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Optimizing PV Module Efficiency: Investigating the impact of Dry and Wet Dust on Solar Panel Output Power

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Abstract

Solar photovoltaic modules convert sunlight into electricity through the photoelectric effect. Dust accumulation on PV modules can significantly reduce their output electrical characteristics such as voltage, current, and power. The power reduction is attributed to the decrease in the amount of light reaching the solar cells due to the absorption and scattering of light by the dust layer. The magnitude of the power reduction depends on the amount and type of dust component of the solar panel. In this work, four dust components such as red soil, sand, wood power, and bird drooping are considered to test the PV performance. An indoor experimental setup is developed to test the dust impact on the PV modules using an artificial sun simulator. Experimental shows that the effect of dust accumulation on the voltage and current characteristics of solar panels is complex and depends on various factors. The percentage of degradation of output power is measured using dust under dry and wet conditions. Moreover, different amounts of dust such as 1gm, 3gm, 5gm, 7gm, and 9gm are considered for dry conditions, and 3gm and 5gm are considered for wet conditions. Bird drop causes a maximum degradation of 24.5% in dry conditions and it reduces by 17.2% in wet conditions.

Keywords: PV Degradation, wet and dry dust, photovoltaic output power degradation, photovoltaic array.

Highlights

- Investigating the impact of dry and wet dust on solar panel output power.
- Experimental results show varying effects of different types of dust on PV module efficiency.
- Novel strategies proposed to mitigate the impact of dust accumulation on PV panels for enhanced performance.

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1 Introduction

Solar cells are the most practical choice for producing energy in the age of global warming. Yet, a few factors can affect how effectively solar panels work. Dust is one of the main factors causing the rapid rate of deterioration. Due to the huge expansion of the PV panel market brought on by the growing installation of PV systems globally, researchers are extremely concerned about the problem [1]. The rate of output power degradation of PV modules is accelerated by many environmental factors, such as dust, humidity, temperature, solar radiation, moisture, tilt angle, and others [2]. These elements contribute to various issues indirectly linked to the decline in solar panel efficiency. Dust, an environmental factor, accelerates the deterioration of solar panels and contributes to the aging of solar photovoltaic systems, ultimately reducing the lifespan of the panels. Despite Bangladesh exploring solar energy as an alternative source, it seems improbable due to their specific environmental conditions.[3], [4]. Bangladesh is comparable to other countries in South Asia such as India, Pakistan, Sri Lanka, Nepal, Bhutan, and many more. Their climate and meteorological characteristics are essentially the same. In these countries, dust is the main challenge to the use of solar panels to generate power [5]. The features and the component of the duty may differ from one country or region to another, depending on factors like the presence of industrial dust in certain areas or agricultural dust in others owing to the use of rice husk or ash in specific agricultural fields[6]. Notwithstanding these things, the most concerning issue, according to scientists and professionals from all around the world, is the dust effect.

The root of this significant issue has been the focus of the continuing investigation by scientists and researchers all around the world. An experimental investigation has been performed by Yusuf N. Chanchangi et al. [7]on the effect of soiling and dust properties on PV output degradation and the study has found that charcoal appears to have the worst degradation effect on PV performance with about 98% reduction in short circuit current while salt seems to have the least impact with about 7%. The influence of 2 PV surface materials on dust accumulation was examined, and results show that acrylic plastic accumulates more dust when compared to low iron glass. However, the impact of dust varies from region to region because of different weather conditions. Although a wide view of the impact of dust on PV modules in dry conditions has been presented, the impact of the same dust in wet conditions has not been investigated. Another study performed by Ahmed Amine Hachicha et al.[8] about the impact of dust particles on solar PV in UAE climatic conditions and the result illustrates a linear relationship between the dust density and the normalized PV power with a drop of 1.7% per g/m2. Dust accumulation is a function of the tilt angle, and it increases by 37.63%, 14.11%, and 10.95% concerning the clean module for the 0°, 25°, and 45°tilted modules, respectively.

The research exclusively examined the influence of dust in desert environments on the specified tilt angles, neglecting an investigation into the effects of dust in wet conditions for the same tilt angles. This aspect was not explored by Amirhossein Zabihi Sheshpoli et al. [9] focused on the impact of agricultural dust on the efficiency of the PV panel in an experimental study and the result shows a clear difference in the efficiency of a clean and dusty panel. y. The highest efficiency gained for a clean, dusty panel was 15.69%, and 10.29% respectively. A clear drop in PV efficiency due to agricultural dust has been shown but what will be the scenarios in monsoon when the dust will be wet is not mentioned. Anil Kumar Sisodia and Ram Kumar Mathur [10] presented the impact of bird droppings on the performance of the PV panel and the result shows that it could reduce the output power by a maximum of up to $\approx$ 23.8%. notably, the experiment has performed from October to March and the bird droppings are initially in form of liquid and throughout the whole experimental period, they become dry. The impact in initial liquid or wet conditions has not been investigated.

Previous research has revealed the complexity of the impact of dust on the voltage and current characteristics of solar panels [11]. The relationship between dust accumulation and these electrical parameters depends on several factors, making it crucial to consider various conditions and dust components in experimental investigations [12]. While many studies have focused solely on dry dust conditions, this research extends the investigation to include wet conditions. The difference in the effects of dust accumulation under wet conditions compared to dry conditions is a significant aspect explored in this study [13]. Different amounts of dust are considered for both conditions, providing a comprehensive understanding of the impact of dust on PV module efficiency [14].

To bridge all the gaps in current investigations of dust impact on the performance of PV modules, a comparative study of PV dust in both dry and wet conditions needs to perform. In this paper, different amounts of PV dust were investigated in both wet and dry conditions and the impact of the dust on the efficiency and the output power has been presented. A comparative analysis of the degradation rate between wet and dry dust conditions also took place [15].

2 Methodology

This experiment was conducted at the Green University of Bangladesh at a lab located in the faculty of science and engineering building. Fig. 2 depicts the procedure for testing a PV module. To verify the solar panel's specifications inside a lab setting, an artificial sun simulator was employed to produce artificial sunshine that is almost identical to natural sunlight. A 60W solar panel that has been in service for a while was employed in this experiment. A procedure of the experimental methodology has been shown in Fig.1.

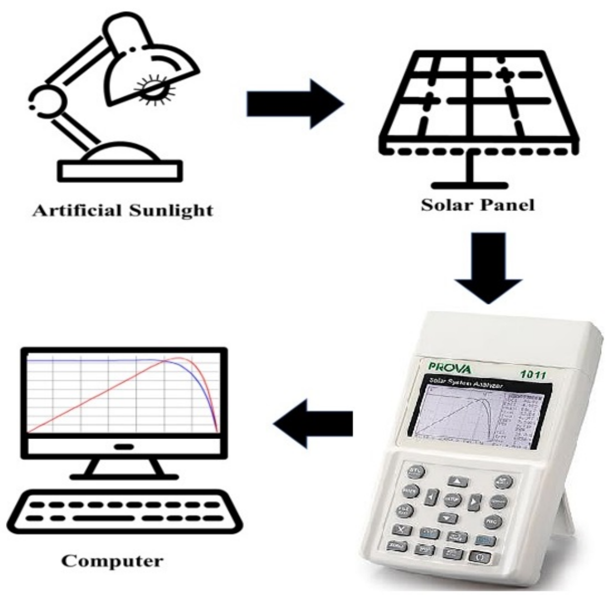

Fig 1. Experimental procedure of investigating PV degradation.

2.1 PV Dust

PV dust refers to the accumulation of dust and other particulate matter on the surface of photovoltaic (PV) panels. Over time, dust can accumulate on the surface of the panels and reduce their efficiency by blocking sunlight and reducing the amount of electricity that can be generated. This is a common problem in dry and dusty environments, and it can have a significant impact on the performance of PV systems if not managed effectively. Cleaning the panels regularly and using anti-soiling coatings are common strategies used to reduce the impact of dust accumulation on PV panels.

2.2 Accumulation of Dust on PV Panel

Dust can accumulate on the surface of photovoltaic (PV) panels through a variety of mechanisms. The most common mechanism is through airborne particles settling on the panel's surface. These particles can come from a variety of sources, including soil, pollen, and industrial pollution. Wind can also carry dust particles from nearby sources and deposit them on the panel's surface. Another mechanism of dust accumulation on PV panels is through splashes from rain and water. When raindrops or water droplets hit a dusty surface, they can cause the dust to splash onto nearby surfaces, including PV panels. This can result in the accumulation of dust and other particulate matter on the surface of the panel. Dust accumulation can also occur due to human activity, such as construction or agricultural work, which can create dust and debris that settles on the surface of PV panels. Overall, the accumulation of dust on the surface of PV panels is a common problem that can reduce the performance of the panels. Regular cleaning and maintenance of the panels are necessary to prevent dust accumulation and ensure optimal performance.

2.3 Experimental Procedure

To create artificial sunshine using a sun simulator, halogen lamps were employed as the source of light. This is where the experimental cycle begins. The photonic energy produced by this artificial light can be compared to that of sunlight. PV modules typically capture photonic energy and convert it to electricity.
Figure 4 depicts the experimental configuration. Here, a PV system analyzer (PVSA) with the model number PROVA-1011 is used to extract the output characteristics (I-V and P-V curves) of the PV array. To complete the measurement, an irradiance sensor, and temperature sensors are incorporated with the measuring apparatus, PROVA-1011. In the middle of a sunny day with a clear sky, PROVA-1011 can measure and save the output characteristics of the PV array in actual meteorological circumstances. When maintaining normal test conditions outside, the module rearrangement procedure takes ten minutes and a single PROVA-1011 test takes around one minute. The irradiance should be at least 800 W/m2 when measuring the I-V curve outdoors by IEC 60904-1 regulations. As a result, the experimental results are captured within the (800 to 950) W/m2 range of irradiance. In the first cycle of the experiment, the dust is investigated in dry conditions and the data was extracted by the PV analyzer and stored in a computer. To create moisture in the dust a water spray gun is used where 2.68 ml water is taken to moisturize the dust which was equal for each dust sample.

Fig 2. Experimental setup of a 4×4 PV array for testing different interconnection topologies at the non-uniform aging condition.

The temperature of the laboratory was 23°C. The panel was cleaned properly before applying new dust to record data.

3 Results and Discussion

This section investigates the experimental findings. The results of the experiment have demonstrated that depending on the dust's wetness, different types of dust have varied effects. The four types of dust that are most frequently encountered in the environment are explored in this experiment: red soil, sand, wood powder, and bird droppings. Starting with an experiment using red dirt in a dry environment, the open circuit voltage (Voc) for the accumulation of 3g dust is 22.86 volts, the short circuit current (Ish) is 3.08 amps, the maximum output power (Pmax) is 55.1 W, and the efficiency is 2.988%. Although sand has had a different outcome under the same circumstances. The maximum output power for 3g of dust in a dry environment is 53.62 W, and the efficiency is 2.891%. With the same amount of dust deposition, the highest output power for wood powder and bird droppings is 46.8 W and 45.25 W, respectively. The wood powder and bird dropping exhibit efficiency of 2.407% and 2.327%, respectively, under the same testing conditions. The various performance parameters of the PV surface when 3g dust accumulated were reported in Table 1.

The four types of dust performance characteristics under wet conditions are shown in Table 2. The output power of the PV increased by 57.8 w when 3g of red soil dust accumulated on it while it was wet. Pmax is 53.62 w for the same amount of wet sand, which is less than red soil. The maximum output power for bird droppings and wood powder in wet conditions is 46.8 w and 45.25 w, respectively. Equation 1 is used to calculate the percentage of degradation for each dust constituent.

$$\%Degradation = P_{maxrated} \times P_{maxexp} \times 100 \quad (1)$$

In dry circumstances, Fig. 3 compares 1g, 3g, 5g, 7g, and 9g of various types of dust, including red soil, sand, wood powder, and bird droppings. It is evident that as the amount of dust deposition increases, output power degradation also increases. When 1gm of dust is placed on the surface of the PV, the maximum output power for each dust component is discovered. The output power rapidly decreases in each dust particle as the amount of dust increases. Sand has the highest output power of the four dust samples that were examined, while bird droppings have the lowest.

Figure 4 on the other hand shows the impact of the same dust on a wet PV surface. Unexpectedly, several variances have been observed for this reason. Red soil has the highest output power (57.4 w) for 3gm of wet dust, while wood dust has the lowest output power (48.97). Sand and bird droppings both had Pmax values of 54.25 and 49.66 w under identical circumstances. Sand, wood power, bird droppings, and 3gm of wet red soil all have bigger output powers than 3gm of dry dust, 0.63 w, 2.17 w, and 4.41 w, respectively.

The degradation rate for 3gm of dust deposition in several types of dust, including red soil, sand, wood powder, and bird droppings, is shown in Fig. 5. Table 3 shows the particular pace at which each dust degrades. The graph above demonstrates that dry dust degrades more quickly than moist dust. Red soil degrades at an 8.1% pace in dry conditions while degrading at a 3.6% rate in wet conditions. Sand and wood powder followed red soil in terms of rate of degradation, with dry dust showing a rate of degradation of 10.3% and 22%, respectively, while wet conditions showed a rate of degradation of 9.5% and 18.3%, respectively When dry dust is accumulated, the degradation rate of bird droppings is 24.5%, whereas under wet conditions it is 17.2%. Red dirt degrades the least quickly among the four examined dust, whereas bird droppings degrade the most quickly in both wet and dry situations.

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Table 1. Output power obtained in various amounts of Dry Dust deposition

Dust Name	1g	3g	5g	7g	9g
Red Soil	55.55	55.51	48.62	49.7	47.12
Sand	57.63	53.62	53.96	52.54	52.9
Wood Powder	51.87	46.8	40.2	38	34.96
Bird Dropping	50.78	45.25	42.78	40.45	39.03

Table 2. Output power obtained in various amounts of Wet Dust deposition

Dust Name	3g	5g
Red Soil	51.8	50.33
Sand	54.01	52.01
Wood Powder	48.97	47.97
Bird Dropping	49.66	44.89

Table 3. Degradation rate() of 3gm Dry and Wet conditions

Dust Name	Wet	Dry
Red Soil	3.67	8.31
Sand	9.58	10.63
Wood Powder	18.33	22
Bird Dropping	17.23	24.58

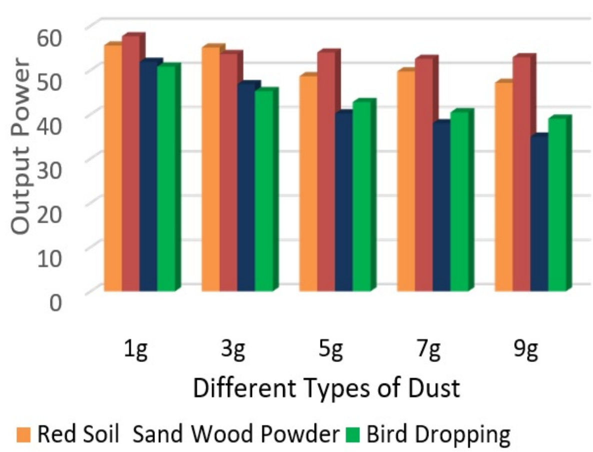

Fig 3. Output power obtained by four different types of dusts in various amount of dust deposition at dry condition.

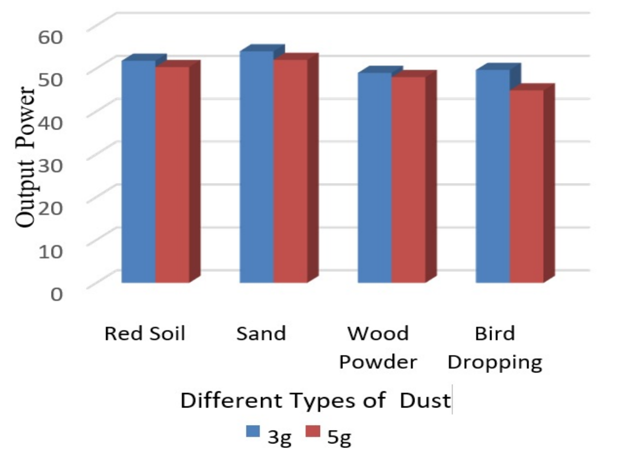

Fig 4. Output power obtained by four different types of dust in various amounts of dust deposition at wet conditions.

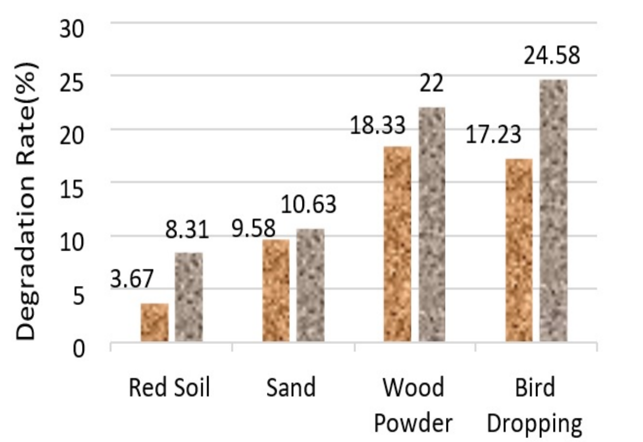

Fig 5. Degradation rate of the four investigated dust elements.

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4 Conclusion

The four types of PV dust that are most often discovered—red soil, sand, wood powder, and bird droppings—are examined in this article. According to this study, the dust condition and density have an impact on how well PV output performs. In other words, the output power of a PV system changes depending on whether the dust is moist or dry, and the rate of output deterioration increases as dust accumulation rates increase. It is interesting to state that the PV module has a smaller deterioration rate in a wet situation than in a dry one. Red soil, sand, wood powder, and bird droppings degrade at rates of 8.1%, 10.3%, 22%, and 24.5%, respectively, whereas dust degrades at rates of 3.6%, 9.5%, 18.3%, and 17.2% when exposed to moisture. In conclusion, while there are differences between the effects of dry and wet dust conditions on PV panels, bird droppings, and red soil have the highest and lowest rates of deterioration, respectively. To summarize, the study highlights the significant influence of dust buildup on the effectiveness of photovoltaic (PV) systems. The findings underscore the importance of effectively managing dust buildup by addressing the distinct forms of dust and their respective states (dry or wet) to uphold the peak performance of PV modules. The knowledge acquired from this research can guide future maintenance methods and technical advancements aimed at reducing the negative impact of dust on solar energy systems. By comprehending and tackling these problems, it is feasible to improve the durability and effectiveness of PV installations, thereby aiding in creating more dependable and environmentally friendly solar energy.

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