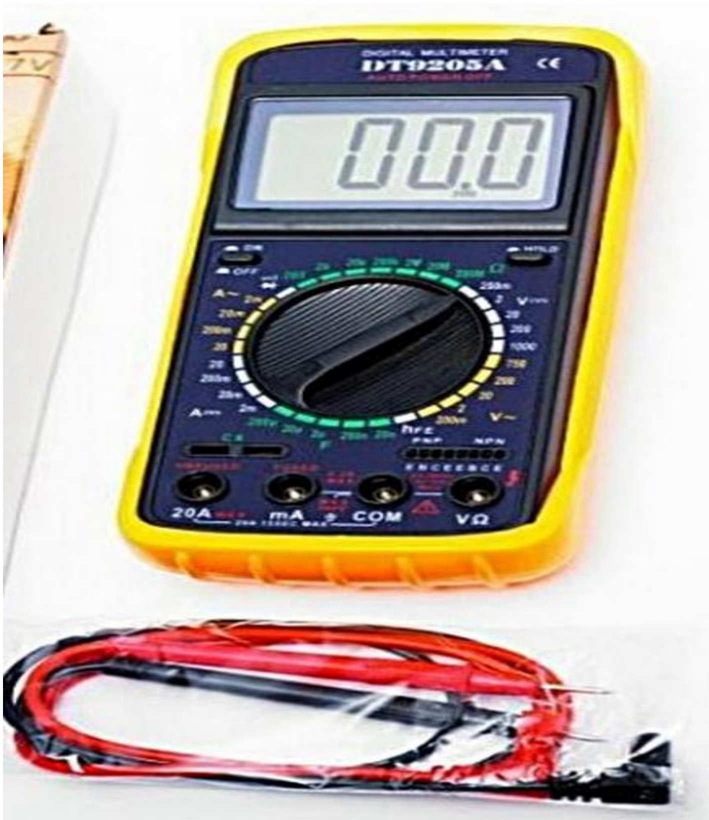

Figure-2. Employed digital multimeter.

Figure-3. In-Situ Experimental Set-Up.

3. RESULTS AND DISCUSSION

Previously, the influence of dust on the output performance of a solar module has been largely ignored. The typical measured values obtained during the period of the experiment are shown in Table 1 and 2. However, the results obtained in this experiment shows that dusty solar modules also generate electricity, but at a minimal rate as compared to clean solar modules.

Figures 4 and Figure 5 show respectively the I-V curve for the control module and dusty module for the measured values of short-circuit current Isc and open-circuit voltage Voc for day 1. In Figure 4, the maximum values of Isc and Voc generated by the control module were 8.38A and 28.1V respectively. Whereas in Figure 5, the maximum values of Isc and Voc generated by the dusty panel were 7.45A and 27.4V respectively. There was a reduction in the maximum Isc generated by the dusty module as compared to the control module because of the presence of dust on the solar module.

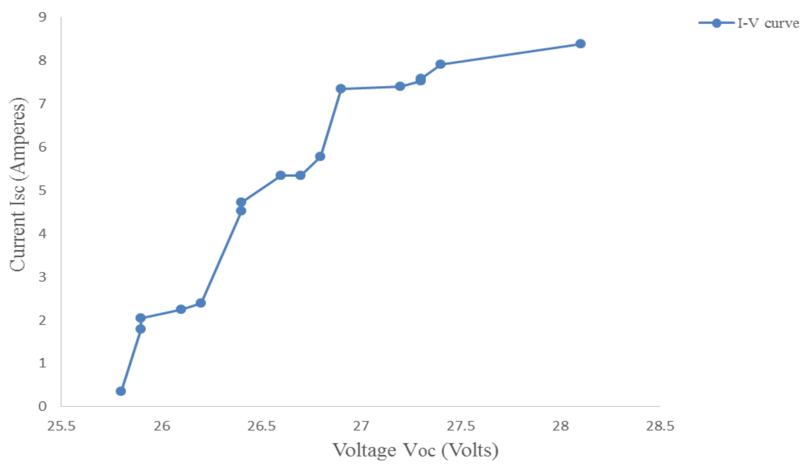

Figure-4. I-V curve for control panel Day 1.

Table-1. Measured Values for Day 1.

Time (mins)	Weather	Isc (short circuit current) for control panel (A)	Voc (open circuit voltage) for control panel (V)	Average Power Pdc for control panel (watt)	Isc (short circuit current) for dusty panel (A)	Voc (open circuit voltage) for dusty panel (V)	Average Power Pdc for dusty panel (watt)
7:00a.m	Cloudy	0.35	25.90	9.065	0.29	27.40	7.946
7:15a.m	Cloudy	1.79	26.70	47.793	1.68	26.30	44.184
7:30a.m	Cloudy	4.72	27.40	129.328	2.30	27.00	62.100
7:45a.m	Cloudy	2.05	26.40	54.120	1.31	26.00	34.060
8:00a.m	Cloudy	2.40	26.80	64.320	1.45	26.10	37.845
8:15a.m	Rainfall	–	–	–	–	–	–
8:30a.m	Rainfall	–	–	–	–	–	–
8:45a.m	Rainfall	–	–	–	–	–	–
9:00a.m	Rainfall	–	–	–	–	–	–
9:15a.m	Rainfall	–	–	–	–	–	–
9:30a.m	Rainfall	–	–	–	–	–	–
9:45a.m	Rainfall	–	–	–	–	–	–
10:00a.m	Rainfall	–	–	–	–	–	–
10:15a.m	Rainfall	–	–	–	–	–	–
10:30a.m	Rainfall	–	–	–	–	–	–
10:45a.m	Rainfall	–	–	–	–	–	–
11:00a.m	Rainfall	–	–	–	–	–	–
11:15a.m	Rainfall	–	–	–	–	–	–
11:30a.m	Rainfall	–	–	–	–	–	–
11:45a.m	Rainfall	–	–	–	–	–	–
12:00p.m	Rainfall	–	–	–	–	–	–
12:15p.m	Rainfall	–	–	–	–	–	–
12:30p.m	Rainfall	–	–	–	–	–	–
12:45p.m	Rainfall	–	–	–	–	–	–
1:00p.m	Rainfall	–	–	–	–	–	–
1:15p.m	Rainfall	–	–	–	–	–	–
1:30p.m	Sunny	7.40	28.10	207.940	5.59	26.50	148.135
1:45p.m	Sunny	7.53	27.20	204.816	6.03	26.00	156.780
2:00p.m	Sunny	7.92	25.80	204.336	6.98	25.90	180.782
2:15p.m	Sunny	5.78	26.20	151.436	3.76	26.10	98.136
2:30p.m	Sunny	7.34	25.90	190.106	7.08	25.90	183.372
2:45p.m	Sunny	8.38	26.10	218.718	7.45	26.30	195.935
3:00p.m	Fair	2.24	26.40	59.136	2.29	25.30	57.937
3:15p.m	Sunny	5.34	27.30	145.782	4.70	27.10	127.370
3:30p.m	Sunny	4.52	26.90	121.588	3.85	26.70	102.795
3:45p.m	Sunny	5.34	27.30	145.782	4.72	26.60	125.552
4:00p.m	Sunny	7.59	26.60	201.894	6.78	26.60	180.348

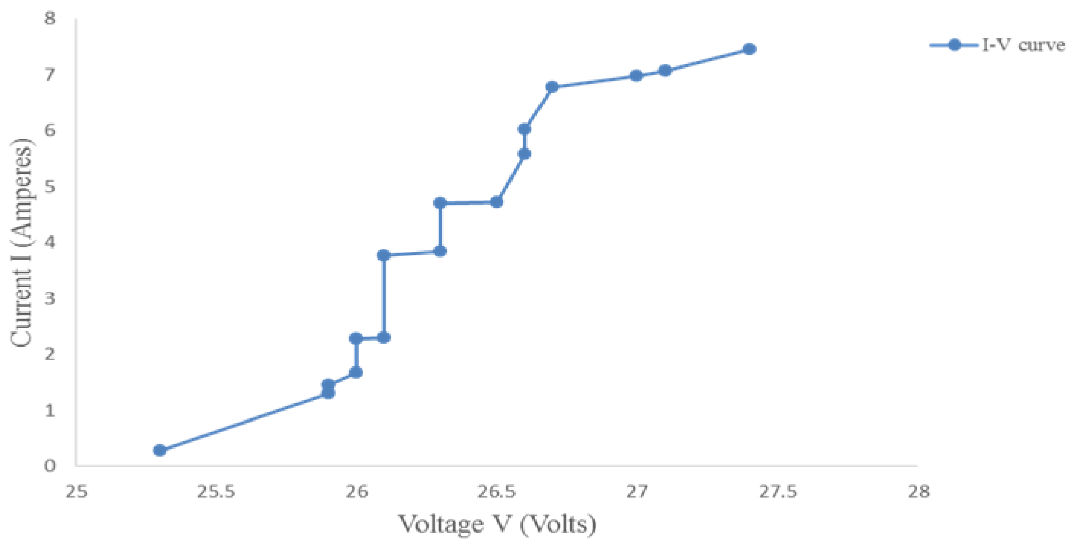

Figure-5. I-V curve for dusty panel Day 1.

Figure 6 shows a plot of open-circuit voltage Voc for both control and dusty module against time of day. As seen in the Figure 6, the maximum open-circuit voltage Voc produced by the control module was 28.1V at 1:30p.m while that of the corresponding dusty module was 26.5V at the same time.

Thus, the percentage (%) loss in output voltage at 1:30p.m from both the control and dusty modules can be calculated from Figure 6 as follows:

$$\% \, Loss \, in \, Output \, Voltage = \frac{Max. V_{oc} \;\; for \; control - \; Max. V_{oc} \;\; for \; dust}{Max. V_{oc} \;\; for \; control} \;\; x \; 100\% \qquad (3)$$

Thus,

$$\% \, Loss \, in \, Output \, Voltage = \frac{28.1 \; - \; 26.5}{28.1} \;\; x \; 100\% \; = \; 5.69\%$$

This 5.69% loss in output voltage is due to the presence of dust on the solar module which traps more heat to the solar cells thus reducing the solar cell's output voltage which is temperature regulated.

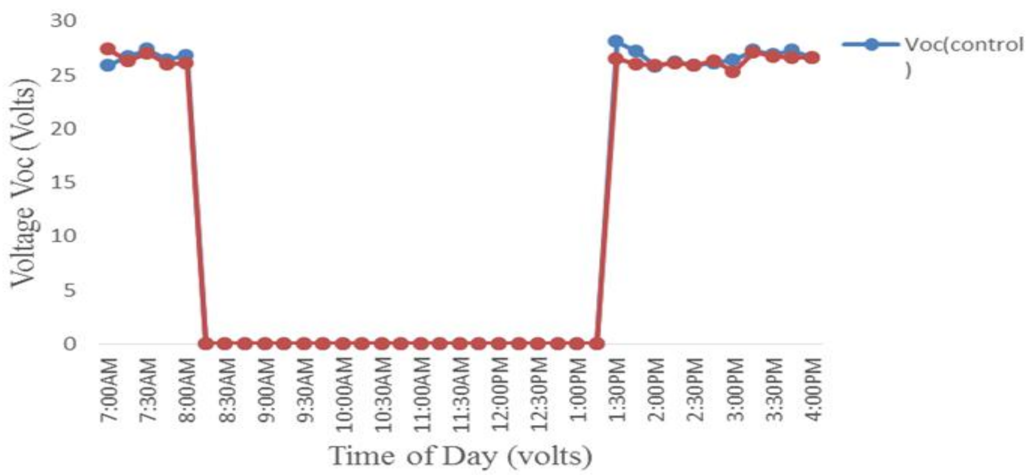

Figure-6. Voc (control and dust in volts) against Time of day for day 1.

Figure 7 shows a plot of average power Pdc (watts) for both control module and dusty module against time of the day (mins). There was no power generated between 08:15a.m and 01:15p.m for both the control and dusty module due to rainfall during this time interval since both panels have to be kept from the rain. The maximum power generated by the control module was 207.940W at 1:30PM while the corresponding value for the dusty module was 148.135W at the same time. It is clear from the Figure 7 that solar modules work effectively or optimally when they are completely clean.

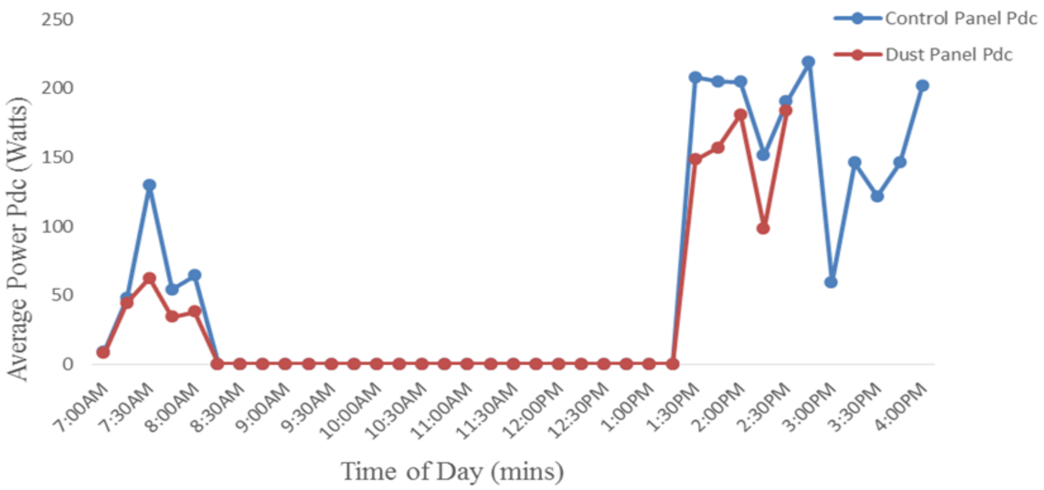

Figure-7. Average Power Pdc (watts) for control and dusty panels against Time of day (mins) for day 1.

Therefore, the percentage (%) Power Loss at instance can be calculated as:

$$\% \; Power \; Loss = \frac{207.94 - 148.135}{207.94} \; x \; 100\% = 28.76\%$$

This 28.76% loss in the output power could be attributed to the effect of dust that was accumulated on the solar module. In the same vein, the maximum power produced by the control module was 218.718W at 02:45p.m and that of the corresponding dusty module was 195.935W at the same time. Hence,

$$\% \; Power \; Loss = \frac{218.718 - 195.935}{218.718} \; x \; 100\% = 10.42\%$$

Figures 8 and 9 show respectively the I-V curve for the control module and dusty module for the measured values of short-circuit current Isc and open-circuit voltage Voc for day 7. In Figure 8, the maximum values of Isc and Voc generated by the control module were 9.25A and 27.0V respectively. Whereas in Figure 9, the maximum values of Isc and Voc generated by the dusty panel were 8.79A and 26.9V respectively. There was a reduction in the maximum Isc generated by the dusty module as compared to the control module because of the presence of dust on the solar module.

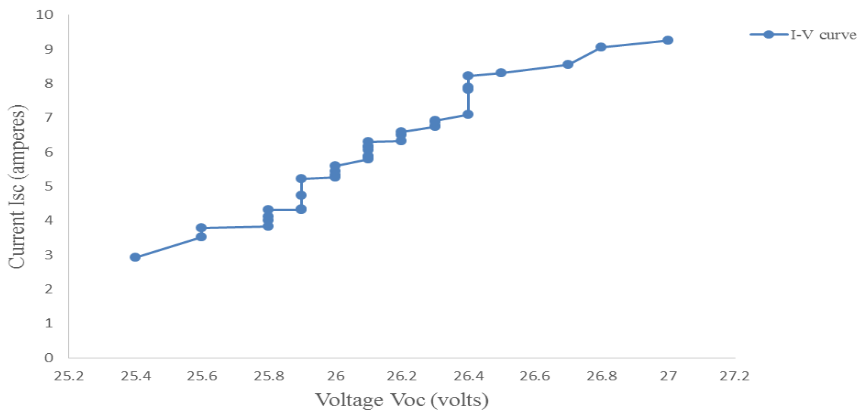

Figure-8. I-V curve for control Panel Day 7.

Table-2. Measured Values for Day 7.

Time (mins)	Weather	Isc (short circuit current) for control panel (A)	Voc (open circuit voltage) for control panel (V)	Average PowerPdcfor control panel (watt)	Isc (short circuit current) for dusty panel (A)	Voc (open circuit voltage) for dusty panel(V)	Average Power Pdc for dusty panel (watt)
7:00a.m	Sunny	5.21	27.00	140.670	4.49	26.90	120.781
7:15a.m	Sunny	5.59	26.80	149.812	4.72	26.60	125.552
7:30a.m	Sunny	4.12	26.50	109.180	3.69	26.40	97.416
7:45a.m	Sunny	4.74	26.30	124.662	3.87	26.20	101.394
8:00a.m	Sunny	5.27	26.30	138.601	4.76	26.10	124.236
8:15a.m	Sunny	5.88	26.20	154.056	4.87	25.90	126.133
8:30a.m	Sunny	6.32	26.00	164.320	5.69	25.90	147.371
8:45a.m	Sunny	6.59	26.00	171.340	5.74	25.80	148.092
9:00a.m	Sunny	7.89	25.80	203.562	6.79	25.60	173.824
9:15a.m	Sunny	6.88	26.10	179.568	5.77	25.90	149.443
9:30a.m	Sunny	8.22	26.40	217.008	7.49	26.00	194.740
9:45a.m	Sunny	9.25	26.20	242.350	8.79	25.80	226.782
10:00a.m	Sunny	8.55	25.90	221.445	7.69	25.50	196.095
10:15a.m	Sunny	6.75	25.80	174.150	4.89	25.60	125.184
10:30a.m	Sunny	5.87	26.10	153.207	4.85	25.90	125.615
10:45a.m	Sunny	6.16	26.00	160.160	5.46	26.00	141.960
11:00a.m	Sunny	6.30	26.10	164.430	5.65	25.90	146.335
11:15a.m	Sunny	4.34	26.40	114.576	3.38	26.20	88.556
11:30a.m	Sunny	3.79	26.40	100.056	3.06	26.10	79.866
11:45a.m	Sunny	4.00	26.70	106.800	3.05	26.40	80.520
12:00p.m	Sunny	5.79	25.80	149.382	3.42	25.50	87.210
12:15p.m	Sunny	4.31	25.40	109.474	3.61	25.20	90.972
12:30p.m	Sunny	3.82	25.90	98.938	3.27	26.20	85.674
12:45p.m	Sunny	6.50	26.10	169.650	3.69	25.80	95.202
1:00p.m	Sunny	7.83	25.60	200.448	6.22	25.30	157.366
1:15p.m	Sunny	8.32	25.60	212.992	6.74	25.60	172.544
1:30p.m	Sunny	3.52	25.90	91.168	2.82	25.80	72.756
1:45p.m	Sunny	6.92	26.00	179.920	5.34	26.10	139.374
2:00p.m	Sunny	2.92	25.80	75.336	1.74	25.90	45.066
2:15p.m	Sunny	6.76	26.40	178.464	4.84	25.80	124.872
2:30p.m	Sunny	4.32	26.30	113.616	3.88	26.00	100.880
2:45p.m	Sunny	5.32	26.30	139.916	4.20	25.80	108.360
3:00p.m	Sunny	9.06	26.10	236.466	7.60	26.00	197.600
3:15p.m	Sunny	6.15	25.90	159.285	5.43	25.50	138.465
3:30p.m	Sunny	7.09	26.20	185.758	5.96	25.90	154.364
3:45p.m	Sunny	6.06	26.10	158.166	4.78	25.10	119.978
4:00p.m	Sunny	5.43	26.10	141.723	3.95	26.20	103.490

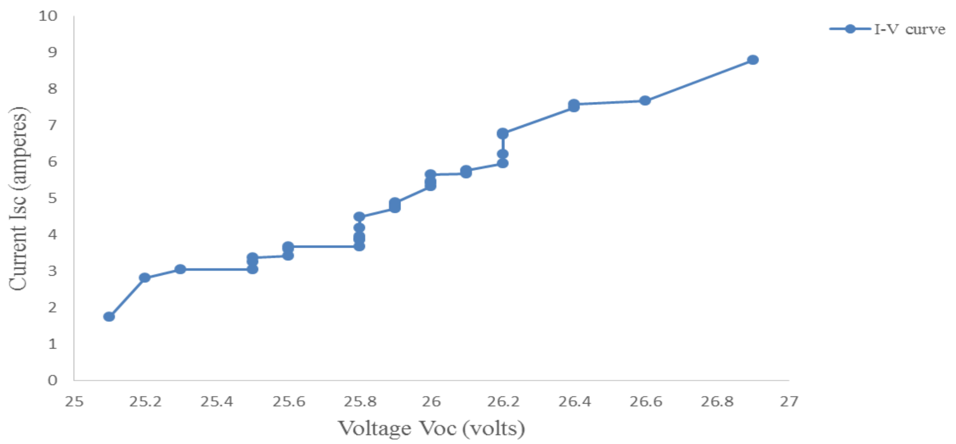

Figure-9. I-V curve for dusty Panel Day 7.

Figure 10 shows a plot of open-circuit voltage Voc for both control and dusty module against time of day. As seen in the Figure 10, the maximum open-circuit voltage Voc produced by the control module was 27.0V at

07:00a.m while that of the corresponding dusty module was 26.90V. The percentage (%) loss in output voltage at 07:00a.m from both the control and dusty modules is:

$$\% \; Loss\, in\; Output\, Voltage = \frac{Max.V_{oc} \;\; for\; control - \;\; Max.V_{oc} \;\; for\; dust}{Max.V_{oc} \;\; for\; control} \quad x \; 100\%$$

Thus,

$$\% \; Loss\, in\; Output\, Voltage = \frac{27.0 - 26.9}{27.0} \quad x \; 100\% \; = \; 0.37\%$$

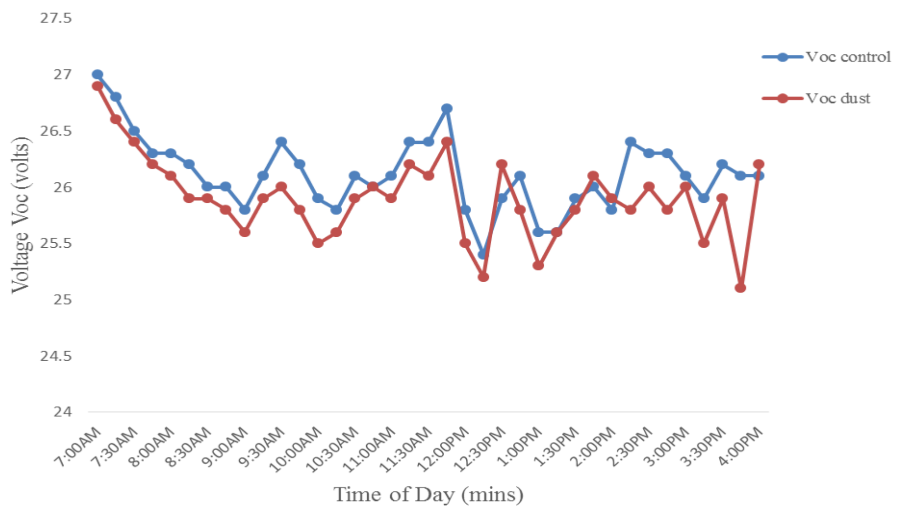

Figure-10. Voc (control and dust in volts) against Time of day (mins) for Day 7.

Figure 11 shows a plot of average power Pdc (watts) for both control module and dusty module against time of day (mins). The maximum power generated by the control module was 242.32W at 09:45a.m while the corresponding value for the dusty module was 226.782W. It is observed that solar modules work effectively or optimally when they are completely clean.

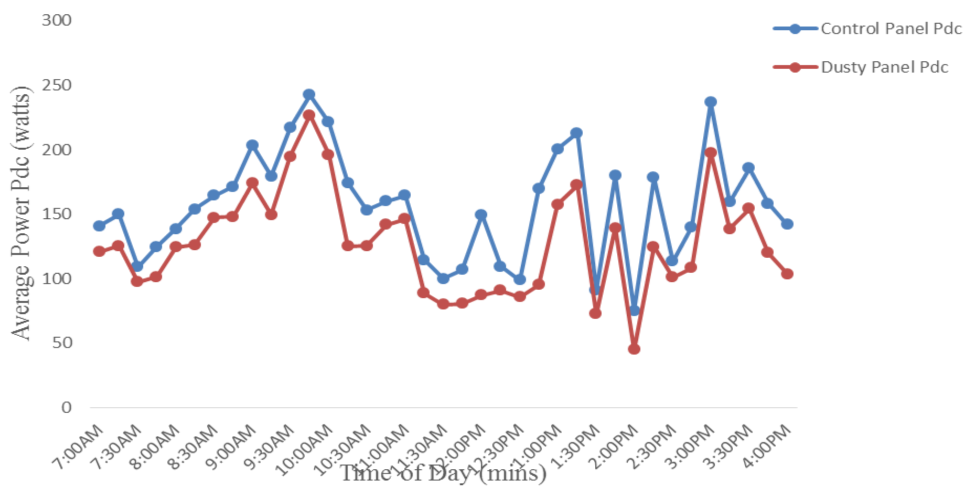

Figure-11. Average Power Pdc for control and dusty panel against Time of day (mins) for Day 7.

Therefore, the percentage (%) Power Loss is :

$$\% \, Power \, Loss = \frac{242.35 - 226.782}{242.35} \, x \, 100\% \; = 6.42\%$$

The 6.42% loss in the output power could be attributed to the effect of dust that was accumulated on the solar module. Also, the maximum power produced by the control module was 236.466W at 3:00p.m and that of the corresponding dusty module was 197.60W.

Hence,

$$\% \, Power \, Loss = \frac{236.466 - 197.60}{236.466} \, x \, 100\% \; = 16.44\%$$

Table 3 summarizes the total average power output obtained during the period measurements for the control and dusty modules. It shows that the accumulation of dust on a solar module significantly reduces the average power output it generates irrespective of the intensity of solar radiation incident on it.

Table-3. Summary of total average output power for the control and dusty modules for the days of measurement.

Days	Cumulative Average Power Output for Control Module (watt)	Cumulative Average Power Output for Dusty Module (watt)	% Power Loss
1.	2156.16	1743.277	19.14%
2.	2830.672	2520.39	10.96%
3.	3680.373	3141.732	14.64%
4.	4123.265	3310.238	19.72%
5.	5129.94	4185.149	18.42%
6.	3097.706	2462.337	20.51%
7.	5790.655	4714.068	18.59%

At instance of measurement, the range of output power loss can be from 5.92% to 28.76%. Cumulatively, the total output power loss daily ranges from 10.96% to 20.51%. The observed variations in percentage (%) loss of average output power is primarily caused by the variations in short-circuit current Isc and open-circuit voltage Voc generated by both the control and dusty modules which control the output power Pdc generated by both modules.

It was also observed that increase or decrease in volume of the dust particles accumulated on the surface of the solar module will determine the level of glass transmittance and thus the amount of solar irradiation reaching the solar cells which in turn affects the output current and output voltage generated by the solar module. The higher the quantity of dust particles spanning the panel's surface, the greater the reduction in solar irradiation reaching the solar cells which in turn affects the output power.

These losses in output power are commonly referred to as optical losses because they chiefly influence the power generated from the solar module by reducing the short-circuit current. Optical losses consist of light energy which could have generated an electron-hole pair, but does not, because the light is reflected from the front surface by particles present on the surface of the solar module such as dust. Thus, the photons can't get through the dust particles to the solar cells and most of the current is lost due to the reflection of the photons by the particles.

4. CONCLUSION

The output efficiency and performance of a solar module with dust particle accumulation was studied. The materials used were two 250Watts monocrystalline solar modules and a digital multimeter. The output performance of the modules with the presence of dust on one module (dust) and the absence of dust on the other (control) was analyzed and evaluated at a time interval of 15minutes with respect to the weather condition. The study shows that the I-V characteristics of a solar module is largely altered by the presence of dust particles such that the maximum current and voltage generated by the module decrease regardless of the amount of solar irradiation reaching the module because of dust particle accumulation. For instance, a maximum current of 8.38A and a maximum voltage of 28.1V were measured from the control module on day 1 as compared to a maximum current of 7.45A and a maximum voltage of 27.4V measured from the dusty panel on same day under same solar intensity. This indicates that the I-V relationship for a clean solar module is more efficient than that of a dusty one. The study also shows that accumulated dust particles greatly influences the power output of a solar module, thus reducing its overall performance. For instance, the maximum power generated by the control module was 308.34W at 09:15a.m while the corresponding value for the dusty module was 277.504W at the same time during day 2 of the experiment. Thus, the reduction in output power for the solar module with dust typically ranges from 5.92% to 28.78%. With these results, the output power of solar modules decreases with increase in dust particle accumulation. Thus, regular cleaning of the panel's surface should be carried out to ensure that its maximum potential is utilized.

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