Global Scientific JOURNALS

GSJ: Volume 8, Issue 11, November 2020, Online: ISSN 2320-9186
www.globalscientificjournal.com

THE EFFECT OF SOLID DIRT ON THE OUTPUT PERFORMANCE OF SOLAR MODULE

Amusan, Joseph Abiodun[1*] and Igwe, Chimaobi Emmanuel[2]
Department of Physics,
University of Port Harcourt,
Port Harcourt, Nigeria.

[1]E – mail : amusanabiodun@yahoo.com
Tel : +2348035622473
* Corresponding Author

[2] E-mail : chimaobiigwe402@yahoo.com
Tel : +2348121083062

ABSTRACT

Accumulation of solid dirt on the surface of solar modules over time arouses researchers' curiosity of likely effect on the output performance of the solar module. Thus, the effects of solid dirt accumulation on the solar panel's surface was investigated and quantified. The study was carried out at the Basic study unit environment of University of Port Harcourt, Rivers state, Nigeria (longitude 4.9˚N and latitude 6.9˚E and 468m elevations above the sea level). Two 250W mono-crystalline modules were employed for the study. One served as control (clean) and the other as Device Under Test (dirty). The output performance of the solar panels were evaluated using the testing parameters that include open circuit voltage and short circuit current, I-V characteristics and the soiling losses. 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. This reveals 26.82% loss in the power output due to dirt on the surface of the solar module. Also, at another instance, total daily output power of 3539.326W was obtained from the control solar module while dirty solar module yielded 2051.732W which corresponds to 42.03% loss in power output. The output power losses due to dirt accumulation on the surface of the solar module thus range between **26%** and **42%.** Averagely, dirty solar module significantly loses **34.0% ± 8.0 %** output power daily. The study shows that the solid dirt affects the output power of the solar module and consequently reduces the efficiency of the solar module.

Keywords : Solar module, Solid Dirt, Solar radiation, Open circuit voltage, Short circuit current, Output power, Efficiency.

1. Introduction

Photovoltaic technology uses solar cells made of semiconductors to absorb the irradiance from the sun and convert it to electrical energy. Presently, solar energy has drawn worldwide attention and is playing an essential role in providing clean and sustainable energy.

Solar power system is increasingly used these days by cooperate organizations and individuals as independent power generation because of dramatic drop in the cost of components and installations. However, some factors influence the ideal output or optimum yield of the solar modules. These could be climatic, environmental, device makeup and operational conditions. Among these factors, solid dirt was considered.

Accumulation of solid dirt on the surface of the array of solar cells that are exposed to incoming solar radiation over a long period of time has been observed. The accumulation of the solid dirt on the surface of the solar module could be so thick that the frequent rainfalls could not wash away the dirt. The dirt is solidified and adhesively glued to the surface of solar cells, thus inhibiting the penetration of impinging solar radiation.

Accumulation of solid dirt from the outdoor environment on the solar module is natural. It is a complex phenomenom that is influenced by the different environmental and weather conditions.

There were studies that showed that accumulated dust can reduce the performance of solar power system but some of the results were not clearly quantified. Dust on the surface of solar module may be temporary because frequent rainfalls have tendency to wash it off for optimum performance.

In case of solid dirt, it is more permanent on the surface of the solar module as a result of long time exposure to the environmental and weather conditions such that rainfalls may not be able to wash it off except by manual or mechanical means of solid dirt removal. Also, the composition of solid dirt is different from the ordinary dust.

Solid dirt accumulation on a solar village PV system near Riyadh indicated a 32% reduction in performance after eight months and also indicated a reduction in PV power by 17% due to sand accumulation on panels in Kuwait city after six days [1].

Factors affecting the optimum yield generation of PV panels considering soft shading and hard shading caused by dust were also reported [2].

Moist air and solid dirt were reported to significantly influence the performance of PV installations [3].

The impact of solid dirt on solar collector performance was studied. The maximum degradation in collector performance of 4.7% with an average loss in incident solar radiation being less than 1% was reported [4].

The effect of wind speed, air-borne dust and dirt concentration on the surface of PV cell was studied [5].

Experiment on the effect of deposited dust particles on PV modules and its electrical performance based on parameters such as radiation availability, efficient operating strategies, design and sizing of the systems was also conducted [6].

The influence of dirt accumulation on performance of PV modules was studied and analysed. The study reported that external resistance could reduce PV performance by up to 85% [7].

A fundamental study on solid dirt fouling effects on the glass cover of multi-crystalline PV module was carried out. It was found that the spectral transmittance reduction was 35% and the overall transmittance was around 20%. The solid dirt was due to the deposition of different pollutants and accumulation. The dust particles accumulated were spherical in shape [8].

The pattern of dust distribution, accumulation, types, specifications and the corresponding impact on PV panels were also investigated [9].

Review and summary of impact of dust on the efficiency of PV panels and the factors that caused the dust deposition on their surfaces were presented [10].

Since dirt constitutes one of the environmental factors naturally occurring, the accumulation of dirt on the surface of installed solar panels is site-specific. The dirt solidifies on the surface of the solar module over a long period of time. The type of solid dirt and its impact could also be site-specific.

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:

$$P = Isc \ x \ Voc \quad (1)$$

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 solid dirt. 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.

$$Efficiency, E = \frac{Output \ Power}{Input \ Power} \ x \ 100 \quad (2)$$

In this regard, this paper reports and quantifies the effect of solid dirt accumulated over a long period of time on 250Watts mono-crystalline solar module within the geographical location. The experimented solid dirt thus comprises mixture of sizeable Algae, sand, dust and moist air.

2. Materials and Methods

The employed materials for the study are:

1. Solar Photovoltaic panels: Two monocrystalline silicon solar PV panels (Figure 1) rated 250Watts were used in the study. The specifications of the employed solar modules are:
   i. Maximum Power/Pmax(W) 250W
   ii. Maximum Power/Tolerance +3%
   iii. Open circuit Voltage/V_{OC} (V) 37.60V
   iv. Short circuit Current/Isc (A) 8.75A
   v. Maximum Power Voltage/Vimp 31.20V
   vi. Maximum Power Current/Imp (A) 8.02A
   vii. Power specifications at STC: 1000W/m^2, 1.5AM and Tc = 25^0C.
   viii. Weight 23kg
   ix. Dimension 1640mm x 992mm x 40mm
   x. Maximum System Voltage 1000V
   xi. Maximum over current protection rating 16A
   xii. Efficiency 16.1%
   xiii. Module application class A

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. DC 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.

Figure 1: Employed 250W Solar Panels

Figure 2: Employed Digital Multimeter

Experimental Set-Up

The experiment was set up in the University of Port Harcourt environs, precisely at the Basic Unit, Rivers State, Nigeria (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 [11]. A total of two panels were used in the experiment. The first solar module was completely clean (referred to as the control solar module) and the surface of the second solar module was partially covered with dirt (accumulation of mixture of algae, sand, dust and moist air). The control solar module was thoroughly cleaned every day to ensure that dirt materials do not cover the surface of the solar module so as to obtain best readings (Figure 3). After the setup, the measurements for the short circuit current, Isc and open circuit voltage, Voc were taken with digital multimeter at 15 minutes interval between the hours of 9.40a.m and 5.00p.m daily. This was done for period of days characterized with different weather conditions. The results were used to determine the efficiency of the solar panel.

Figure 3: In-Situ Experimental Set-Up

3. Results

In the time past, quantification of the influence of solid dirt with these compositions (algae, sand, dust and moist air) on output performance of solar module has not been given much attention. Often times, the influence can be site specific. The typical measured values obtained during the period of the experiment are shown in Tables 1, 2 and 3. However, the results obtained in this experiment shows that dirty solar modules also generate electricity when solar radiation impinges on it but at a minimal rate as compared to clean solar modules.

Table 1: Measured Values for Day 1

Time	Voc/V (Control)	Isc /A (Control)	Power (Pdc)/W (Control)	Voc /V (Dirt)	Isc /A (Dirt)	Power (Pdc)/W (Dirt)	Weather condition
9:40	27.3	2.32	63.336	26.2	1.27	33.274	Fair
9:55	27.0	2.28	61.56	26.1	1.33	34.713	Sunny
10:10	27.1	2.26	61.246	26.1	1.37	35.757	Fair

10:25	26.5	1.60	42.4	25.8	0.97	25.026	Cloudy
10:40	27.2	2.70	73.44	26.5	1.70	45.05	Sunny
10:55	26.5	1.42	37.63	25.6	0.90	23.04	Cloudy
11:10	27.5	5.25	144.375	26.9	3.38	90.922	Sunny
11:25	26.8	5.02	134.536	26.1	3.50	91.35	Sunny
11:40	26.0	2.26	68.12	25.6	1.67	42.752	Fair
11:55	26.7	7.85	209.595	26.8	5.00	134	Sunny
12:10	26.8	4.04	108.272	25.7	2.33	59.881	Sunny
12:25	27.5	3.04	83.6	26.1	1.30	33.93	Fair
12:40	26.4	1.80	47.52	25.5	1.03	26.265	Cloudy
12:55	27.4	3.24	88.776	26.2	1.82	47.684	Fair
13:10	26.4	2.28	60.192	25.3	1.19	30.107	Cloudy
13:25	26.4	1.84	48.576	25.3	1.08	27.324	Cloudy
13:40	26.3	1.18	31.034	25.0	0.68	17	Cloudy
13:55	27.3	3.66	99.928	26.4	2.14	56.496	Sunny
14:10	27.3	4.02	109.746	26.2	2.25	58.95	Sunny
14:25	27.0	3.33	89.91	26.1	1.78	46.458	Fair
14:40	26.4	2.78	73.392	26.6	2.50	66.5	Fair
14:55	27.1	5.02	136.042	26.1	3.10	80.91	Sunny
15:10	26.9	4.03	108.407	26.2	2.32	60.784	Sunny
15:25	27.0	4.39	118.53	26.3	2.41	63.383	Sunny
15:40	26.9	2.96	79.624	26.2	1.87	48.994	Fair
15:55	26.7	2.42	64.614	26.0	1.46	37.96	Fair
16:10	26.9	2.27	61.063	26.1	1.50	39.15	Fair
16:25	26.1	1.28	33.408	25.4	0.84	21.336	Fair
16:40	26.0	0.92	23.92	25.1	0.61	15.311	Cloudy
16:55	25.6	0.79	20.224	24.9	0.52	12.948	Cloudy

Table 2 shows the measured values for day 5

TABLE 2: Measured values for Day 5

Time	Voc/V (Con-trol)	Isc /A (Control)	Power (Pdc)/W (Control)	Voc/V (Dirt)	Isc/A (Dirt)	Power (Pdc)/W (Dirt)	Weather condition
9:40	26.5	2.03	53.795	25.7	1.70	43.69	Fair
9:55	25.5	1.47	37.485	24.5	1.04	25.48	Fair
10:10	25.5	1.17	29.835	25.3	0.89	22.517	Fair
10:25	26.2	2.37	62.094	25.8	1.64	42.312	Fair
10:40	26.6	2.94	78.498	25.1	2.07	51.957	Fair
10:55	26.2	1.77	46.374	25.7	1.36	34.952	Fair
11:10	26.4	2.33	61.512	26.0	1.87	48.62	Fair
11:25	26.4	2.08	54.912	25.6	1.69	43.264	Fair
11:40	26.3	2.11	55.493	26.0	1.58	41.08	Fair
11:55	26.7	3.44	91.848	26.1	2.66	69.426	Sunny
12:10	26.5	6.83	180.995	26.2	4.65	121.83	Sunny
12:25	24.6	1.74	42.804	24.6	1.31	32.226	Fair
12:40	26.6	6.35	168.91	26.3	4.86	127.818	Sunny

12:55	25.2	1.85	46.62	24.9	1.42	35.358	Fair
13;10	25.9	2.03	52.577	25.3	1.43	36.179	Fair
13:25	25.8	2.14	55.212	25.2	1.82	45.864	Fair
13:40	26.0	2.20	57.2	25.5	1.55	39.525	Fair
13:55	26.1	2.15	56.115	25.4	1.57	39.878	Fair
14:10	26.3	2.74	72.062	25.9	2.00	51.8	Fair
14:25	25.9	2.10	54.39	25.3	1.56	39.468	Fair
14:40	25.5	1.17	29.835	25.1	0.90	22.59	Fair
14:55	26.3	2.30	60.49	26.0	1.99	51.74	Fair
15:10	26.1	2.08	54.288	25.6	1.51	38.656	Fair
15:25	26.0	1.85	48.1	25.7	1.35	34.695	Fair
15:40	25.8	1.53	39.474	25.5	1.14	29.07	Fair
15:55	25.6	1.13	28.928	24.9	0.81	20.169	Fair
16:10	26.1	1.72	44.892	25.8	1.46	37.668	Fair
16:25	25.4	1.39	35.306	24.7	0.91	22.477	Fair
16:40	25.1	1.37	34.387	24.2	0.82	19.844	Fair
16:55	24.8	0.97	24.056	23.8	0.70	16.66	Fair

4. Discussion

Figure 4 shows the plot of Isc against Voc for control solar panel for day 1.
The trendline shows direct proportionality between short circuit current, Isc and open circuit voltage,Voc.

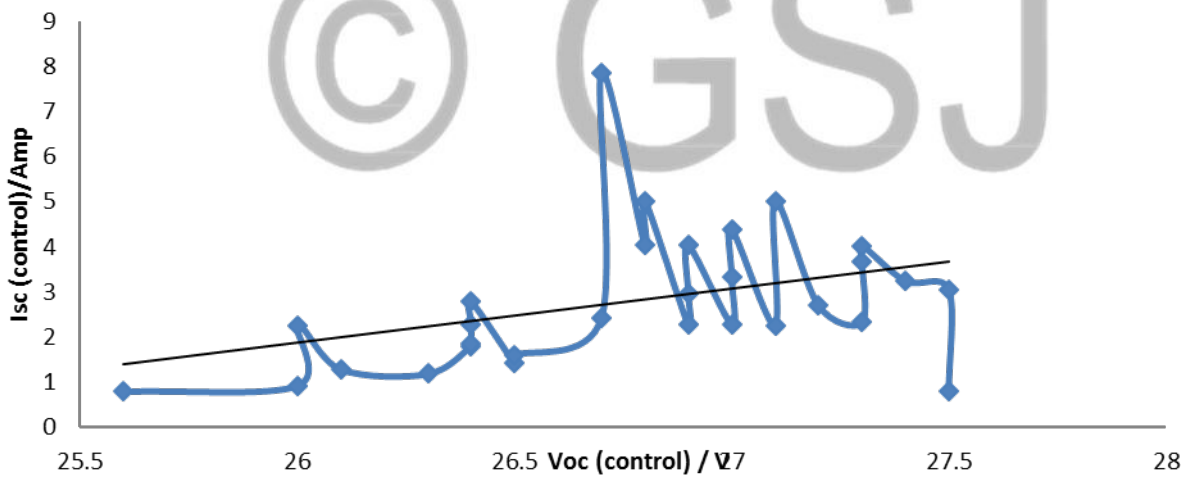

Figure 4: I-V characteristics for control solar panel for day 1

Figure 5 shows the plot of Isc against Voc for solid dirty solar panel for day 1. The trendline for I-V curve for solid dirty panel is also directly proportional.

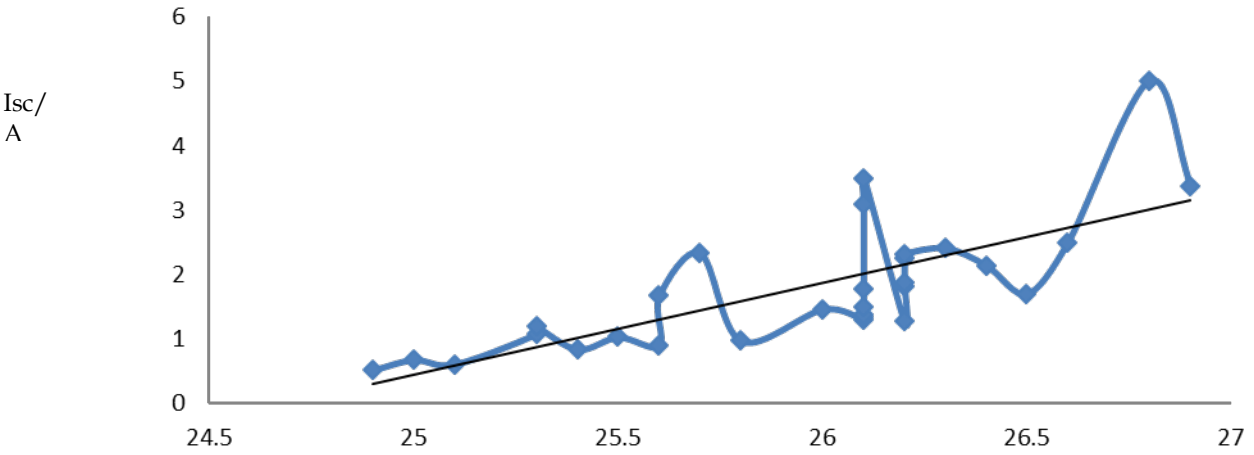

Figure 5: I-V characteristics for Solid dirty solar panel for day 1.

Figure 6 shows the plot of Voc for control and dirty solar modules against time of the day for day 1. The Voltage (Voc) generated by the control solar module was 27.5V at 11:10a.m while the corresponding value for the dirty solar module was 26.9V. At 12:25p.m, the voltage generated by the control solar module was 27.5V while the corresponding value for the dirty solar module was 26.1V at the same time. The figure 6 shows decrease in output voltage by dirty solar module at the same instance under the same insolation as compared with control solar module.

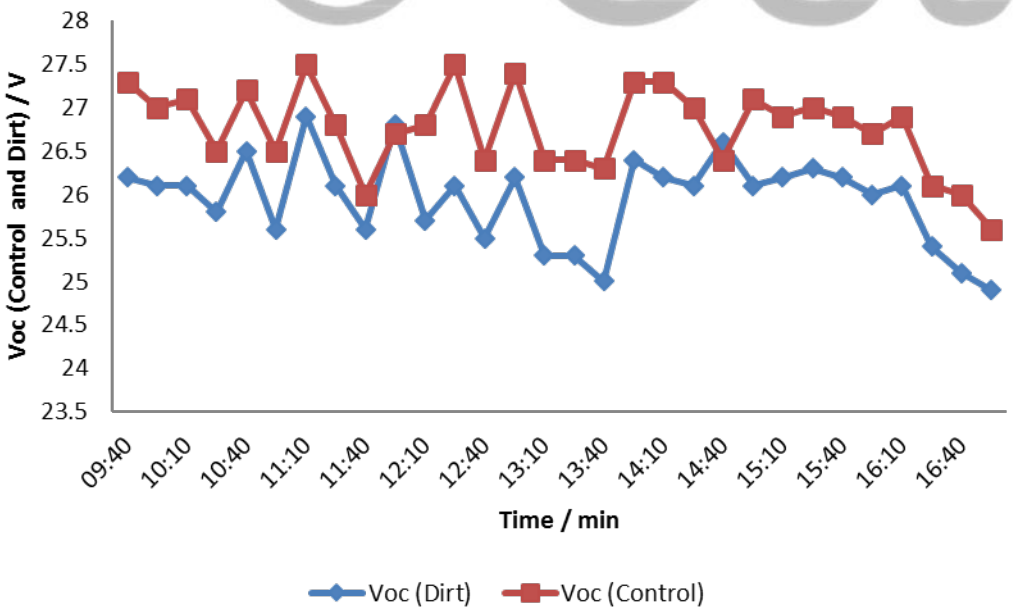

Figure 6: Voc (control and dirt) against time of the day for Day.

The percentage (%) voltage losses due to accumulated solid dirt at the instances were estimated as:

$$\% \, Voltage \, Loss = \frac{27.5 - 26.9}{27.5} \, x \, 100 \, = \, 2.18\%$$

$$\% \, Voltage \, Loss = \frac{27.5 - 26.1}{27.5} \, x \, 100 \, = \, 5.09\%$$

Figure 7 shows the plot of output power against time of the day for control and dirty solar panels for day 1. The maximum power generated by the control solar module was 209.595W at 11:55a.m while the corresponding value for the dirty solar module was 134.0W at the same time.

At 16:55p.m, the output power generated for the control solar panel was 20.224W while dirty solar panel read 12.948W.

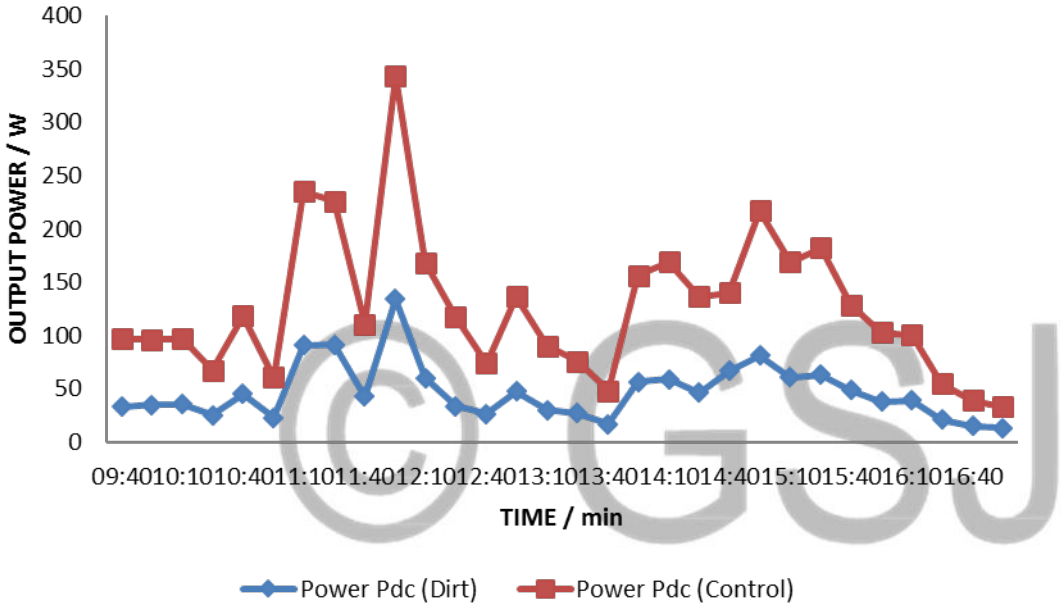

Figure 7: Output Power against time of the day for Day 1

The percentage (%) power losses at the instances due to accumulated dirt were estimated as:

$$\% \, Power \, \, Loss = \frac{209.595 - 134.0}{209.595} \, x \, 100 \, = \, 36.07\%$$

$$\% \, Power \, \, Loss = \frac{20.224 - 12.948}{20.224} \, x \, 100 \, = 35.98\%$$

It was observed that low irradiance of sunlight leads to low power output. Also, the accumulated solid dirt on the surface of solar module reflected part of solar radiation meant to be absorbed by the solar module.

Figure 8 shows the plot of Isc against Voc for control solar panel for day 5. The relationship between short circuit current and open circuit voltage is directly proportional as confirmed by the trendline.

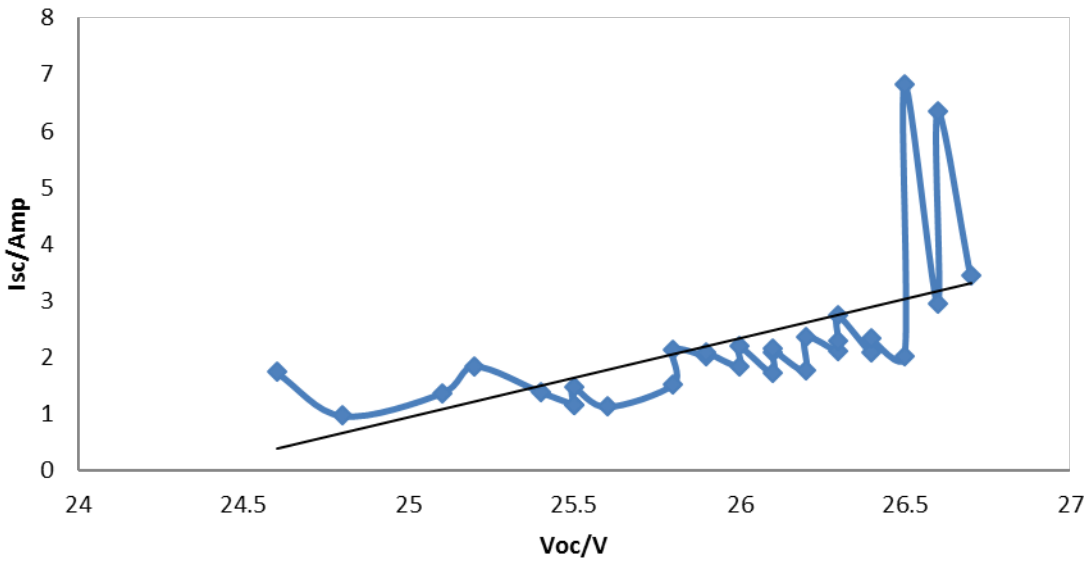

Figure 8: I-V characteristics for control solar panel for day 5

Figure 9 reveals the plot of Voc for control and dirty solar panels against time of the day for day 5. The Voltage (Voc) generated by the control solar module was 26.7V at 11:55a.m while the corresponding value for the dirty solar module was 26.1V at the same time.
At 16:55p.m., the voltage generated by the control solar panel was 24.8V while the voltage from the dirty solar panel was found to be 23.8V.

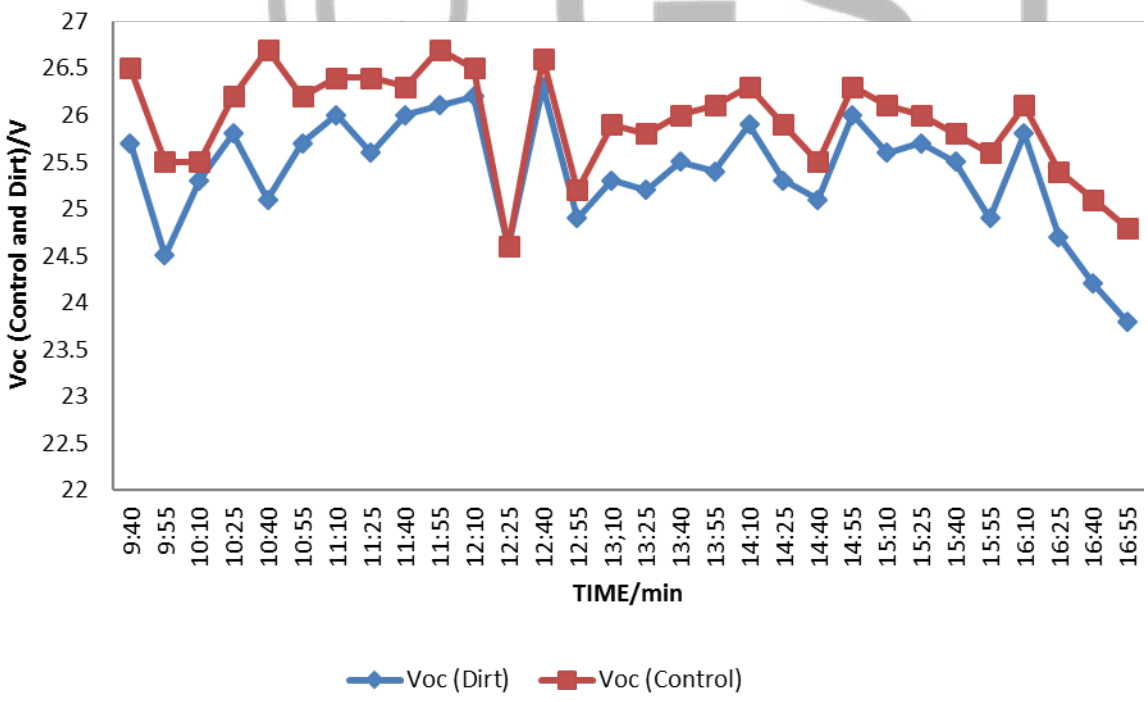

Figure 9: Voc (control and dirt) against time of the day for Day 5

Therefore, the percentage (%) voltage losses at the instances due to accumulated dirt were estimated as:

$$\% \, Voltage \; Loss = \frac{26.7 - 26.1}{26.7} \; x \, 100 \; = \; 2.25\%$$

$$\% \, Voltage \; Loss = \frac{24.8 - 23.8}{24.8} \; x \, 100 \; = \; 4.03\%$$

Figure 10 shows the plot of output power against time of the day for control and dirty solar panels for day 5. The maximum output power generated by the control solar module was 180.995W at 12:10 p.m while the corresponding value for the dirty solar module was 121.83W at the same time. At 16:55 p.m., the maximum output power generated by the control solar module was 24.056W while the maximum power output from the dirty solar module was found to be 16.66W.

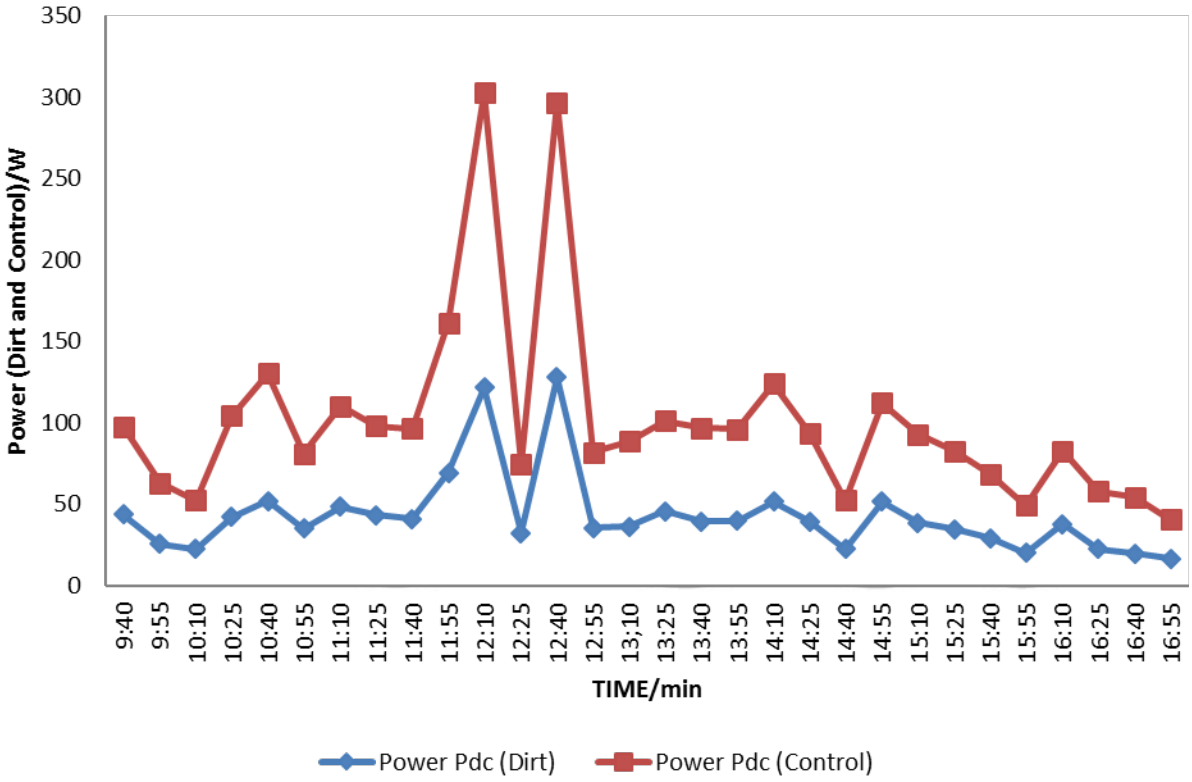

Figure 10: Output Power (control and dirt) against time of the day for Day 5

Therefore, the percentage (%) power losses at the instances due to accumulated dirt on the surface of solar module were calculated as:

$$\% \, Power \; Loss = \frac{180.995 - 121.83}{180.995} \; x \, 100 \; = \; 32.69\%$$

$$\% \, Power \; Loss = \frac{24.056 - 16.66}{24.056} \; x \, 100 \; = \; 30.74\%$$

Accumulated solid dirt (mixture of Algae, sand, dust and moist air) over time on the surface of solar module thus reflects part of solar radiation impinging the module. This causes reduced output voltage and consequently reduced output power as compared with fully illuminated cleaned solar module.

Table 3 summarizes the daily total power output produced by the control (cleaned) and dirty (soiled) solar modules and the daily percentage power losses.

Table 3: Daily power output and percentage loss.

Days	Daily total output power (Control)/Watts	Daily total output power (Dirty)/Watts	Percent Power Loss (%)
Day 1	2383.016	1407.255	40.95
Day 2	3539.326	2051.732	42.03
Day 3	1611.075	1087.175	32.52
Day 4	774.993	539.386	30.40
Day 5	1758.487	1286.813	26.82
Day 6	2130.025	1505.048	29.34

The daily output power loss due to the accumulation of solid dirt (mixture of Algae, sand, dust and moist air) over-time on the surface of solar module as compared with cleaned solar module ranges between **26%** and **42%** in this geographical location. Averaging these values amount to **34.0% ± 8.0 %** output power loss. This is a huge loss to the output power as a result of accumulated solid dirt on the surface of installed solar module.

5. Conclusion

The impact of cumulative accumulation of solid dirt (Algae, sand, dust and moist air) was investigated by collecting data from solar panels exposed to sunlight in condition that mimic their real life application. The output performance of the solar panels were evaluated using the testing parameters that include open circuit voltage and short circuit current, I-V characteristics and the soiling losses. The output power losses due to dirt accumulation on the surface of the solar module range between **26%** and **42%.** Averagely, dirty solar module loses **34.0% ± 8.0 %** output power daily. Hence, regular cleaning of the surface of the solar module should be adopted for optimum power yield.

References

[1] H. Salim. "Solid dirt accumulation on a solar-village PV system near Riyadh", *Rijeka Vol.* 9, no.3, pp 251–278, 1988.

[2] M. Mani and R. Pillai "Impact of dust on solar photovoltaic (PV) performance: research status, challenges and recommendations". *Renewable and sustainable Energy reviews, Vol.* 14, no. 9, pp 3124 – 3131, 2010.

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

[4] T. Sarver, A. Al-Qaraghuli and L. L. Kazmerski (2013). "A comprehensive review of impact of solid dirt on the use of solar energy", *History, investigations, results, literature and mitigation approaches, Vol.* 4, no. 2, pp 59-72, 2013.

[5] Z. A. Darwish and S. Mekhilef, "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.

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

[7] J. Driesen , "Effect of soiling on photovoltaic modules". *Solar Energy, Vol.*96, no.1, pp 283-291, 2013.

[8] H. Qasem, T. Betts, and H. Mullejans. "Dust and dirt induced shading on photovoltaic modules", *Progress in photovoltaic Research and application, Vol.* 22, no.1, pp 218-226, 2014.

[9] D. A. Ghazi, M. Sayrah and T. K. Kazem, "Solid dirt distribution and accumulation in distinct parts of the world". Vol. 45, no.3, pp. 211-219, 2014.

[10] M. Zaihidee. "The impact of dust on the efficiency of PV panels", *Environmental health perspective, Vol.* 8, no. 2, pp 17-23, 2016.

[11] 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.