

Study of Decreasing Efficiency of a Photovoltaic Cell Caused by Accumulated Dust Particles of Different Types.

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Abstract— We studied the negative impact of dust accumulation on the surface of a photovoltaic (PV) solar cell using environmental dust, ash dust, charcoal dust, and chalk dust. Our study confirmed a reduction in the fill factor of the photovoltaic model accumulated by dust particles, which may likely be linked to an increase in the operating temperature of the PV model. The accumulated environmental dust particles on a PV model reduced the efficiency by more than 80%, making it have the most negative influence on a PV model, which signifies a great economic loss. The chalk dust particles have the least negative impact on the panel, with 41% reduction in efficiency. The reduction in efficiency caused by all the dust particles suggested that most irradiation from the sun is scattered by the dust particles and does not get to the panel. The result indicated that the accumulated dust particles on a PV cell affected both the output power and the short-circuit current, but had no significant effect on the open-circuit voltage

Keywords—Photovoltaic panel, dust particles, environmental dust, solar radiation

I. INTRODUCTION

A photovoltaic (PV) cell is a device used to convert solar energy from the sun to electrical energy, using a process known as the photovoltaic effect to produce a direct current (DC) [1]. The generated DC current is either utilized in that form or converted to an alternating (AC) current, using a device known as an inverter. Other components of a PV solar system are the battery and charge controller [2]. The batteries are used for storage, to compensate for off-peak hours, while the charge controller is used to control the charging and discharging of the batteries. A PV panel can be classified into three generations, namely (i) first generation, (ii) second generation and (iii) third generation. The 1st-generation solar cell, mostly made of silicon, is still the most commonly used PV solar cell to date. When a photon of energy from the sun falls on a PV cell, the orbital electron of the semiconductor material is energized to cause a photovoltaic effect, resulting in the generation of electric voltage and current.

The overall efficiency of a PV system is affected by different factors, such as ageing, radiation intensity, temperature, climatic conditions, accumulation of dust particles, and shading [3,4]. Dusts are crushed minute particles of less than 500 μ m, found in the atmosphere or settled on a surface [5]. Bamisile et al. [6] stated that the efficiency of a solar panel can be reduced by over 60% in a desert area, due to high accumulation of dust particles. The effect of the accumulation of dust particles on a PV panel, especially in the desert region, was also emphasized by Alzahrani et al. [7]. Interestingly, this region offers the optimal solar radiation and minimal cloud cover, making it an ideal location for the installation of a solar PV system. Hence, the need for a cleansing mechanism [8]. Maghami, [9], established that deposition of dust particles on a PV surface weakens their optical and electrical performance. The accumulation of dust particles on a PV cell, according to Nipu et al. [10], increases the surface temperature, which negatively affects the output performance of the cell. Sharaf et al. [11] suggested that the use of an air blower to force air conventionally towards the panel is one of the best dust cleaning mechanisms. A better understanding of the dust deposition mechanism and adhesion on the panel surface helps in the selection of the appropriate cleaning mechanism [12]. As a result, the selected cleaning method depends on the unique conditions of each site location. Dust particles from different sites exhibit different adhesive forces on the panel surface due to variations in particle size, environmental humidity, and chemical compositions [13]. Borah et al. [14] in their publication in 2023, stated that the performance of a PV module is affected more by finer dust particles than coarser dust particles. The installation of a PV system in a windy environment helps reduce the negative effects of an increase in temperature, but on the other hand, it also increases the dust and sand particles on the surface [15]. The accumulation of these dust particles on a PV solar cell leads to an economic loss, either by a reduction in the revenue generation of the solar energy harvesting system or by additional capital and operational costs due to the use of a cleaning mechanism [16].

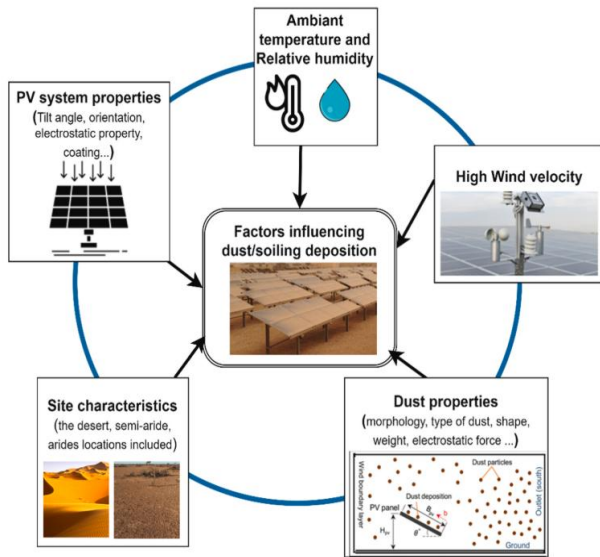


Figure 1. The cycle of contributing factors to the accumulation of dust particles on a PV panel [17].

Most irradiation from the sun is blocked by dust particles on the surface of a PV cell, while some is scattered, leading to a reduction in the absorbed radiation from the sun by the PV panel. Different factors like wind speed, module's tilt angle, chemical properties of dust particles, and humidity influence the deposition of dust particles on the surface of a PV cell [8].

The study focuses on the effects of dust accumulation on a PV solar panel, using different dust particles and possible ways of overcoming such challenges. Studies have shown that positioning the panel at an angle helps reduce the accumulation of dust particles on its surface, when compared with that mounted on a flat (zero tilt angle) surface [18,19]. We study the output efficiency of a solar panel at zero tilt angle with different types of dust particles of the same quantity on the panel. To achieve that, we mathematically model the effect of different dust particles on the output power of the panel. Establish the dust particle that most effectively affected the output performance of the panel by recording the output short circuit current (I_{sc}) and open circuit voltage (V_{oc}), using the same intensity of radiation from the sun.

II. METHODOLOGY

Materials

The required materials for the research are two digital multimeters, two 100-watt monocrystalline PV panels, and dust samples (environmental, charcoal, ash, and chalk) collected from different sources in February 2025.

Dust Collection, Preparation and Analysis

The collected dust particles came from the roadside undergoing construction along Enugu-Onitsha Road in Anambra state, Nigeria; Oyeagu market at Otuacha, Anambra state, Nigeria, where cooking charcoal is sold; a cooking spot in a local kitchen in Awka Anambra State, Nigeria; and a classroom that uses a chalkboard in Awka North local government area, Anambra state, Nigeria, for environmental dust, charcoal dust, ash dust, and chalk dust, respectively. The collected dust samples were sieved with an infinitesimal hole floor strainer to remove heavier particles. The samples of each dust after sieving are displayed in Figure 2.



Figure 2. Samples of charcoal dust, environmental dust, chalk dust and ash dust after sieving.

Experimentation

The experiment was carried out in March 2025 at Greenhouse junction, Ifite Awka, in an outdoor environment using two photovoltaic panels, for a period of five hours on four sunny days. The setup is as shown in Figure 3, and the experiment takes effect at exactly 12 noon on each day, for a period of five hours. Two identical photovoltaic panels produced by Direct Electric Inc., with each having 40 mono-crystalline cells, rated 100 watts each, were placed on a flat surface directly under the sunlight. The electrical characteristics of each panel are shown in Table I. To determine the effect of dust particles on the efficiency of the panel, 10g of the charcoal dust particles were first uniformly spread on one of the panels, while the other panel was exposed to sunlight, very clean without dust particles. To obtain the V_{oc} and I_{sc} readings, two digital multimeters are connected, one to a panel, and the readings were simultaneously taken every ten minutes from each panel, for one hour.

After an hour, the charcoal dust was removed, and the panel was properly cleaned before uniformly spraying the same quantity of environmental dust. Simultaneously, the same process was repeated to obtain the readings for another hour, using the two digital multimeters. In the same manner, the readings for the chalk and ash dust were obtained in the third and fourth hours, respectively. On the second day, the experiment was repeated, starting with the environmental dust first. The chalk, ash, and charcoal dust readings were taken every ten minutes in the second, third, and fourth hours, respectively. On the third day, the whole experiment was repeated, starting with the chalk dust, then the ash dust, and the charcoal dust, before ending with the environmental dust in the last hour. Finally, on the fourth day, we repeated the whole process, starting with the ash dust at noon, then the charcoal dust, the environmental dust and the chalk dust at the second, third and fourth hours, respectively.



Figure 3. The experimental setup of PV panels, with one sprinkled with environmental dust particles.

TABLE I
THE ELECTRICAL CHARACTERISTICS OF THE PHOTOVOLTAIC PANELS USED FOR THE EXPERIMENT.

PARAMETERS	SYMBOLS	UNIT	SPECIFICATION
Peak power	P_{max}	W	100.00
Max power Voltage	V_{mp}	V	18.47
Max power current	I_{mp}	A	5.41
Product Tolerance	-	%	0 +3
Short circuit current	I_{sc}	A	5.74
Open circuit voltage	V_{oc}	V	22.16
Weight	W	Kg	8.80
Length	l	Mm	1100
Width	w	Mm	668
Breadth	b	Mm	35
Max system voltage	-	(VDC)	1000
Wind Resistance	-	Pa	2400

III. DATA ANALYSIS

To analyze the data, the average of all the real-time data collected for each sample was taken. The calculated efficiency of the PV model using Equation 3 depends on several factors, which include the exposed surface area, the type of accumulated dust particles on the PV surface, and the average intensity of the sun. The average power output of the panel, using each dust sample, is calculated using Equation 1.

$$P = V_{oc}I_{sc} \quad 1$$

Where P is the average power output from the panel, V_{oc} is the recorded open circuit voltage from the panel, and I_{sc} is the recorded short-circuit current of the panel.

$$PV \text{ panel } eff. (\%) = \frac{P}{AXG} \times 100 \quad 2$$

Where P is the average power output of the panel for each sample, A is the calculated surface area of the panel, and G is the global solar radiation intensity.

The average global solar radiation intensity was assumed to be 1000 w/m^2 on a sunny day, and the calculated surface area of the panel is 0.737m^2 . Therefore, the overall efficiency of the panel will be calculated using Equation 3.

$$PV \text{ panel } eff (\%) = \frac{(I_{sc} \times V_{oc})}{0.737\text{m}^2} \times \frac{1}{1000} \times 100 \quad 3$$

Where I_{sc} and V_{oc} are the short-circuit current and open-circuit voltage, respectively.

The efficiency loss of the PV panel was calculated, making use of Equation 4.

$$\eta_{loss} = \frac{\eta_{clean} - \eta_{dirty}}{\eta_{clean}} \times 100 \quad 4$$

Where η_{loss} is the efficiency loss in the panel, η_{clean} is the efficiency of the clean panel, and η_{dirty} is the efficiency of the panel with dust particles.

To calculate the fill factors of the panels, Equation 5 was used.

$$FF = \frac{P_m}{V_{oc} \times I_{sc}} \quad 5$$

Where FF is the fill factor, $P_m (= \eta \times A_c \times G)$ is the maximum power output of the panel, while the V_{oc} and I_{sc} are the open-circuit voltage and short-circuit current, respectively.

IV. RESULTS AND DISCUSSION

The average measured short-circuit current and open-circuit voltage from the four days of the experiment were used to calculate the output power, output efficiency, efficiency loss and fill factors for all four dust samples on a PV panel.

The calculated values, as seen in Table II, revealed a decrease in the V_{oc} and I_{sc} , when dust particles are sprinkled on the panel. The reduction in these two important electrical parameters of a PV panel is the reason for a reduction in the output power of the PV panel sprinkled with the dust particle. The result from the table indicated that dust particles affected the short-circuit current more than the open-circuit voltage. The calculated fill factor also revealed a decrease when dust particles of different types are used on the panel. The results also indicated that the fill factor obtained from the panel when the environmental dust particles are sprinkled on it is mostly affected. The dust particles that have the least effect on the fill factor of the panel is that of the chalk dust particles, with only 45.16% decrease in the fill factor. The environmental dust particles with a 0.16 fill factor have over 82.79% reduction in the fill factor value, indicating the reason for the poor output power of the panel. The calculated efficiency loss also indicated that the efficiency of the panel with environmental dust is mostly affected, with over 80.9% loss in efficiency. This loss in efficiency is followed by the panel sprinkled with charcoal dust, with 76.93% efficiency loss. The panel efficiency loss, making use of ash dust, is 69.20%. The panel sprinkled with chalk dust has the least efficiency loss of 40.52%.

TABLE II
The average measured open-circuit voltage and short-circuit current, with calculated electrical parameters, of the PV panel covered with different dust particles.

Different Types of Dust	V_{oc}	I_{sc} (Amps)	P (Watts)	η (%)	η_{loss} (%)	FF
Clean panel	19.90	5.41	107.66	14.61	-	0.93
Environmental dust	18.97	1.07	20.30	2.78	80.97	0.16
Charcoal dust	18.83	1.31	24.67	3.37	76.93	0.19
Ash dust	19.70	1.68	33.10	4.50	69.20	0.26
Chalk dust	19.10	3.29	62.84	8.69	40.52	0.51

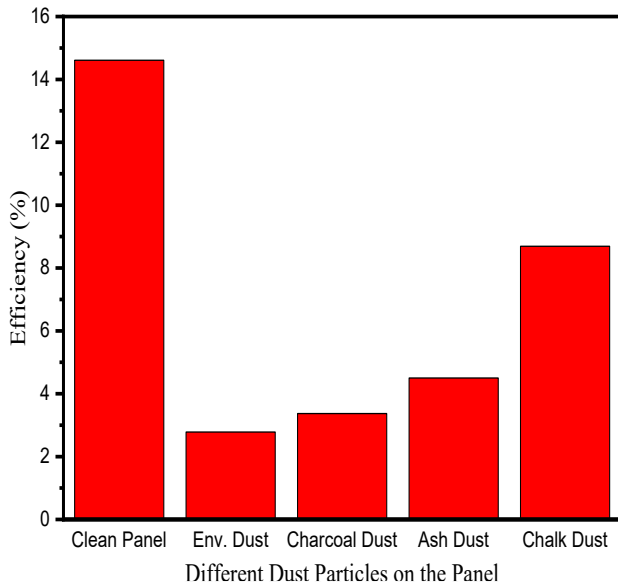


Figure 4. The overall efficiency of the panel uniformly sprinkled with the same quantity of different dust particles.

The Chart plot of the efficiency of the panel using all the dust samples indicated that environmental dust, mostly from the roadside, drastically affected the overall efficiency of the panel more. Suggesting that PV installation at a dusty load suffered more loss in efficiency, with the efficiency decreasing drastically in the dry season. Leading to a great economic loss. The next dust particle in line, affecting the overall efficiency of a panel from our research, is the charcoal dust particle. The chalk dust particle had the least effect on the efficiency, followed by the ash dust particle. The power output of the panel was affected by all the dust particles, with the environmental dust having the most negative effect on the panel (Figure 5). The average output power of the clean panel is 107.66 watts. The value decreases to 20.3 watts, signifying a great economic loss, when the panel is covered with environmental dust particles. The output power of the panel when covered with charcoal, arch, or chalk dust particles is 24.67 watts, 33.1 watts and 62.84 watts, respectively.

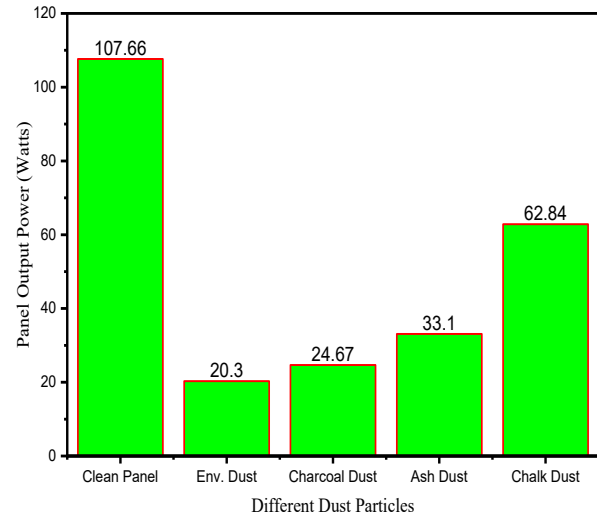


Figure 5. The output power of the panel uniformly covered with the same quantities of different dust particles.

The study indicated a great loss in the efficiency of the panel due to accumulated dust particles. Our study, as seen from Figure 6, indicated a great loss in efficiency up to 81%, with the use of environmental dust particles, indicating a great economic loss. The result indicated that the panel output is just 19% of its normal efficiency when covered with 10g of environmental dust particles. On the other hand, the use of 10g of chalk dust only reduced the panel efficiency by 41%, making it the least dusty particle that negatively affects the PV efficiency. Leaving the panel to operate with just 59% of its normal efficiency. The charcoal dust, as seen from Figure 6, reduced the efficiency of the panel by 77%. Making it the next after environmental dust that negatively affects the panel efficiency. The panel only operate with 23% efficiency with the spraying of just 10g of charcoal dust. The ash dust particle on its own reduces the panel efficiency by 69%, meaning that the panel operate with only 31% of its normal efficiency when covered with 10g of ash dust particles. Our research results reveal that 10g of all the dust particles, except for chalk dust particles, reduces the efficiency of the panel by more than half. Signifying a great economic loss.

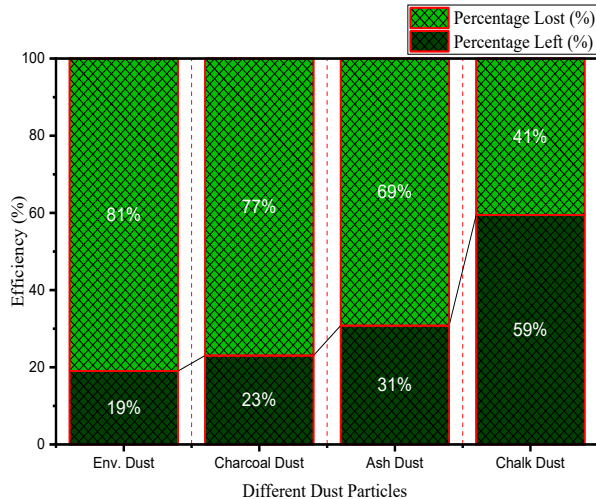


Figure 6. The percentage efficiency loss of the panel, using any of the dust particles.

V. CONCLUSION AND RECOMMENDATION

Our study of different dust effects on the efficiency of a PV panel on a flat surface, using 10 grams of environmental dust, charcoal dust, ash dust, and chalk dust each, indicated that all the dust particles reduced the output efficiency of the panel. The environmental dust particles that have the most significant effect on the fill factor reduced the panel efficiency by 81%, signifying a great economic loss. Using the same quantity of chalk dust particles on the PV panel also reduces the panel output efficiency by less than 45%. Other dust particles (charcoal dust and ash dust) also affect the efficiency of the panel, reducing it by more than 50%. All the dust particles affected the panel's fill factor. The reduction in the fill factor is an indication that the accumulated dust particle on the panel surface increases its operating temperature, thereby affecting the output efficiency of the panel. More reduction in the fill factor, which was observed with the use of environmental and charcoal dust particles, indicated that both environmental and charcoal dust particles increase the panel temperature more than ash and chalk dust particles, which was the reason for the greater efficiency loss with the use of these dust particles. The fill factor of the PV panel was affected less by the chalk dust particles, suggesting a smaller increase in the operating temperature of the panel when compared with other dust particles. The great decrease in the fill factor of environmental dust, and most especially the charcoal dust, is understandable, considering the black color of these dust particles.

The black nature of the dust particles makes it absorb nearly all the wavelengths of light energy from the sun and convert it to heat energy, which ends up heating the panel. The lighter color on the other hand, reflected most of this radiation, preventing it from getting to the panel surface.

The accumulated dust particles on the surface of the panel scattered the direct radiation from the sun, preventing most of the radiation from reaching the surface. The reduction of this solar radiation that gets to the panel surface is the reason for the reduced output power of the panel. Our research outcome suggested that all the dust particles scattered this radiation and prevented more of this radiation from getting to the panel surface. One major reason for the reduction in the efficiency of the panel.

Recommendation

We recommend further research with an infrared (IR) thermometer or a thermal imager/camera to measure the operating temperature of the panel with all the dust samples (environmental, charcoal, ash and chalk dust particles).

Data Availability

Data will be available on request.

Conflict of Interest

There is no conflict of interest.

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