Sensitivity of Monocrystalline Photovoltaic Cell's Output power and Fill-factor to Dust Particles

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Abstract: **Accumulation of particles like dust on the surface of photovoltaic cell (PVC) normally impede photon energy form reaching the photovoltaic cells, this accumulation tends to scatters light radiation thereby reducing the power output of the cell. In this paper, the effects of atmospheric dust on the PVC surface has been investigated. Measurement of electrical output power, fill factor (FF) and efficiency of 160 W monocrystalline PVC panel has been investigated. Analog multimeter was used to measure the electrical properties of the PVC with and without dust surface. From the experimental data obtained, the output power, FF and efficiency was determined. The results revealed that, increase in dust density on PVC leads to decrease in open circuit voltage, short circuit current and output power. Also, the fill factor which is one of an important parameters for estimating the performance of PVC module was also found to decrease with increasing dust density with high correlation coefficient of -0.9573 (Strong inverse relations). The dust with 10 g/m^2 reduces the fill factor by 17.5%. Furthermore, it was also noted that the output peak power of the PVC without dust and with dust on the surface are 13.40 W and 6.89 W respectively, which implies that dust particles impede the light incident on the PVC surface and reduces the output power. An empirical model for dust deposition and how it affects the photovoltaic FF was also developed to better predict the FF and energy yields and to optimize the PV module.**

Key words: **Dust density, fill factor, open circuit voltage, polycrystalline PVC, short circuit current**

I. INTRODUCTION

Solar panel cells are devices that use the photovoltaic effect of semiconductors to convert the energy conveyed by light electromagnetic radiation into electrical energy [1]. Due to its green, high-efficiency and renewable characteristics, they are currently used in rural electrification system, in a water pumping irrigation from deep well. Hence, it is considered to be one of the major ways to solve the current energy problem. PVC are generally installed in open areas such as roof tops and wastelands which exposed it to the winds. In these places, surrounding areas are empty, the general configuration of the ground surface is mostly sandy soil which makes the surface of PVC to be covered with dust. The accumulation of dusts on PVC leads to decrease in solar irradiance reaching the surface of the module there by causing a reduction in the power output, efficiency and fill factor of the solar cell [2]. The short circuit current, open circuit voltage, output power and efficiency of solar panels depends on solar radiation that falls on the surface of the PVC [3]. If the amount of incoming sun light falling on PV panel surface decrease the efficiency of PV system also decreases and vice versa. On the other hand, the dust particles on panel surface creates a barrier in the path of sunlight, that falling on panel surface. Due to this, part of solar cell in the panel will be shaded, which degrades the performance of PV panel [4]. Also, the output power, fill factor and efficiency of solar cells are reduced by some external factors such as temperature, relative humidity, atmospheric pressure which reduces the intrinsic lifespan of the solar cells. Study of an extrinsic factors like dust accumulation that affects the performance of the PVC is very important in the dusty, humid and climatic region so as to alleviate the effects [5]. Therefore, it is useful to understand and quantify dust accumulation effects on electrical losses from dust deposition both globally and specifically on location for a solar field.

II. THEORETICAL BACKGROUND

Accumulation of dust on PVC can be described theoretically in terms of adhesion forces. These forces are responsible for the interactions between the dust particles and the PVC surface. The force is divided into three, namely; capillary adhesion, Van-der walls adhesion and electrostatic adhesion force [6]

2.1 Capillary adhesion

Capillary adhesion are present due to the presence of water molecules between dust particles and the surface of solar cell thereby forming a meniscus that results in an attractive force. This is due to the influence that the surface tension has on the internal pressure and this also depends on weather conditions which is given as, [7]

$$F_c = F_{st} + F_{mc} \tag{1}$$

With,

$$F_{st} = 2\pi b\gamma \tag{2}$$

$$F_{mc} = \pi b^2 \rho_o \left\{1 - e^{\left[-\lambda_k\left(\frac{1}{a}-\frac{1}{b}\right)\right]}\right\} \tag{3}$$

$$\lambda_k = \frac{\gamma V_m}{R_m T} \tag{4}$$

where T is the adhesion temperature, F_c is the capillary force, F_{st} is the surface tension force, F_{mc} is the difference in pressure between Pa and water meniscus, a and b are coefficient, Rm is the molar gas constant, V_m is the molar volume, λ_k is the kelvin length, ρ_o is the saturation vapor pressure and γ is the surface tension.

2.2 Electrostatic adhesion

This is the interaction of the charge particles resting on a solar panel surface, that is, the charge that holds dust particles to the surface of the PVC. Electrostatic adhesion takes place under dry environment with dust particles greater than 50 µm [8]. Electrostatic force, $\vec{F}$ is given as [6]

$$\vec{F} = K\frac{q_o q_1}{r^2}\hat{r} \qquad (5)$$

where K= constant, qoq1 is the quantity of charge on each body, $\hat{r}$is the distance between charged particles and $\hat{r}$ is a variable unit vector.

2.3 Van dar walls adhesion

It is the force of attraction occurring between the dust particles and the PVC surface with particle size less than 50 µm. Van dar walls adhesion, F_{vdw} is given as, [9]

$$F_{vdw} = \frac{AR}{6d^2} \qquad (6)$$

With,

$$A = \pi^2 C\rho_1\rho_2 \qquad (7)$$

where A is the interaction constant, R is the radius of dust particles, d is the distance between the particles and the surface, C is the attractive interaction strength, ρ_i is the number of density of molecules in the solid.

III. MATERIALS AND METHODOLOGY

The experimental campaign of this study took place on the roof of the faculty of science, The Polytechnic, Ibadan. Oyo state, Nigeria (7.4296°N, 3.8919°E). Two 160 W monocrystalline PVC was used, one for experimental and the other one for control as shown in figure 1. An electronic balance was used to measure different dust density starting from 10 g/m^2, this was spread evenly on the surface of PVC. The open circuit voltage (Voc) and short circuit current (Isc) was measured using ananalog multimeter. The procedure was repeated using 20 g/m^{2}dust particles up till 110 g/m^2 at a step of 10 g/m^2, the Voc and Isc for each dust density was noted and recorded. For the control experiment, the other PVC in clean state (without dust) was placed beside the former under the same atmospheric weather condition, the Voc and Isc were also measured and recorded. From the data obtained, the output power, fill factor and the efficiency for both PVC (with and without dust) were determined using equations (8), (9) and (10) respectively.

$$P_{max} = V_{max} \times I_{max} \qquad (8)$$

$$FF = \frac{P_{max}}{V_{oc}I_{sc}} = \frac{\eta \times A \times G}{V_{oc}I_{sc}} \qquad (9)$$

$$\eta = \frac{P_{max}}{AG} \times 100 \qquad (10)$$

where G is the measured solar irradiance intensity and A is the area of the solar panel module

Figure 1: Clean and dusty photovoltaic modules.

IV. RESULTS AND DISCUSSION

Figure 2 shows the output power against the dust density of 160W Monocrystalline PVC. It was noted that, the highest output power (46W) was observed when the surface of the panel was cleaned without dust. When the dust of about 10g /cm² was spread on the panel, the output power decreases. The adverse effect of dust get worst with increasing amount of dust density on the PV surface, that is, the power output of PV panel drops drastically with increasing in surface dust density. This is because the dusts block the incoming radiation (light) to the panel surface and generate loss charge carrier compared to a scenario when there is no dust. Hence, dust reduces the output power of the panel which equally degrades the performance of PV panel.From the output power obtained, the efficiency of the solar panel as a function of dust density was determined, the results is as shown in figure 3. It was noted that, the efficiency of solar panel decreases exponentially with increasing dust density. Empirical model for predicting the efficiency (η) of photovoltaic solar cell at different dust density (ρ) is shown in (11)

$$\boldsymbol{\eta = 26.68\exp(-0.02368\rho)} \qquad \mathbf{(11)}$$

Coefficients (with 95% confidence bounds) gives the model shown in equation (11), with the following goodness of fit; sum of square error = 12.04, R^2= 0.9835, adjusted R^2 = 0.9818, RMSE = 1.097.

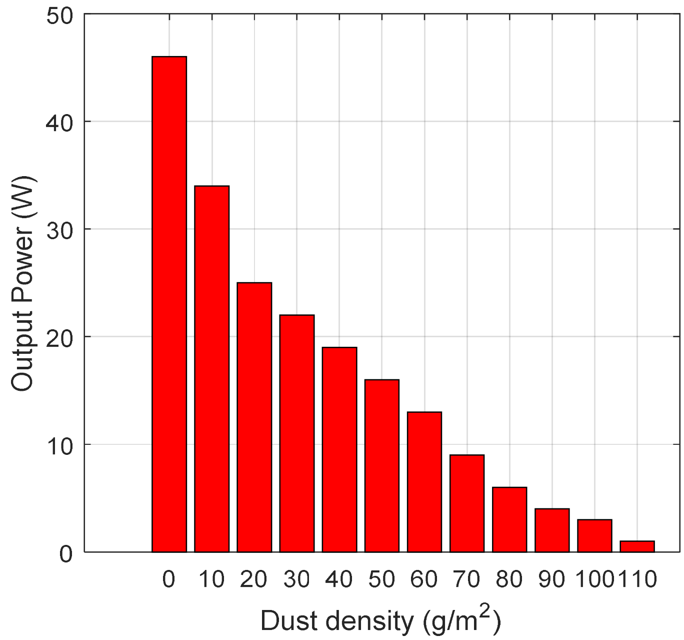

Figure 2: Graphical representation of output power against dust density

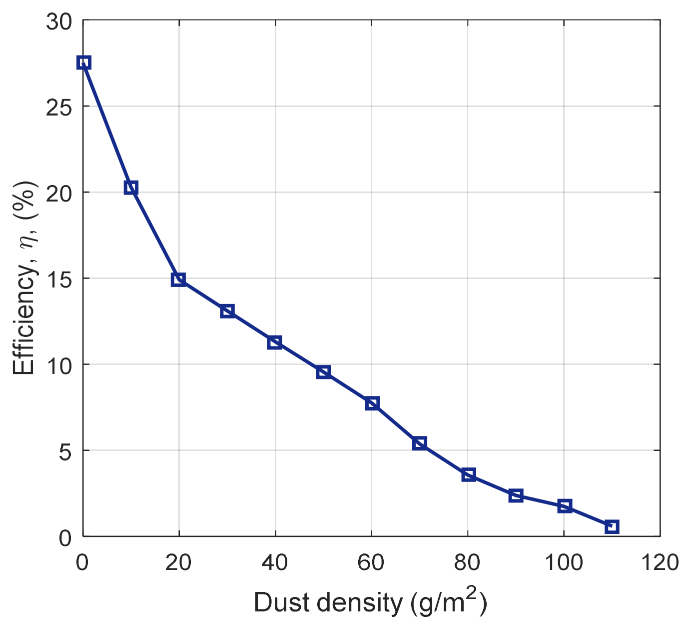

Figure 3: Graphical representation of panel efficiency against dust density

4.3 Current-voltage characteristics with and without dust result

Figure 4 shows the I-V characteristics of PVC without dust and with dust. It was noted that, the maximum current recorded remains fairly constant 0.87A with increasing in voltage up to 48 V, it then dropped sharply with fairly increase in voltage. Higher value of short circuit current was obtained without dust compared with when the solar panel surface was spread with dust. Also, the maximum no load voltage (V_{NL}) and maximum short circuit current (I_{SC}) obtained were 49 V and 0.89 A respectively. When the solar panel surface was filled with dust, it was noted that a current of about 0.430A which is nearly constant up to 39.8 V was obtained. Also, the V_{NL} and I_{SC} decreases due to the presence of dust on the surface of the panel. The area under the curve gives the electrical power (product of Im and Vm) of the solar panel system. The highest power (42.70 W) was obtained when the surface of PVC was not covered with dust while the power obtained becomes low (17.94 W) when the surface of was covered with dust. The output power of the system with dust and without dust is represented by the area of the current-voltage characteristics shown in the figure 3.

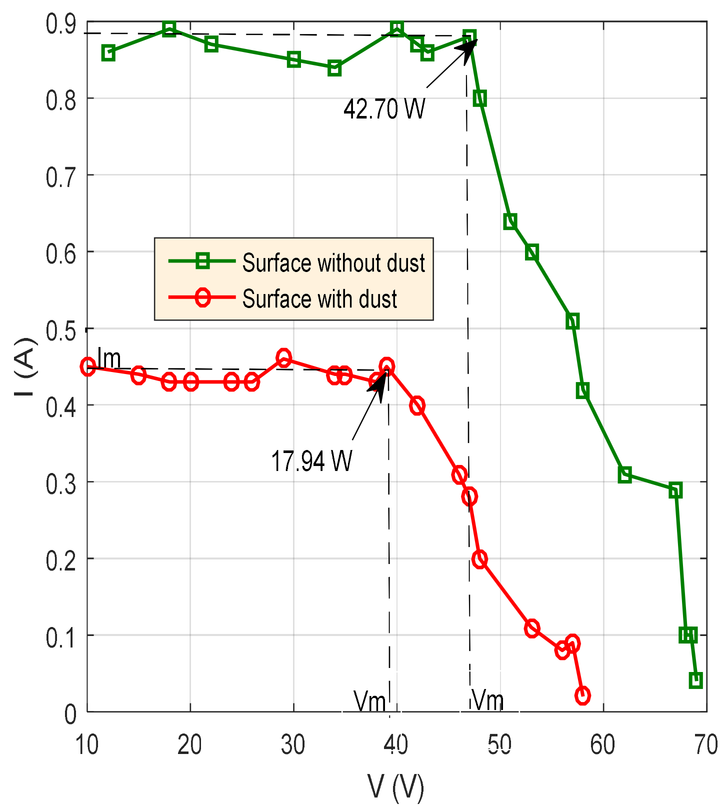

Figure 4: Relationship between I, V and the output power

4.4 Relationship between I-V and output power

The maximum powers for both dust and without dust conditions were obtained from calculations using the measured values of current and voltages. The maximum power, which is represented by the top corner point of the curve, also shows the same trend of reduction due to the presence of dust. Figure 5 and 6 shows the relationship between the current-voltage and power output for both solar panel without dust and with dust respectively. It can be seen that the highest power (42.70 W) was produced when the panel is not covered with dust. With the introduction of dust as depicts in figure 6, the area within the curve become smaller and the peak power which is normally denoted by the top corner point of the curve was noted to be (17.94 W).

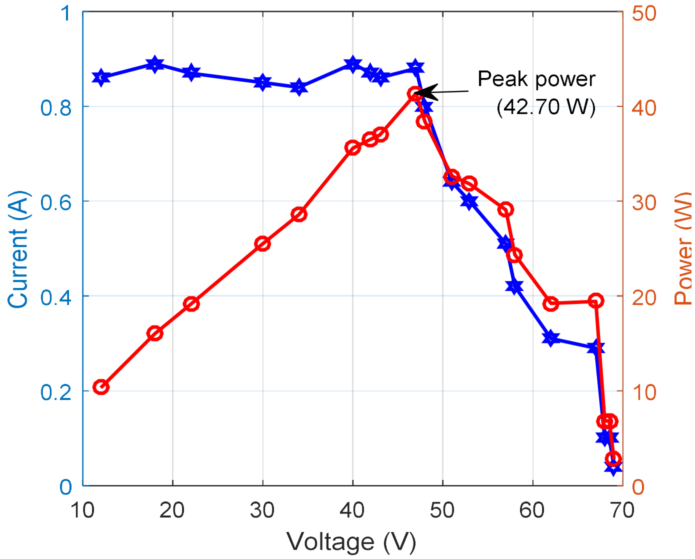

Figure 5: Current-voltage and power output for PVC surface without dust

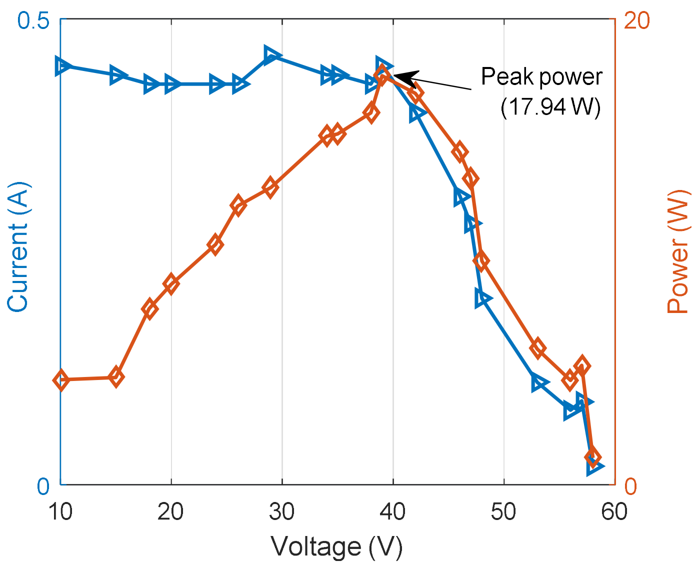

Figure 6: Current-voltage and power output for PVC surface with dust

4.5 *Variation of FF with dust density*

Figure 7 shows the effect of FF at different dust densities. When the surface of PV is clean without dust, the fill factor was found to be very high (0.96) but when the dust density of PV is 10g/m^2, the FF decreases by about 17.5%. Generally, when the dust density increases the FF decreases. This shows a high negative correlation coefficient (-0.9573). It was also noted that when the dust density increases from 10g/m^2 to 70g/m^2, the decrease of fill factor is the largest but as the dust density reaches 80g/m^2, the value of fill factor was noted to be nearly constant. Figure 8 shows the curve fitting tool for fill factor against dust density, a simple model was obtained with Matlab 2015Rb using exponential model fitting 1at off robust region. The proposed model capable of predicting fill factor with different dust density is as shown in equation (12)

$$FF = 0.9945 * exp\ (0.02133 * \rho) \qquad (12)$$

where ρ is the dust density in g/m^2 and FF is the fill factor. The goodness of fit using coefficient at 95% confidence bounds are given as shown in Table 1

Table 1: Goodness of fit at 95% confidence bounds

Goodness of fit	Value
Sum of square error, SSE	0.01442
R^2	0.9852
Adjusted R^2	0.9838
Root mean square error, RMSE	0.03797

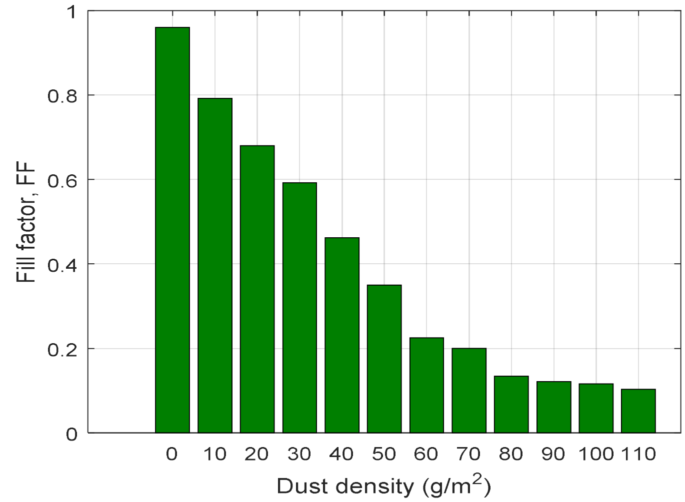

Figure 7: Variation of fill factor with dust density

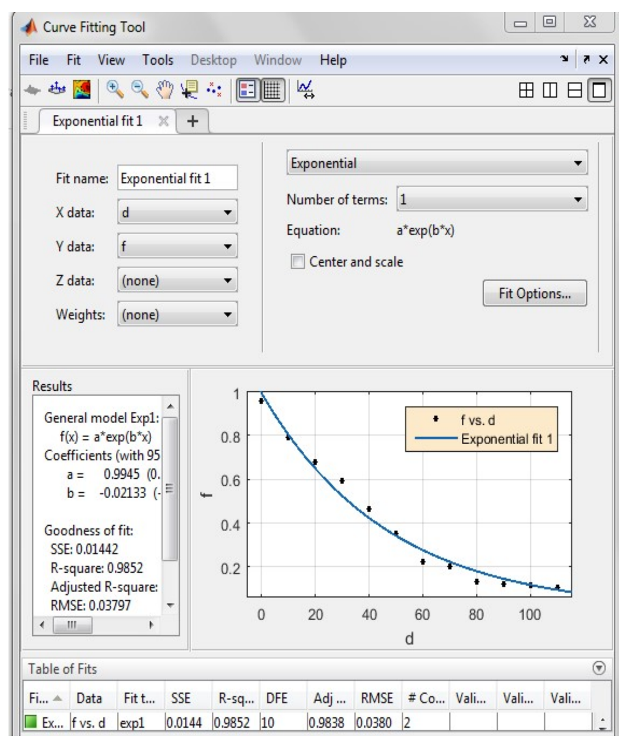

Figure 8: Curve fitting tool of dust density and fill factor

V. CONCLUSION

In this paper, the effects of atmospheric dust on the PVC surface has been studied. It was revealed that as the dust density increases, the short circuit current, open circuit voltage and output power of the PV are all decreases. Also, the fill factor which is one of the important parameters for estimating the performance of PVC module was also found to decrease with increasing dust density having high correlation coefficient of -0.9573 (Strong inverse relations). The dust with 10 g/m^2 reduces the fill factor by 17.5%. Furthermore, it was also noted that the output peak power of the PVC without dust and with dust on the surface are 42.70 W and 17.94 W respectively, which implies that dust particles impede the light incident on the PVC surface and reduces the output power.

An empirical model for dust deposition and how it affects the photovoltaic FF was also developed to better predict the FF and energy yields and to optimize the PV module.

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