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THE EFFECT OF BLACK SOOT ON THE OUTPUT PERFORMANCE OF SOLAR MODULE

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ABSTRACT

This study investigates the effect of black soot on the output performance of solar module. The study was carried out at Basic studies building of the University of Port Harcourt, Rivers state, Nigeria (longitude 4.9004^0 N and latitude 6.9204^0 E and 468m elevations above the sea level). Two monocrystalline solar modules were employed for the study. One served as a control (clean) while the other as a device under test (sooty). A multimeter was used to measure the parameters that include:

short-circuit current I_{SC} and open-circuit voltage V_{OC} while the output power and percentage (%) losses were calculated for with the measured values. Also, the measured values and graphical analysis were employed to determine the I-V characteristics of both solar modules. From the measured values, the maximum value of V_{OC} on day 1 for the control module is 35.7V at 11:15am while the corresponding value for the sooty module is 34.3V at the same time. Typically, the total daily output power for the control module was 7103.15W while the corresponding value for the sooty solar module was found to be 4827.38W. This shows 32.04% loss in the power output due to black soot on the surface of the solar module. Cumulatively, the total output power loss daily ranges from 32.04% to 63.90%.

Keywords : Black Soot, Solar Module, Short-circuit current, open circuit voltage, Output Power.

1.0 Introduction

Of recent, the presence of black soot has been observed in localities. The black soot thickly covered surfaces of objects like tables, water, cars, books, tree leaves, chair, floors, window nets, bed sheets, wall and so on. In fact, any object exposed to the outdoor environment has great tendency of being covered with the black soot. The thickness of black soot increases daily on the surface of the exposed objects. The presence of soot pollution is more pronounced in the oil rich cities and highly industrialized environments due to incomplete combustion of Carbon from wood, coal, fossil fuels e.t.c.

Soot sometimes called lampblack or carbon black, is a fine black or brown powder that can be slightly sticky and is a product of incomplete combustion. A major component of soot is black carbon. Since soot is sticky, it tends to stick to exhaust pipes and chimneys where combustion occurs. In pollution terms, soot is the common term for a type of particle pollution known as PM 2.5, which is particulate matter 2.5 micrometers in diameter or smaller [1]. Soot is composed of variety of chemicals and its exact composition depends strongly on what is being burned.

Solar panel which is the source of renewable, clean, energy source is not an exception for soot accumulation when installed outdoor for power generation. Solar cell directly converts the solar radiation that shines on its surface to current electricity. The solar radiation impinges the solar cells and the electrons are knocked out of the cell, thus creating electron – hole mobility that produces the electricity. The direct current generated from solar cells can further be converted to alternating current needed in homes to power appliances such as laptops, phones, refrigerator, lamp, light bulbs, air conditioner, electric fans and so on.

The accumulation of black soot on the surface of the installed solar panels thus necessitates this study. Other factors such as dirt, droppings from birds, shadow, tilt angle, ambient temperature, relative humidity have been considered by several authors. Figure 1 below shows a typical human foot that was stained by black soot.

Figure 1: Typical human foot stained by black soot.

It was shown that the reduction in PV module conversion efficiency were 10%, 16% and 20% respectively for 12.5 g/m^2, 25 g/m^2 and 37.5 g/m^2 dust deposition on its surface [2].

An experiment was conducted to investigate the impact of wind speed and dust accumulation on the PV cell performance. The results showed that Wind speed affects the PV cell performance largely since the output reduction is greater in high winds than in low winds. At the same time, the wind affects the sedimentological structure of the dust coating on the cell, resulting in a higher transmittance (of light) for coatings created during high winds. The experiment investigated the effect of aeolian dust deposition on photovoltaic solar cells [3].

In the Eastern Province of Saudi Arabia, the effect of dust accumulation on the output of PV modules was conducted. After six months of exposure to the environment, it was observed that power decreased by as much as 50% as experienced by the solar modules. In the study, it was found that due to sand dust deposition on PV panel surface, the reduction in short circuit current (I_{sc}) and maximum power output (P_{MAX}) are respectively 40% and 34% [4].

The effect of dust on the transparent cover of solar collectors was discussed. The reduction in glass normal transmittance depends strongly on the dust deposition density in conjunction with plate tilt angle, as well as on the orientation of the surface with respect to the dominant wind direction [5].

It was reported that dust is the lesser acknowledged factor that significantly influences the performance of the PV installations [6].

The influence of dust in the aggravated environment of the Greek capital, Athens, was studied and considered that the dust effects are site-specific [7].

An experimental study to compare the energy performance of two identical pairs of PV panels was conducted; the first being clean and the second being artificially polluted with ash, i.e. a by- product of incomplete hydrocarbons' combustion mainly originating from thermal power stations and vehicular exhausts [8].

An analysis on the dust effect on the performance of PV systems in Athens was conducted. The studies were done using three different pollutants, red soil, limestone and carbonaceous fly-ash particles. It was found that there was a 6% reduction on PV performance with carbonaceous fly-ash, 10% with limestone and 19% with red soil [9].

The impact of airborne dust deposition on the performance of PV module inside the laboratory under the controlled conditions in a test chamber was investigated. Dust was uniformly distributed on the panel surface with the help of a fan. It was concluded that efficiency of PV module reduced to 26 % as mass of dust increased to 22 g/m^2 [10].

The thickness of dust collected on PV module and difference in efficiencies in composite climate were correlated. They inferred that there is a significant reduction in PV module output, near 10–20%, when heavy layers of dust are accumulated. They also reported that a small amount of dust on solar PV module covers has a negligible effect on the sunlight transmission to the silicon PV module [11] .

The experimental effect of three types of dust pollutants (red soil, ash and sand) on the performance of PV panels (mono-c, multi-c and a-Si technologies investigated) was investigated. The authors claimed that ash have the highest effect in comparison with other pollutants. Also, it is found that a-Si is performing better than mono-c and multi-c in dusty environment [12].

The effect of deposited dust particles on PV modules was investigated experimentally and provided a concept on electrical performances. The study concentrated on parameters such as radiation availability, efficient operating strategies, design and sizing of these systems. It was concluded that dust significantly reduces the efficiency of solar PV module [13].

The mean of the daily energy loss along a year caused by dust deposited on PV module surface is around 4.4%. In long periods without rain, daily energy losses can be higher than 20%. Dust particles differ in phase, sort, chemical and physical properties depending on many environmental conditions. Air, humidity and temperature in addition to wind speed play a significant role in defining isolated dust and how it will collect on the PV cell [14].

The impact of dust on the performance of PV modules by conducting experiment on 96 cm^2 photovoltaic panels with maximum power of 302mW was determined. It was found that the decrease of energy conversion efficiency was 10%, 16% and 20% with increasing of the dust density 0.1g, 0.2g, 0.3g respectively [15].

An experiment to determine the effect of dust physical properties on photovoltaic module in northern Oman was conducted. 64% of the dust particles size ranged from 2 to 63 μm in diameter. There is no significant loss of energy productivity due to the traceability of a little surface of dust (less than 1 g/m^2) on the photovoltaic unit. The daily loss in PV efficiency didn't exceed 0.05%. However, after 3 month exposure to outdoor conditions, the efficiency reduced by 30-35% [16].

The influence of dirt accumulation on performance of PV modules was studied and the effects of particles on solar module performance was analyzed. The study reported that external resistance could reduce PV performance by up to 85%. This study also concluded that water droplet from rain would not affect significantly the performance of PV modules [17].

Fundamental studies on dust fouling effects on PV module glass cover was carried out. It was found that the spectral transmittance reduction was around 35% and the overall transmittance was around 20%. It was also observed that the dust particles accumulated were generally spherical in shape [18].

Another study conducted to determine the effect of pollution and cleaning on photovoltaic performance by [19] showed that the exposure, even within a short period, to air pollutants deteriorated the PV yield.

The polluted and dusty PV panel lost 12%, while the naturally cleaned cell (by rain) lost about 8% compared to the clean panel. The use of sodium surfactant or alcohols preserves high rates of the PV panels' performance.

An experiment using two panels of 10W capacity, mounted on a stand was conducted. The two PV systems are of polycrystalline type. One has carbon particles (grinded charcoal) as black soot debris on the panel while the other has none. They inclined both panel at an optimal angle of 15^o facing the northern hemisphere. From their experiment, they came up with the conclusion that "the highest voltage is produced when the panel is not covered by layer of black soot". They observed that the voltage and power for the panel with black soot is low compared to the panel without soot [20].

The effect of shadow on output performance of solar module in a series-parallel solar cell array was studied. Measurements of the degradation of the power curve with time, current-voltage characteristics as function of total and partial shade were made on 250W monocrystalline silicon solar modules. The results show that the power loss for partially shaded solar modules ranges between 12%-40% when compared with the fully illuminated solar module. So, the power loss for partially shaded solar module can be as high as approximately 40%. For totally shaded module, the power loss ranges between 33% -80% when compared with the fully illuminated solar module. So, the power loss for totally shaded solar module can be as high as 80% [21].

The effects of solid dirt accumulation on the solar panel's surface was investigated and quantified. Typically, a total daily power output for control solar module was 1758.487W while the corresponding value for dirty (mixture of algae, sand, dust and moist air) solar module was found to be 1286.813W at the instance of time and same insolation. The study shows that the solid dirt affects the output power of the solar module and consequently reduces the efficiency of the solar module [22].

This paper thus reports the output performance of two identical pairs of photovoltaic (PV) modules when black soot is deposited on one of the pairs in a specific geographical location. The direct impact of black soot deposition on the solar module performance can be gauged by a comparison of the current-voltage (I-V) characteristics of the panels with and without black soot settlement on their surfaces.

2.0 Materials and Methods

The materials used in conducting the study include;

i. Two solar panels of 250W capacity set up on the ground as illustrated in Figure 2 and Figure 3. The two solar panels are of monocrystalline type. One of the panels served as a **Control.**

ii. Two digital multimeters (Figure 4) were also used to measure the short circuit current, I_{SC} and open circuit voltage V_{OC}.

iii. Carbon particles from vehicle exhaust.

iv. Timer.

Figure 2: Experimental setup for solar panel with soot

Figure 3: Experimental setup for solar panel without soot (control).

Figure 4: Employed digital multimeter

The Table 1 shows the specifications of the employed solar panel for the experiment.

Table 1: Specifications of the employed solar panel(s)

Model Type	HU250
Peak Power	250W
Short circuit current (I_{sc})	8.93A
Open circuit voltage (V_{oc})	36.5volts
System voltage	1000V
Insulation	≥100MW
Peak Power Tolerance	±5%

The Table 2 shows the specifications of the employed digital multimeter for the experiment.

Table 2: Specifications of the employed digital multimeter

Model No.	DT9205A
DC Voltage	200mV – 1000V
AC Voltage	200mV – 750V
DC Current	2mA – 20A
AC Current	2mA – 20A
Net Weight	300g

The experiment is conducted by using the two 250W solar panels inclined at an angle of 15^0 [23] to the ground mount. In this work, the systems of measurements consist of monocrystalline solar panels and digital multimeters to measure electrical parameters like; current and voltage. One of the solar panels had black soot deposited on its surface while the other panel was clean (Control).

Also, the output power P_{dc} for the control and soot panel were calculated. The weather conditions were recorded as well at the instant of measurements. Parameters like; Short circuit current I_{sc} and Open circuit voltage V_{oc} needed for the evaluation of the system were measured at an interval of fifteen minutes (15mins) between 9:00am and 5:00pm daily. This experimental study was carried out in Rivers State at the frontage of Basic studies building, University of Port Harcourt, Abuja campus. The latitude and longitude of the location are: 4.9004^0 N and 6.9204^0 E.

The governing equations for calculating the average power (P_{dc}) for control and soot, percentage loss in output voltage and percentage loss in output power are;

$$Average\ power\ P_{dc} = I_{sc} \times V_{oc} \quad (1)$$

Where:

I_{sc} = short circuit current of the solar panel

V_{oc} = Open circuit voltage of the solar panel

Percentage loss in output voltage is given as:

$$V_{OUT} = \frac{V_w - V_b}{V_w} \times 100 \quad (2)$$

Where:

V_w = Voltage without black soot

V_b = Voltage with black soot

Percentage loss in output power is given as:

$$P_{OUT} = \frac{P_w - P_b}{P_w} \times 100 \quad (3)$$

Where:

P_w = Power output without black soot

P_b = Power output with black soot

From the measured values, graphs are plotted for P_{dc} against time, V_{oc} (for control and soot) against time and also I_{sc} against V_{oc}. Then, the percentage loss in output voltage and output power are calculated to determine the efficiency of the solar panel with soot deposited on its surface and compare its result with the panel without soot.

3. 0 Results and Discussions

The typical measured values obtained during the period of the experiment are shown in Table 3.

Table 3: Measured Values for Day 1

Time of the Day (mins)	**Isc (short circuit current) for control (Amperes)**	**Voc (open circuit voltage) for control (volts)**	**Average Power Pdc for control (watts)**	**Isc (short circuit current) for soot (Amperes)**	**Voc (open circuit voltage) for soot (volts)**	**Average Power Pdc for soot (watts)**	**Weather condition**
9:00am	6.08	35.2	214.02	2.6	34	88.40	Sunny
9:15am	6.3	35.2	221.76	2.61	33.9	88.48	Sunny
9:30am	6.74	35.3	237.92	2.88	34	97.92	Sunny
9:45am	1.53	32.8	50.18	0.63	31.5	19.85	Sunny
10:00am	7.99	35.3	282.05	3.39	34.2	115.94	Sunny
10:15am	1.89	33.2	62.75	0.78	31.7	24.73	Sunny
10:30am	7.68	35.3	271.10	3.22	33.8	108.84	Sunny
10:45am	7.61	35.7	271.68	2.81	33.6	94.42	Sunny
11:00am	7.64	34.8	265.87	3.37	33.2	111.88	Sunny
11:15am	7.01	35.7	250.26	3.16	34.3	108.39	Sunny
11:30am	7.05	34.8	245.34	3.19	33.5	106.87	Sunny
11:45am	1.76	33.5	58.96	0.79	32.1	25.36	Sunny
12:00pm	2.16	34.3	74.09	1	33.2	33.20	Sunny
12:15pm	6.86	34.9	239.41	2.84	33.3	94.57	Sunny
12:30pm	6.86	34.7	238.04	2.39	33.1	79.11	Sunny
12:45pm	6.14	34.8	213.67	2.08	33.2	69.06	Sunny
1:00pm	5.9	34.7	204.73	2	33	66.00	Sunny

1:15pm	5.7	34.6	197.22	1.59	33	52.47	Sunny
1:30pm	5.16	34.5	178.02	1.26	32.7	41.20	Sunny
1:45pm	5.04	34.5	173.88	1.24	32.9	40.80	Sunny
2:00pm	4.66	34.5	160.77	1.21	32.8	39.69	Sunny
2:15pm	3.96	34.4	136.22	0.91	32.6	29.67	Sunny
2:30pm	3.7	34.3	126.91	0.89	32.5	28.93	Sunny
2:45pm	1.35	33.6	45.36	0.6	32.3	19.38	Sunny
3:00pm	2.39	34.4	82.22	0.8	32.3	25.84	Sunny
3:15pm	1.4	34.3	48.02	0.63	32.7	20.60	Sunny
3:30pm	1.5	33.8	50.70	0.63	32.3	20.35	Sunny
3:45pm	1.4	33.6	47.04	0.5	32.2	16.10	Sunny
4:00pm	1.49	34	50.66	0.6	32.5	19.50	Sunny
4:15pm	1.28	33.7	43.14	0.52	32.3	16.80	Sunny
4:30pm	0.89	33.6	29.90	0.41	32.2	13.20	Sunny
4:45pm	0.88	33.5	29.48	0.41	32.2	13.20	Sunny
5:00pm	0.79	33.2	26.23	0.38	31.9	12.12	Sunny

Figures 4 and 5 show respectively the I-V curve for the control module and sooty module for the measured values of short-circuit current I_{SC} and open-circuit voltage V_{OC} for day 1. The maximum values of I_{SC} and V_{OC} for the control module are 7.99A and 35.7V at 10:00am and 11:15am respectively. In figure 5, the maximum values of I_{SC} and V_{OC} for the sooty module are 3.39A and 34.3V at 10:00am and 11:15am respectively. The reduction in I_{SC} for the sooty panel was due to the presence of black soot on the solar module. The trendline shows direct proportionality between short circuit current, I_{SC} and open circuit voltage, V_{OC}.

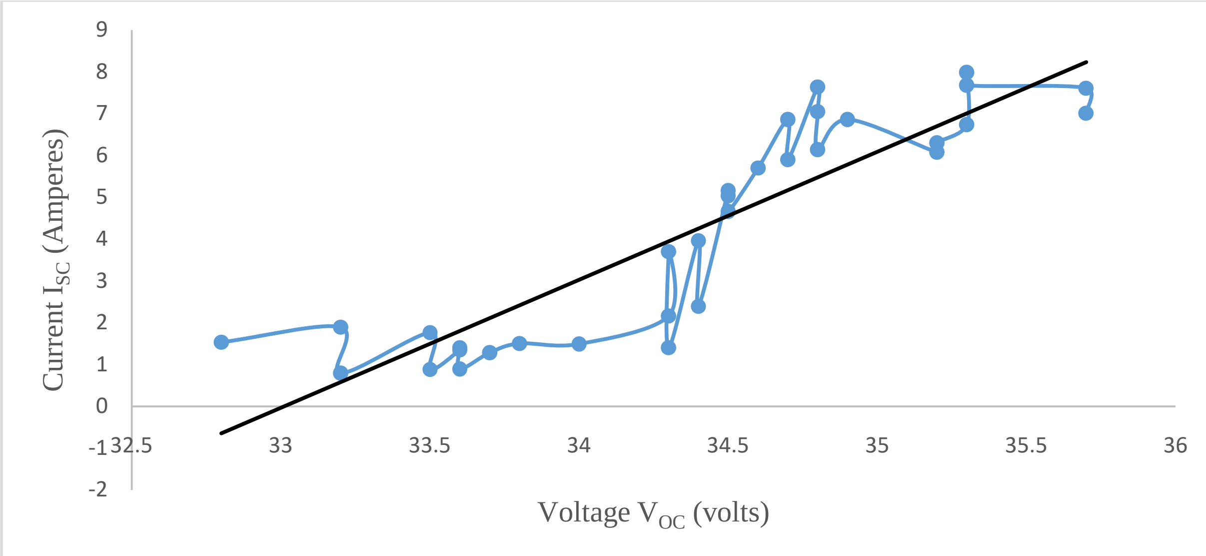

Figure 4: I-V curve for control panel Day 1

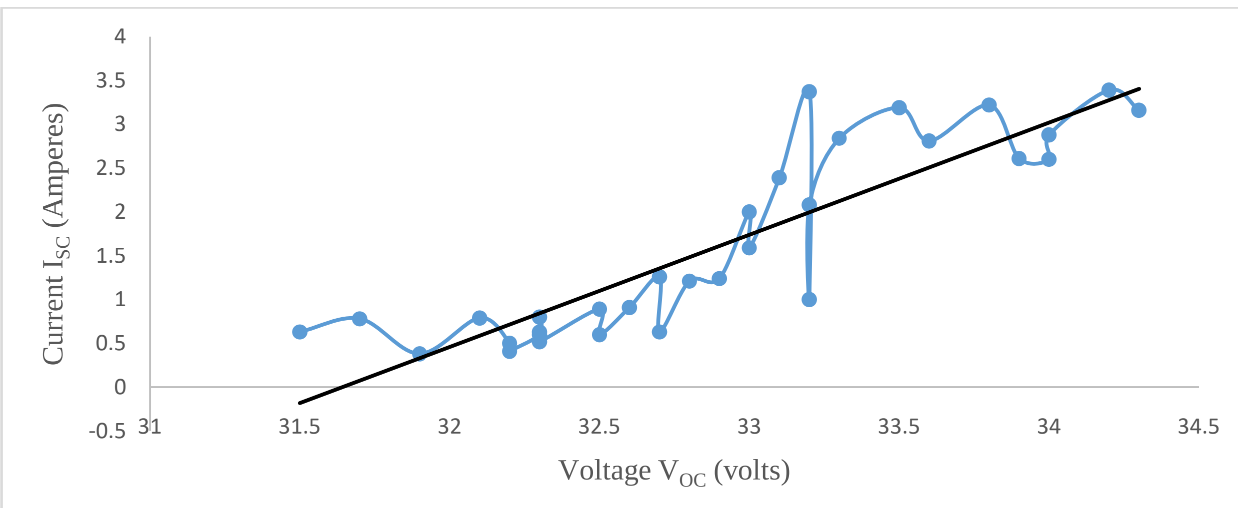

Figure 5: I-V curve for sooty panel Day 1

Figure 6 shows a plot of the open-circuit voltage, V_{OC} for both control module and sooty module against time of day. From figure 6, it can be seen that the maximum open-circuit voltage V_{OC} produced by control module was 35.7V at 11:15am whereas that of the sooty panel was 34.3V at same time.

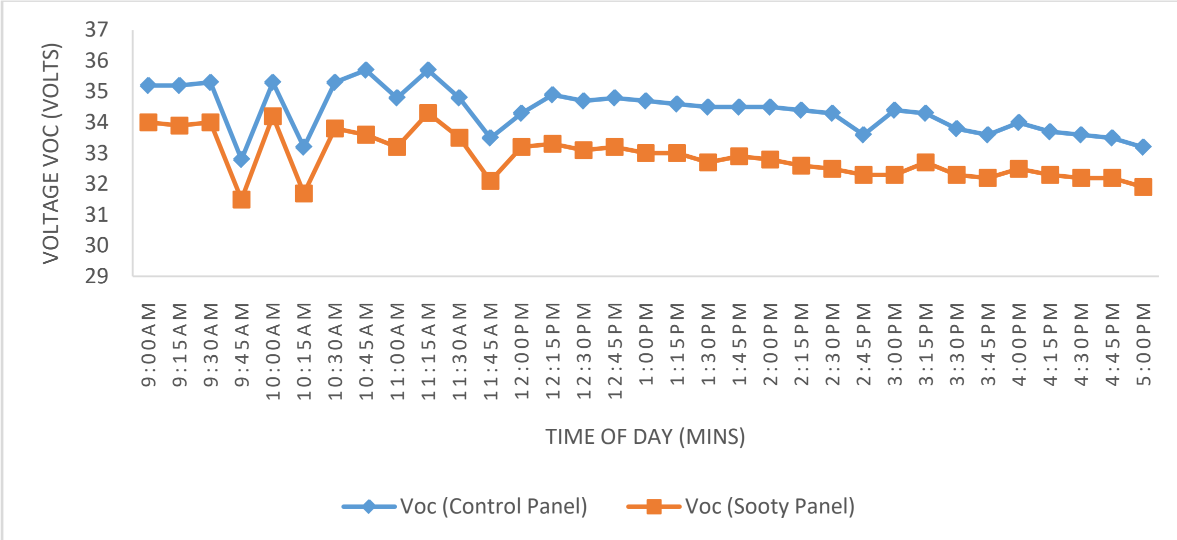

Figure 6: V_{OC} (control and soot in volts) against Time of Day for Day 1(mins)

Hence, the percentage (%) loss in output voltage at 11:15am for both control and sooty modules was calculated as :

$$\%\ Loss\,in\,output\,voltage = \frac{Max.\ V_{oc}\ \ for\ control\ - Max.V_{oc}\ \ for\ soot}{Max.V_{oc}\ \ for\ control}\ x\ 100\%$$

$$\%\ Loss\ in\ output\ Voltage = \frac{35.7 - 34.3}{35.7}\ x\ 100\% \quad = \ 3.92\%$$

The 3.92% loss in output voltage is due to the presence of black soot on the solar module which reduces amount of solar irradiation incident on the module's surface.

Figure 7 shows a plot for the Average power P_{dc} (watts) against Time of day (mins) for both the control and sooty module. For instance, the maximum power generated by the control module was 282.05W at 10:00am while the corresponding value for the sooty module was 115.94W at the same time.

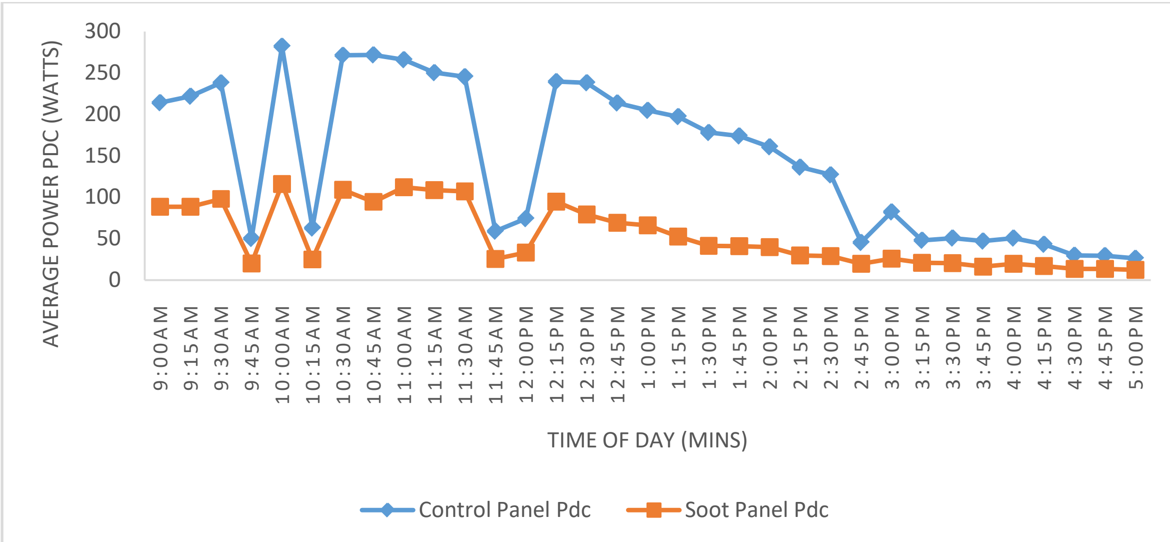

Figure 7: Average Power P_{dc} (watts) for control and sooty panels against Time of day (mins) for Day 1

Hence, the percentage (%) power loss can be calculated as:

$$\%\ Power\ Loss = \frac{282.05 - 115.94}{282.05}\ x\ 100\% = 58.89\%$$

The 58.89% loss in the output power can be traced to the effect of the black soot that accumulated on the solar module.

Also, the maximum power produced by the control module was 271.68W at 10:45am and the corresponding maximum power for the sooty module was 111.88W at 11:00am. Thus,

$$\%\ Power\ Loss = \frac{271.68 - 111.88}{271.68}\ x\ 100\% = 58.82\%$$

From the analysis, it is clear that solar modules work optimally when they are completely clean.

Table 4 summarizes the total average power output obtained during the period of measurements for the control and sooty modules. It shows that the accumulation of soot on a solar module significantly reduces the average power output it generates irrespective of the intensity of solar radiation incident on it.

Table 4: Summary of total average power output power for the control and sooty modules for the days of measurement.

Days	Daily Average Power Output for Control Module	Daily Average Power Output for Sooty Module	% Power Loss
1	4827.6	1742.87	63.9%
2	3192.18	1281.85	59.84%
3	1799.27	847.91	52.87%
4	2859.24	1528.8	46.53%
5	710.75	438.91	38.25%
6	2082.82	1126.94	45.89%
7	7103.15	4827.38	32.04%

At the instant of measurement, the range of output power loss can be from 19.49% to 58.89%. Cumulatively, the total output power loss daily ranges from

32.04% to 63.90%. The variations in percentage (%) loss of average output power is mainly because of the variation in short-circuit current I_{SC} and open-circuit voltage V_{OC} produced by both the control and sooty module. One key observation to note was that an increase or decrease in volume of the soot particles accumulated on the surface of the solar module determines 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 soot particles across 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 black soot. Thus, the photons can't get through the soot particles to the solar cells and most of the current is lost due to the reflection of the photons by the particles.

4.0 Conclusion

The output performance and efficiency of solar modules were studied. The materials used were; two monocrystalline solar panels, and two multimeters. The Output performance of modules with the presence of black soot on one module and the absence of soot on the other was analyzed and evaluated at a time interval of 15 minutes under varying weather conditions. From the I-V characteristics of both the control and sooty modules, the trendline shows direct proportionality between short circuit current, Isc and open circuit voltage, Voc. For instance, the maximum voltage measured from the control module for day 1 is 35.7V and the maximum voltage measured from the sooty module on same day is 34.3V. On day 7, the maximum voltage measured from the control module is 40.0V and the corresponding voltage for the sooty module is 38.6V. Thus, the percentage (%) output voltage loss for day 1 is 3.92% while the percentage (%) output voltage loss for day 7 is 3.50%.

Also, it was observed that accumulated soot particles largely affects the power output of the solar module, thus reducing its overall performance. For instance, the maximum power generated by control module for day 1 was 282.05W at 10:00am while the corresponding value for the sooty module was 115.94W at the same time during day 1 of the experiment. On day 7, the maximum power generated by control module was 353.94W at 1.45 pm while the corresponding value for the sooty module was 227.73W at the same time. Thus, the reduction in output power for the solar module with black soot typically ranges from 19.49% to 58.89%. Cumulatively, the total output power loss daily ranges from 32.04% to 63.90%.

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References

[1] J. M. K. C. Donev, Jordan Hanania, Ashley Sheardown, Kailyn Stenhouse, Energy Education - Soot [Online], 2019. Available: https://energyeducation.ca/encyclopedia/Soot. [Accessed: July 4, 2021].

[2] M. S. El-Shobokshy and F. M. Hussein, “Degradation of photovoltaic cell performance due to dust deposition on to its surface” . *Renewable Energy*, Vol. 3, No.6-7, pp 585-590, 1993.

[3] D. Goossens and E. Van Kerschaever, "Aeolian dust deposition on photovoltaic solar cells: the effects of wind velocity and airborne dust concentration on cell performance," *Solar Energy*, Vol. 66, No. 4, pp 277 – 289, 1999.

[4] A. Y. Al-Hasan and A.A. Ghoneim, “A new correlation between photovoltaic panel's efficiency and amount of sand dust accumulated on their surface.” *International Journal of Sustainable Energy*, Vol. 24, No 4, pp 187-197, 2005.

[5] H. K. Elminir, Effect of dust on the transparent cover of solar collectors. *Energy Conversion and Management*, Vol. 47, pp 3192–3203, 2006.

[6] M. Mani and R. Pillai, "Impact of dust on solar photovoltaic (PV) performance: Research status, Challenges and recommendations." *Elsevier Renewable and Sustainable Energy Reviews*, Vol. 14, pp 3124-3131, 2010.

[7] J. K. Kaldellis and A. Kokala, "Quantifying the decrease of the photovoltaic panels energy yield due to phenomena of natural air pollution disposal. *Energy*, Vol. *35*, pp 4862–4869, 2010.

[8] J. K. Kaldellis and P. Fragos, "Ash deposition impact on the energy performance of photovoltaic generators, *Journal Cleaner Production*, Vol. 19, No. 4, pp 311-317, 2011.

[9] J. K. Kaldellis and P. M. Kapsali, "Systematic experimental study of the pollution deposition impact on the energy yield of photovoltaic installations," *International Journal Renewable Energy*, Vol. 36, No.10, pp 2717-2724, 2011.

[10] H. Jiang, L. Lu , K. Sun, "Experimental Investigation of the Impact of Airborne Dust Deposition on the Performance of Solar Photovoltaic Modules," *International Journal of Atmospheric Environment*, Vol. 45, No.25, pp 4299-4304, 2011.

[11] S. Mekhilef, R. Saidur and M. Kamlisarvestani, "Effect of Dust, Humidity and air velocity on efficiency of photovoltaic cells, *Renewable and sustainable energy reviews*, Vol. 16, pp 2920–2925, 2012.

[12] Hussein A. Kazem, "Dust accumulated on its surface", *Solar Energy*, Vol. 3, No.4, pp 323-333, 2013.

[13] D. S. Rajput and K. Sudhakar, "Effect of dust on performance of solar PV panel", *International Journal of Chemical Technology Research,* Vol. *5,* No.2, pp 1083–1086, 2013.

[14] Z. A. Darwish, "Impact of some environmental variables with dust on solar photovoltaic: Review and research", *International Journal of Energy and Environment,* Vol. 7, No. 4, pp 152–159 , 2013.

[15] E. S. Kumar, B. Sarkar and D. K. Behera, "Soiling and Dust Impact on the Efficiency and the Maximum Power Point in the Photovoltaic Modules", *International Journal of Engineering Research & Technology*, Vol. 2, No. 2, pp 1 - 6, 2013.

[16] A. A. Kazem, M. T. Chaichan and H. A. Kazem. "Dust effect on photovoltaic utilization in Iraq: Review article", *Renewable and Sustainable Energy Reviews*, Vol. 37, pp 734–749, 2014.

[17] S. A. Sulaiman, "Influence of dirt accumulation on performance of PV panels", *Energy Proceedia*, Vol. 50, pp 50–56, 2014.

[18] S. A. M. Said and H. M. Walwil, "Fundamental studies on dust fouling effects on PV module performance", *Solar Energy*, Vol. 107, pp 328–337, 2014.

[19] M. T. Chaichan, B. A. Mohammed and H. A. Kazem, "Effect of pollution and cleaning on photovoltaic performance based on experimental study", *International Journal of Scientific and Engineering Research*, Vol. 6, No. 4, pp 594-601, 2015.

[20] C. O. Emmanuel and J. A. Tamuno-omie, "Effect of Black Soot on the performance of Photovoltaic Systems in Portharcout", *Iconic Research and Engineering journals*, Vol. 2, No. 6, pp 63-67, 2018.

[21] J. A. Amusan and E. B. Otokunefor, “The Effect of shadow on the Output Performance of a Solar Module”, *International Journal of Engineering Science and Computing*, Vol. 9, No. 3, pp 20243-20249, 2019.

[22] J. A. Amusan and C. E. Igwe, “The effect of solid dirt on the output performance of a solar module”, *Global scientific journals*, Vol. 8, No. 11, pp 165-176, 2020.

[23] J. A. Amusan, E. O. Chukwuocha and A. E. Edah, “Determination of angle of inclination for optimum power production from solar power system. A case study. *Scientia Africana*, Vol. 11, No. 1, pp 1-13, 2012.