Effect of Black Soot on the Performance of Photovoltaic Systems in Port Harcourt

EMMANUEL CHINWEIKPE OBUAH [1], TAMUNO-OMIE JOYCE ALALIBO [2]
[1] *Department of Electrical Engineering, Rivers State University*
Nkpolu-Oroworokwo, Port Harcourt, P.M.B. 5080, Rivers State Nigeria
[2] *Department of Computer Engineering, Rivers State University*
Nkpolu-Oroworokwo, Port Harcourt, P.M.B. 5080, Rivers State Nigeria

Abstract -- Solar photovoltaic (PV) is currently the fastest growing power generation technology in the world. The performance of PV modules depends upon the geographical factors such as solar intensity, longitude, latitude; and the environmental factors such as humidity, pollution, temperature, wind, dust, rain, etc. Design assumption has been a major research topic in PV systems and has usually been concentrated in studies on radiation availability, efficient operating strategies design and sizing of these systems. On the other hand, the influence of environmental factors such as debris on the performance of PV systems has not been given much attention, particularly in Port Harcourt region of Nigeria. In this work, electrical performances of photovoltaic systems are studied empirically with their effect of soot. The experimental results obtained were used for the calculation of the energy efficiency and power output of the PV systems. It was found that the average reduction of PV efficiency was 12%. It was also observed that power reduction was due to soot in form of carbon particles accumulated on the panel.

Indexed Terms: Soot, photovoltaic, Efficiency, Port Harcourt

I. INTRODUCTION

Electrical power is the most essential need of people worldwide; and it is needed more than ever. Electricity from fossil fuels (coal, oil and gas) is non-renewable, extensively used, and destructive to the environment. Renewable energy has attracted wide academic and industrial research interest, particularly solar photovoltaic (PV) system, to replace the conventional fossil generation, which is rich in carbon dioxide emission.

Solar PV system is a technology that converts energy from the sun into electricity. The main components of PV system are the panels, rated Wp. Appropriate installation design (orientation, exposure, sun-tracers) to maximize solar installation can potentially ensure sustained yield (electricity). However, there are other vulnerable factors, often overlooked such as on-site deposition of debris (dust, bird droppings and soot), which can significantly degrade the efficiency of solar PV installations.

In addition to being dependent on the intensity of solar radiation, the amount of power produced by a given PV system may also be affected by the system efficiency in converting incident irradiance into power, or efficiency of the inverter. Also in PV systems, module efficiency can further be reduced by 10–25% due to losses in the inverter, wiring, and module soiling (dust and debris) [1].

Debris is a term generally applying to minute solid particles with diameters less than 500mm. It occurs in the atmosphere from various sources such as dust lifted up by wind, pedestrian and vehicular movement, volcanic eruptions, and pollution.

The characteristics of debris settlement on PV systems are dictated by two primary factors – its property of dust and its local environment – and these characteristics influence each other. The local environment comprises site-specific factors influenced by the nature of prevailing [human] activities, built environment characteristics (surface finishes, orientation and height of installation), environmental features (vegetation type) and weather conditions. The property of debris (type – chemical, biological and electrostatic property, size, shape and weight), is as important as its accumulation/aggregation [2].

It is also well-known that debris promotes dust. A sticky surface (furry, rough, adhesive residues, electrostatic buildup) is more likely to accumulate debris than a less sticky, smoother one [3]. With the initial onset of debris, the surface becomes more amenable to dust collection and would tend attract or promote further settlement. Taking into account the effect of gravity, horizontal surfaces usually tend to accumulate more dust than inclined ones. This however is dependent on the prevalent wind movements. Generally, a low-speed wind pattern promotes dust settlement while a high-speed wind regime would. On the contrary, scatter dust settlement and have a cleaning effect.

The degree by which debris affects the PV system performance is determined by the amount deposition and removal through rain. According to Kaldellis and his associates, the module efficiency depends upon the output power of PV module and solar irradiance, and it degrades with the dust accumulation on PV module surface. The module efficiency showed an inverse relation with the solar irradiance and module temperature. [4]

Thus, the geometry of the PV system in relation to the direction of wind movements can either increase/decrease the prospects of dust settlement at specific locations of the PV system. Dust is likely to settle in regions of low-pressure induced by high-speed wind movements over inclined/vertical surface.

Further studies conducted to investigate the effect of dust on solar cells are found in [5-14]. From the literatures, it could be concluding that dust deposition on the PV module surface has a major effect in the reduction of output power and it should not be neglected in module performance measurement. In [5], the effect of dust on the performance of PV modules in Saudi Arabia was conducted. After the six months' exposure to the natural environment, 50% reduction in power of PV modules was examined.

In [6], the effect of dust on PV modules was investigated; and it was found that efficiency of PV module was decreased up to 0.4% as dust density increased to 0.09 mg/cm^2. The report in [7] studied the behavior of PV modules with dust deposited on their surfaces. Results showed that power and efficiency of module decreased up to 92% and 89% respectively compared to clean modules.

In [8], it was also reported the decrease of module output power with increase of dust density on the surface of PV modules. In [9], 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. In [10] sand dust particles as pollutant has also been used for a similar study.

Impact of airborne dust deposition on the performance of PV module inside the laboratory under the controlled conditions in a test chamber has also been investigated in [11]. 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

Sand and dust particles deposition on PV surface in dry region are presented with numerical and analytical models in [12], supported by a laboratory investigation of sand particles accumulation on a glass surface. The accumulation of sand particles on horizontal glass surface is found to exponentially reduce the available area for transmission of incident photons. An experimental study was conducted in [13] to compare the energy performance of two identical pairs of Panels; the first being clean and the second being artificially polluted with ash, i.e. a byproduct of incomplete hydrocarbons' combustion mainly originating from thermal power stations and vehicular exhausts.

In [14], experiment on the 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.

Current research into rasterizing deposition of dust and their impact on PV system performance is limited given the fact that dust deposition is a complex phenomenon and is influenced by diverse site-specific environmental and weather conditions.

Due to the fact that Port Harcourt is surrounded by the cement ash plants and refineries and other chemical industries, the effect of debris on PV modules cannot be ignored. Currently, there was report of prevailing soot in Port Harcourt [15]. It is on the basic of this that this research is conducted.

The overall purpose of the project is to investigate the effect of the black soot in this location and, to ascertain the performance of PV systems in other to measure its efficiency.

II. EXPERIMENTAL PROCEDURE

The experiment was conducted using two solar panel of 10W capacity, mounted on a stand as illustrated in Figure 1 and Figure 2. 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.

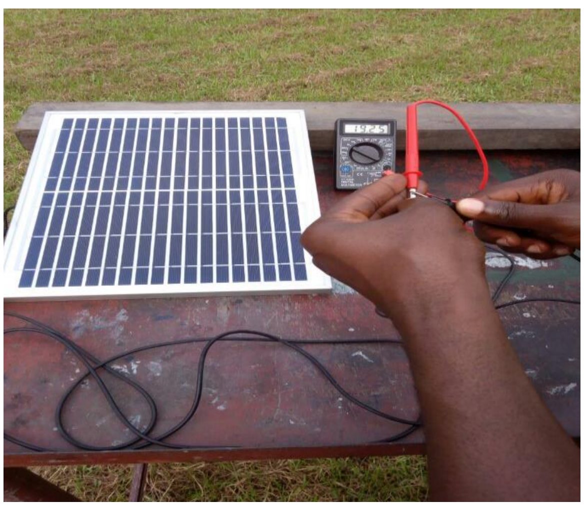

Figure 1: Experimental Setup for PV panel without soot

Figure 2: Experimental Setup for PV panel with soot

Model Type	PLM-10P/12
Peak Power	10Wp
Maximum Power Point Voltage(V_{mpp})	17.40V
Maximum Power Point Current(I_{mpp})	0.55A
Open Circuit Voltage(V_{OC})	21.60V
Short Circuit Current(I_{SC})	0.66A
Maximum System Voltage	18.00V
Normal Operating Cell Temperature	25ºC
Weight	1.80kg
Length	28.50cm
Width	34.50cm
Height	12.50mm

Table 1: Specification of the PV Project panel

III. GOVERNING EQUATIONS

The maximum power of the PV in Watt can be calculated as:

$$P = V_{\max} * I_{\max} * F_F \quad (1)$$

Where,
$V_{\max}$ is the voltage of electricity produced (Volts)
$I_{\max}$ is the current produced by the solar PV panel (Ampere)
F_F is the Fill Factor
The Fill Factor is given as:

$$F_F = \frac{P_{max}}{P_T} = \frac{I_{mp} * V_{mp}}{I_{sc} * V_{oc}} \qquad (2)$$

Where

I_{mp} is the Maximium Power Point Current of the PV

V_{mp} is the Maximium Power Point Voltage of the PV

I_{sc} is the Short Circuit Current of the PV

V_{oc} is the Open Circuit Current of the PV

The percentage efficiency (%) of the solar panel is calculated by the formulae:

$$\eta = \frac{P}{IA} * 100 \qquad (3)$$

Where

A - Area of solar panel (cross-section of panel)

I - Intensity of Solar Radiation (W/m^2)

Percentage reduction in voltage can be calculated by the formulae

$$V_R = \frac{V_a - V_b}{V_a} * 100 \qquad (4)$$

Where

V_a is the voltage without black soot

V_b is voltage with black soot

Efficiency reduction in power can be calculated by the formulae

$$\eta_R = \frac{\eta_a - \eta_b}{\eta_a} * 100 \qquad (5)$$

Where

η_a is the efficiency without black soot

η_b is efficiency with black soot

IV. EXPERIMENTAL RESULTS

Figure 3-7 shows various results for voltage with time on different days of the week. In all the cases, it is shown that the highest voltage is produced when the panel is not covered by layer of black soot. In this case, the fill factor is increase and the system PV efficiency is as well increased. By way of calculation, table 2 shows the power and efficiency of the PV panel in all the cases. It was observed that the voltage and power for the panel with black soot is lower compared to the panel without soot. The parameters of the panel as shown in Table 1. The panels are inclined with at an optimal angle of 15° facing the northern hemisphere, so that the sun makes an incidence angle of 0°. The ambient temperature and the solar PV power are measured using thermometer and power digital multimeter respectively. Data are collected and recorded hourly (mostly sunny time) for five days at the interval of one hour between 9.00am and 14.00pm.

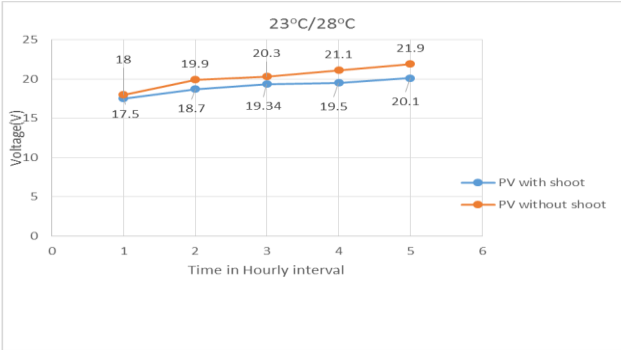

Figure 3: Graph of voltage against time (Day 1)

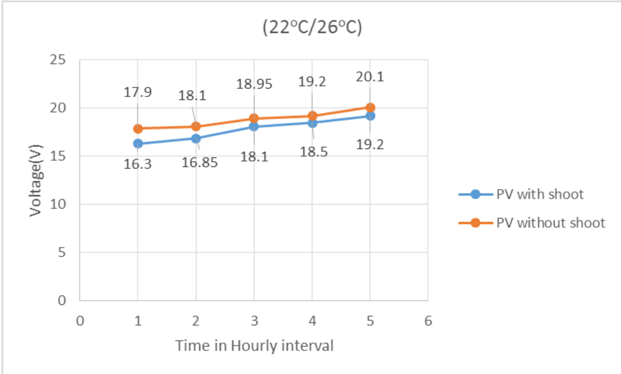

Figure 4: Graph of voltage against time (Day 2)

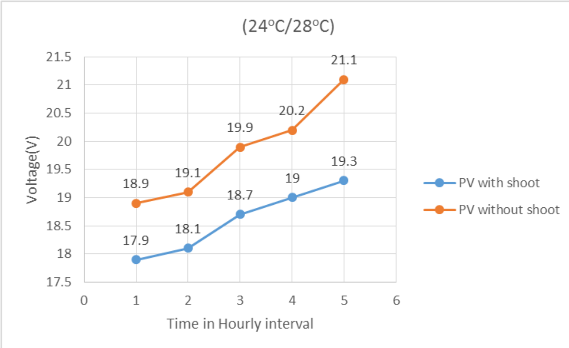

Figure 5: Graph of voltage against time (Day 3)

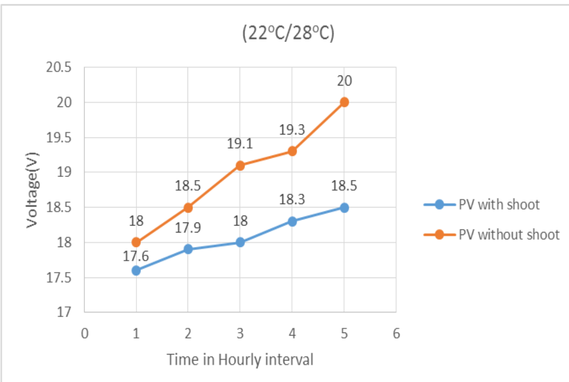

Figure 6: Graph of voltage against time (Day 4)

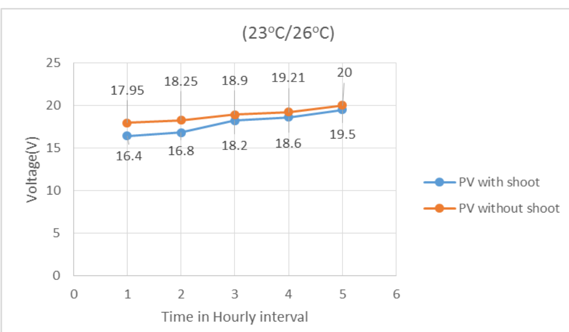

Figure 7: Graph of voltage against time (Day 5)

Days	Generated Power of PV with black soot (W)	Generated Power of PV without black soot (W)	Percentage Reduction in Voltage (V)	Percentage Reduction in Efficiency
1	5.98	6.63	2.78	10.97
2	6.64	7.73	6.03	14.70
3	7.13	8.30	4.73	13.09
4	7.84	8.80	7.58	10.44
5	8.21	9.54	8.22	13.40

Table 2: Calculated Results Generated Power and Efficiency

V. CONCLUSION

The effects of dust on PV panel have been studied experimentally in Port Harcourt region of Nigeria using carbon particles in form of black soot. The carbon particles have major impact on performance and efficiency of the solar PV panel. The reduction in the peak power generated can be up to 12%. It was observed that voltage reduction was because of the particles accumulated on the panel. Hence, in practice, dust must be removed from the surface of solar PV panel in order to ensure highest performance. The cleaning intervals is different from site to another. So, it is important before such arrangement is scheduled, full knowledge of region environment pollution type and its occurrence period should be at hand.

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