# DUST ACCUMULATION ON SOLAR PHOTOVOLTAIC PANELS
## An Investigation Study on Power Loss and Efficiency Reduction

by

***Gowtham VEDULLA and Anbazhagan GEETHA**** 

Department of Electrical and Electronics Engineering, Faculty of Engineering and Technology,
SRM Institute of Science and Technology, Kattankulathur, Chengalpattu, Tamil Nadu, India

Original scientific paper
https://doi.org/10.2298/TSCI221103112V

*This study mainly focuses on understanding the properties of dust particle deposition (cement, brick powder, white cement, fly ash, and coal) on a solar PV panel under dry conditions in an indoor environment to record the percentage efficiency reduction profile. For the experimental study, a solar PV panel is manually drifted at three different tilted angles (0°, 15°, and 30°) with respect to five different dust samples taken to replicate dry conditions. To maintain optimal power storage by ensuring maximum ray reflection as the angle of inclination of the solar PV panel changes. It entails long-term postoperative improvement of the solar PV module by increasing feasibility and meeting user needs. From the experiment result, it is observed that percent of power loss of each dust particle is measured accurately such as cement (0.067), brick (0.190), white cement (0.163), fly ash (0.164), and coal (0.177), consolidated for three different tilt angles. Similarly, percent of power efficiency of each dust particle is measured accurately for three different tilt angles such as cement (76.689%), brick (61.822%), white cement (52.792%), fly ash (59.859%), and coal (75.381%), respectively.*

Key words*: PV performance, dust deposition, power losses, tilt angle, solar irradiance*

## Introduction

Electricity is a very important source for industries, commercial and day-to-day life activities. There are different sources of energy, such as petrol, coal, and diesel, through which we can produce electricity. Regular conservation of energy causes a lot of pollution and resource degradation. To save our resources, there is a need to look for alternative resources such as solar, biofuel, tides, biothermal, and wind to produce electricity. These natural resources are commonly called renewable energy (RE). Globally around 16% of the electricity is consumed through these RE sources due to their eco-friendly nature, reduction in maintenance cost, easy deployment without any usage of expensive power lines, and mainly inexhaustible [1].

The PV cell converts solar light energy (photons) that falls on them into electricity. An active solar thermal system collects the solar radiations from the surrounding air and water by means of solar thermal collectors and collection tubes for commercial, industrial, and do-

*Corresponding author, e-mail: geethaa2@srmist.edu.in

mestic usage. In a solar concentration system, they use mirrors placed uniformly, forming a circular pattern to absorb the maximum amount of sunlight radiation into receiving element. The sunlight that is very concentrated heats the water or any fluid and starts transferring heat through molten salt and generates steam, which in turn rotates the turbines to produce electricity. The electricity production is very clean, reliable, and reduced dependency on the grid. The USA installed its first PV system in the year 1954, and it is still operating even today. Due to the PV cells' long lifespan, many countries have shifted to using them as the norm for powering public facilities like streetlights, traffic signals, public restrooms, condominiums, and shopping complexes [2, 3].

There are many factors that reduce the performance of PV systems, such as temperature, aging, wind, radiation, pollution, shading, and cleanliness. Changes due to variations in climatic change alter the solar radiation and ambient temperature, causing the PV output performance to vary. One of the main reasons for this variation is the deposition of dust in the PV cells. Dust is a form of minute particles that comes from the environment through industrial pollution, windstorm, and construction sites. It is either visible or invisible [4].

The performance of the PV panel is decided by the dust particle accumulation on its surface, and the density of occupancy of the dust particles determines the amount of power loss and the efficiency deterioration. As the size of the dust becomes very small, the power output deficiency increases as small particles block the radiation on the PV module. Some kinds of depositions are ash, red soil, silica, and sand. There is a decrement in energy production of up to 6.5% with outdoor panel exposure for a short period of two months without cleaning due to air pollution [5]. The dust particle accumulation on the PV cells is high in the desert area. Some analyses of the environmental effects and cleaning methods are proposed in many types of research [6]. Several experiments were performed to analyze the drop in solar irradiation due to more dust deposition [7]. The electrical performances are analyzed based on the dust deposits by means of available radiation, size, mass, and operating conditions [8]. The performance is reduced by 4.4% over the year. Over a long period without any rain, the energy loss was over more than 20%. Based on the environmental condition, the dust particles differ in physical and chemical properties. It also differs in size and mass. Temperature, humidity, and the air are also important factors, along with the wind, in defining the dust and the way it is collected in the PV cell [9]. The dust has lesser inference in determining the performance of the PV panel [10]. Research is done on the transparent cover of solar energy collectors based on dust deposition. The glass's normal transmittance reduces depending on the plate tilt angle along with the dust deposition density. When the solar cell is installed at 45° tilt angle facing south, the output power is decreased by 17.4% in a month [11]. Research on the effects of PV module glass cover is done by studying the dust fouling effects. The spectral transmittance and overall transmittance are reduced by 35% and 20% by this method. On observation, the shape of the dust particle is identified as spherical [12].

Study on the analysis of the Muti crystalline PV module performance and reduction due to occupancy of different dust compositions [13]. The thickness of the dust collected in the PV system and the efficiencies in different climatic conditions are correlated to power output performance. Nearly 10-20% of reduction in the module output when more dust accumulated. When the occupancy of the dust composition is less on the PV panel, the effects on the sunlight reflection/transmission are very low. Also, various studies were conducted on the influential parameters to determine the efficiency and performance of the PV module [14]. The external dirt accumulation also reduces the PV output performance by upto 85%. The droplets from rain will not affect the PV module performance [15]. Out of the 100% energy coming from the Sun, only 30% (approximately) will be reflected or absorbed by land masses, clouds, or oceans. There is a loss in the solar energy reflected/absorbed by the solar cell. Nearly 15-30% of energy loss happens [16]. An aluminum or steel bimetallic strips passively activate the experimental solar tracker. This method improved the efficiency by 23% when compared to fixed solar panels. This solar tracker is done with a single axis [17]. Smart track system operating at variable settings to account for various climates using light dependent resistor. Its model is experimentally analyzed to show the performance of the smart solar power track system [18]. An experimental study on polycrystalline PV and 5 W amorphous modules is performed in terms of current and voltage. This is to evaluate the electric generation and thermal energy of the PV panel [19]. The most important parameters that, includes heat loss, module temperature, fill factor, voltage, and current, are analyzed for future investigation [20]. A review of the exergy and energy of the construction of a unified PV system is performed using electrical efficiency [21]. The annual performance is done in terms of different types of power loss. Software tools like PV-GIS and PV-SYST are used to compare the obtained results of the PV module [22]. The performance is evaluated by isolating a rooftop solar PV module in a hostel building using simulation.

In this work, the construction site as a case is considered for dust particle deposition on the solar PV panel. Cement, brick powder, white cement, fly ash, and coal is all mentioned as potential constituents of the construction dust that has accumulated on solar PV panels, according to the survey. It focuses on studying and analyzing the PV characteristic of the PV panel under five different dust particles deposition on the SPC surface to observe the power loss and efficiency (%$h$) for varying irradiance (200, 400, 600, 800, and 1000 W/m$^2$), respectively. It makes the researchers understand the effect of characteristic changes of SPC with and without dust particle deposition by adjusting the tilt angle (0°, 15°, and 30°), respectively.

## Materials and methods

An experimental system for investigation of dust particles on the PV system requires:

- A PV module placed under an artificial lightening source of 16 electric lamps with each 100 W power.
- Dust free panel.
- A dust deposition panel.
- Dust samples: cement, bricks, white cement, fly ash, and coal.
- Weighing scale to calculate the number of dust samples.
- Rotatory angle meter.
- Panel temperature.
- Data logger and plotter.

### *Dust sample analysis*

Many sources are sampled for considering dust particles. These images are analyzed to get the dust particle's topography and nature. Figure 1 shows the various dust samples taken for analysis.

### *Experiment set-up*

It is a two-sided indoor solar panel system capable of investigating the PV characteristic changes of a solar PV panel by applying dust particles on either side. It uses halogen lamps to simulate the sun and illuminate PV panels and can be configured either serially or parallelly based on the user's needs. Before starting the actual experiment, some pre-set time is fixed for every measurement by changing the tilt angle. That means after the lamp radiation is turned on, there is a predetermined amount of time for the experimental set-up. The performance of solar PV panels is measured after they have been allowed to reach a constant temperature, which takes at least 15 minutes for each tilt angle.


**Figure 1. Dust samples; (a) cement, (b) bricks, (c) white cement, (d) fly ash, and (e) coal**

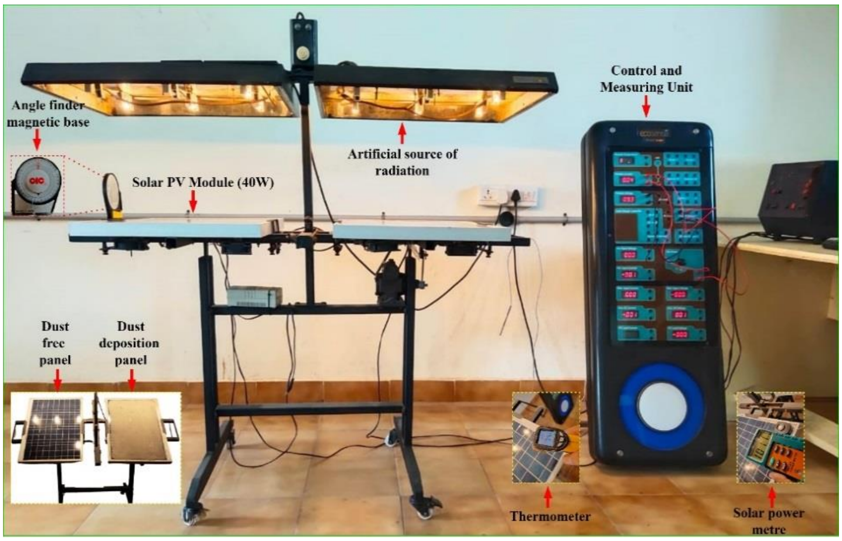


**Figure 2. Experimental set-up**

The experiment is conducted in three sections: PV characteristics in the absence of dust particles, PV characteristics in the presence of dust particles, and percentage efficiency calculation for power loss reduction. Moreover, the current hardware configuration allows for a maximum irradiance of 1000 W/m$^2$. If the irradiance is increased, more energy photos should become available, but dust particles can reduce how deeply a photo can penetrate a PV cell, reducing the cell's capacity to store and use that photo's energy. The goal of this experiment is to analyze the power loss of various dust particle mixtures deposited on the solar PV panel and investigate the percentage of reduction under three different tilt angles, respectively. The maximum power retainment of the solar PV panels is determined at the end of this experiment. The power loss of a solar PV panel is calculated using a voltage regulator, an inverter, an AC/DC load, and a battery. An experimental set-up is shown in fig. 2. Table 1 summarizes the PV panel specification and the quantity of measuring equipment that is used in this study.

**Table 1. Highlights the solar PV module specifications**

<table>
<tr><th>Components</th><th>Sub-component</th><th>Specifications</th></tr>
<tr><td rowspan="3">Power generating unit</td><td>No. of modes</td><td>2</td></tr>
<tr><td>Type of modes</td><td>Poly-crystalline</td></tr>
<tr><td>Power rate</td><td>80 Wp</td></tr>
<tr><td rowspan="3">Radioactive emitter source</td><td colspan="2">Controllable halogen lamp with dimmer</td></tr>
<tr><td>Power rate</td><td>1800 W</td></tr>
<tr><td colspan="2">DC-DC convertor- auto/manual mode</td></tr>
<tr><td rowspan="7">Power conditioning unit</td><td>Power rate</td><td>25 W</td></tr>
<tr><td>Normalized voltage</td><td>12 V</td></tr>
<tr><td>Maximum current</td><td>2 A</td></tr>
<tr><td>Type of modes</td><td>Buck converter</td></tr>
<tr><td colspan="2">Inverter- auto/manual mode</td></tr>
<tr><td>Power rate</td><td>50 W</td></tr>
<tr><td>Voltage output</td><td>Variable</td></tr>
<tr><td>Battery bank</td><td>A capacitor of each battery (2 batteries)</td><td>4.5 Ah/12V</td></tr>
<tr><td>Radiation meter</td><td>Range</td><td>0-1999/m²</td></tr>
<tr><td>Angle magnetic base</td><td>Range</td><td>4-1/8’</td></tr>
</table>

### *Performance evaluation*

- Power loss: It is a quantity of power measurement in the solar PV panel by taking the difference of power influencing with and without dust particle deposition.

Dust Degradation Factor (DDF) for power is estimated by:

$$DDF_P = 100 \times \frac{P_{pp} - P_{dp}}{P_{pp}} = 100 \times \frac{(V \times I)_{\text{pure}} - (V \times I)_{\text{dust}}}{V_{\text{pure}} \times I_{\text{pure}}} \tag{1}$$

where $P_{pp}$ is the power of the pure panel and $P_{dp}$ is the power of the dust panel.

- Calculation of efficiency: It is a ratio of power and irradiance per sq.m. That implies:

$$\text{\% of Efficiency } (\eta) = \frac{V \times I}{\text{Irradiance} \times \text{area}} \times 100 \tag{2}$$

$$(\%)_{\text{reduction}} = \frac{\eta_{\text{pure}} - \eta_{\text{dust}}}{\eta_{\text{pure}}} \times 100 \tag{3}$$

Dust particles are uniformly spread on the flour strainer whose sieve size is less than 150 micron meter. This module is placed under the artificially made lighting source. The dust particles with a constant weight of 10 g and different irradiance values of 200, 400, 600, 800, and 1000 W/m$^2$ are spread over the strainer. This experimental setup is used to calculate the power loss and efficiency for different tilt angles of 0°, 15°, and 30°, respectively. The analysis and calculation of power loss and efficiency are done without dust particles on the PV panel for efficiency comparison.

## Results and comparison

An experimental and comparative study is performed on the power loss and percent of efficiency reduction of the different dust samples on the PV panel with various tilt angles. It indicates power loss and the percentage of power loss with dust accumulation on the PV panel for the various dust particles. The weight of the dust particles is kept constant at 10 g, and average irradiance values are set to 200, 400, 600, 800, and 1000 W/m$^2$, and the average of the irradiance values are calculated for tabulation.

Therefore, the power loss is computed for five different dust samples, and the results are summarized in terms of the titling angle. Since dust is more likely to settle on a PV panel if it is horizontal, the cement industry has optimized power loss for tilt angles other than 0° to ensure that the panel receives the fewest possible irradiances. In a linear fashion, power is lost as irradiance changes between different values. Despite using the same dust samples, the PV panel displays different power loss results at 30° tilt angles naturally because dust samples retinite is minimum and, thus, irradiance incident is more, producing maximum power is retrained, and power loss is minimal.

The power loss profile was also the same for the other four dust samples (bricks, white cement, fly ash, and coal). This means that the impact of dust accumulation on the irradiance incident phenomena on the PV panel is reduced when the tilt angle is increased. The optimal tilt angle is thus determined for various types of dust. Since the power loss profile varies with dust type, this research helps determine the optimal tilt angle for a PV panel to keep producing the necessary amount of power. The data showed that only 30% of the consolidated power loss was able to be achieved in samples of cement, bricks, white cement, fly ash, and coal at 30° tilt angle, respectively.

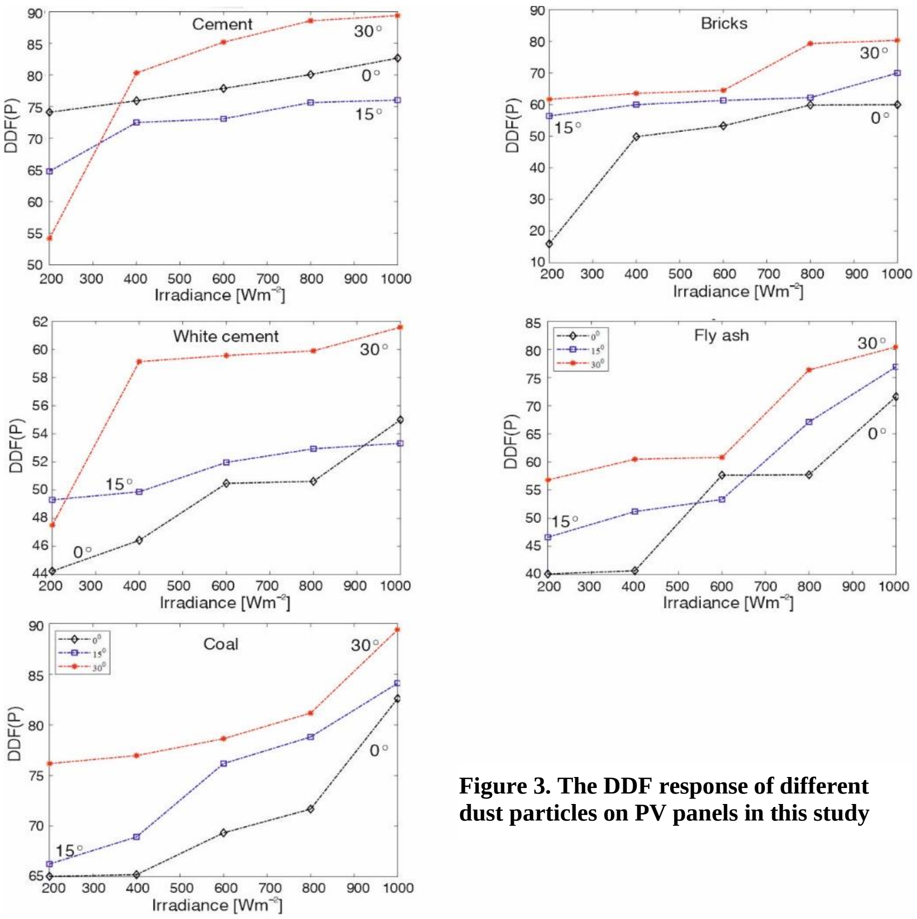


**Figure 3. The DDF response of different dust particles on PV panels in this study**

Similarly, the other two dust samples, bricks, and cement produced the same power loss profile. That means if the tilt angle is more than the accumulation of dust particles is less, but it highly affects the irradiance incident phenomena on the PV panel is minimized. Therefore, the suitable tilt angle is identified for different dust particles. Because the power loss profile is different for each dust sample, and therefore, to maintain the sufficient required energy on the PV panel, the suitable tilt angle is identified from this study. A result conveyed that the maximum power is retrained only at 30° cement, bricks, white cement, fly ash, and coal samples, respectively.

In order to determine the DDF, the irradiance levels are changed and tested on all five dust samples at tilt angles of 0°, 15°, and 30°. Almost the same power loss profile is displayed by all five dust samples, and DDF is linearly affected by changing the tilt angles. This means that the dust sample density is lowest with a wide tilt angle and that the creamy dust layer is powerless to remove the dust particle once it has settled on the PV panel. Since fig. 3 shows a linearly increasing order for the DDF over a wide range of tilt angles, this conclusion can be drawn. It is observed that maximum power is retained only at 30° tilt angle. The average efficiency reduction of all five dust samples is evaluated, which inferred that the cement sample acquired 0.68% of the average efficiency reduction in the overall efficiency chart, as seen in fig. 4. Similarly, other dust particles were acquired, such as bricks (2.34%), white cement (1.88%), fly ash (2.11%), and coal (1.20%), respectively.

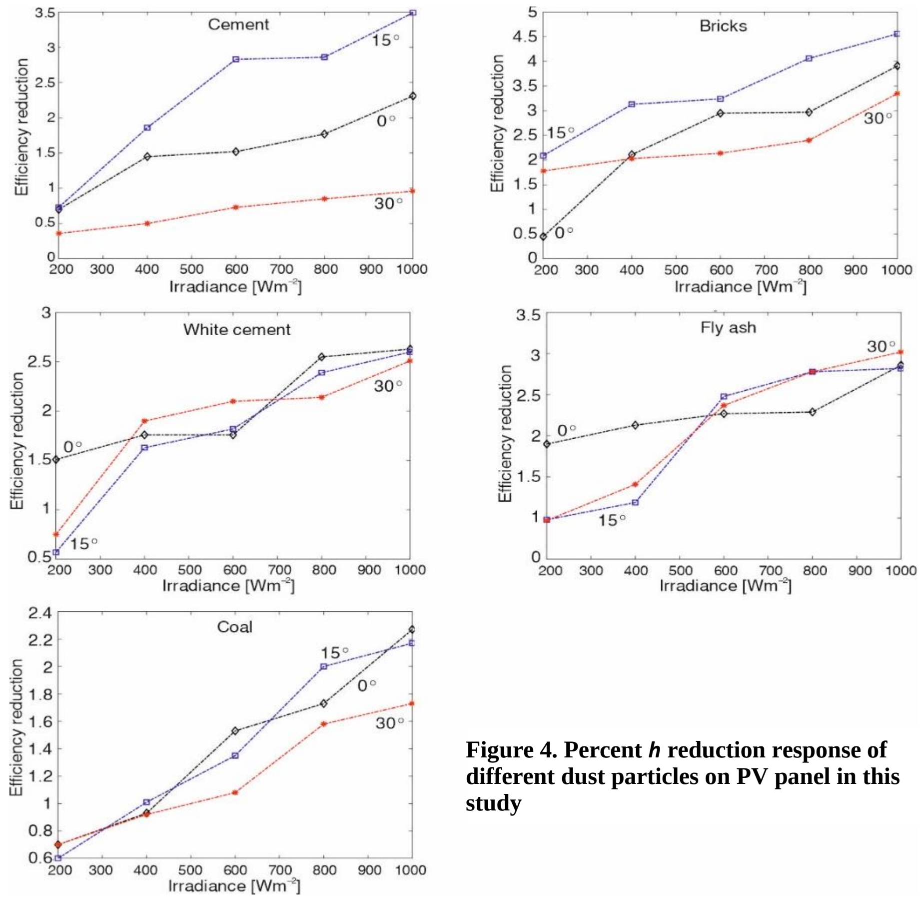


**Figure 4. Percent *h* reduction response of different dust particles on PV panel in this study**

Figure 5 summarizes the average maximum power loss and power efficiency for all five at the tilt angle of 0°, 15°, and 30°, respectively. Both the power loss and efficiency are calculated based on the difference in values obtained from dust and pure PV panel. The maximum average power loss and power efficiency of all five dust samples are summarized as:

- The cement sample's maximum average power loss is 0.072, 0.089, and 0.039, and power efficiency is calculated as 78.134%, 72.408%, and 79.525% for the tilt angle of 0°, 15°, and 30°, respectively.
- Similarly, the maximum power loss of the brick sample is measured as 0.166, 0.184, and 0.218, and the power efficiency is calculated as 56.222%, 62.001%, and 67.243% for the tilt angle of 0°, 15°, and 30°, respectively.
- Based on further analysis with the white cement sample, the power loss was calculated as 0.156, 0.200, and 0.134, and power efficiency was measured as 49.353%, 51.486%, and 57.536% for the tilt angle of 0°, 15°, and 30°.
- The average maximum power loss for the fly ash sample was 0.142, 0.154, and 0.194, and power efficiency was measured as 53.554%, 59.035%, and 66.987% for the tilt angle of 0°, 15°, and 30°.
- The data with the coal sample where the power loss is calculated as 0.158, 0.178, and 0.196 and power efficiency is measured as 70.787%, 74.872%, and 80.485% for the tilt angle of 0°, 15°, and 30°.

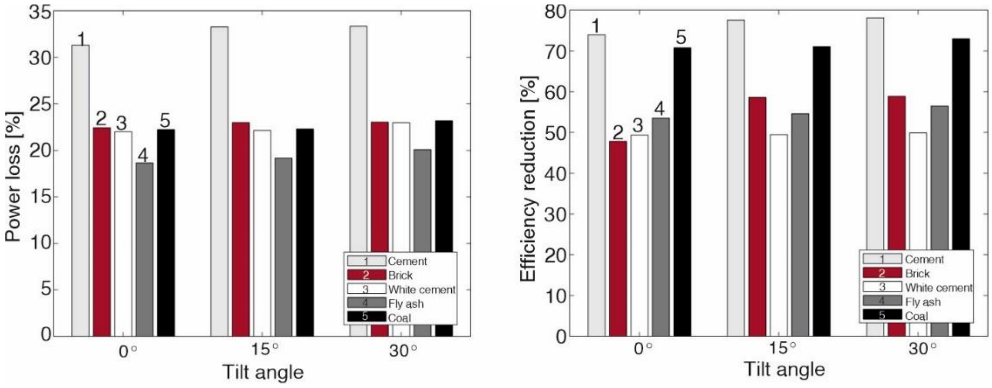


**Figure 5. Comparative analysis of the percentage of power loss and the percentage of efficiency reduction caused by various dust particles on a solar PV module**

Many other existing experimental methods investigate the percentage of power loss and the power transfer rate of a solar PV panel when exposed to various chemical composites, most of which are related to roadside dust particles. In addition, they measured the percentage of power loss and the rate of power transferred by varying the irradiance value and the weight of the dust samples to assess the efficiency of solar PV panels. The researchers did not mention the research finding for the variety of tilt angles to keep dust from building up on the solar PV panels over time, as indicated in tab. 2.

## Conclusion

A detailed and comparative study of five different dust samples on the solar PV panel is carried out with average irradiance values set to 200, 400, 600, 800, and 1000 W/m$^2$, and the sample weight is kept constant at 10 g. These dust particles reduce the output power based

**Table 2. Comparison of power retainment and accurate measurement of power reduction profile**

| Ref. | Percent of power retainment | | | | | Percent of accurate measurement | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cement | Bricks | White cement | Fly ash | Coal | Cement | Bricks | White cement | Fly ash | Coal |
| This study | 89.38 | 80.33 | 61.58 | 80.46 | 89.42 | 0.36 | 0.78 | 0.58 | 0.56 | 0.81 |
| [9] | 88.57 | 79.31 | 59.9 | 76.36 | 81.18 | 0.5 | 0.83 | 0.63 | 0.7 | 0.86 |
| [10] | 85.19 | 64.51 | 59.57 | 60.82 | 78.65 | 0.73 | 0.85 | 0.65 | 0.81 | 0.88 |
| [13] | 80.33 | 63.55 | 59.14 | 60.49 | 76.98 | 0.85 | 0.92 | 0.72 | 0.89 | 0.94 |
| [20] | 54.17 | 61.7 | 47.5 | 56.8 | 76.19 | 0.96 | 0.95 | 0.75 | 0.93 | 0.96 |

on size. When the size of the dust particles is less, the power loss is more as it blocks the solar panel. The power loss and efficiency are calculated for all the dust samples, and it is observed that with the deposition of the fly ash samples on the solar PV module, the power loss is low and the reduction in power efficiency is also very less compared to other dust samples. This is due to the intensity of the chemical composition $Al_2O_3$ in the fly ash. As the future scope of this work, the PV panel performance must be analyzed outdoors with varying climatic conditions for the dust particle occupancy and the dust particle chemical composition.

## References

[1] Ali, H. M., *et al*., Effect of Dust Deposition on the Performance of Photovoltaic Modules in the City of Taxila, Pakistan, *Thermal Science*, *21* (2017), 2, pp. 915-923
[2] Radonjic, I. S., *et al*., Investigation of the Impact of Atmospheric Pollutants on Solar Module Energy Efficiency, *Thermal Science*, *21* (2017), 2, pp. 2021-2030
[3] Amber, K. P., *et al*., Self-Cleaning Device for Pole-Mounted Solar Photovoltaic Installations, *Thermal Science*, *23* (2019), 2A, pp. 739-749
[4] Radivojevic, A. R., *et al*., Influence of Climate and Air Pollution on Solar Energy Development in Serbia, *Thermal Science*, *19* (2015), Suppl. 2, pp. S311-S322
[5] Tanesab, J., *et al*., The Effect of Dust with Different Morphologies on the Performance Degradation of Photovoltaic Modules, *Sustainable Energy Technologies and Assessments*, *31* (2019), Feb., pp. 347-354
[6] Sisodia, A. K., *et al*., Impact of Bird Dropping Deposition on Solar Photovoltaic Module Performance: a Systematic Study in Western Rajasthan, *Environmental Science and Pollution Research*, *26* (2019), 30, pp. 31119-31132
[7] Hachicha, A. A., *et al*., Impact of Dust on the Performance of Solar Photovoltaic (PV) Systems under United Arab Emirates Weather Conditions, *Renewable Energy*, *141* (2019), Oct., pp. 287-297
[8] Olivares, D., *et al*., Determination of the Soiling Impact on Photovoltaic Modules at the Coastal Area of the Atacama Desert. *Energies*, *13* (2020), 3819
[9] Wang, H., *et al*., Effect of Air Quality and Dust Deposition on Power Generation Performance of Photovoltaic Module on Building Roof, *Building Services Engineering Research and Technology*, *41* (2019), 1
[10] Isaifan, R. J., *et al*., Evaluation of the Adhesion Forces Between Dust Particles and Photovoltaic Module Surfaces, *Solar Energy Materials and Solar Cells*, *191* (2019), Mar., pp. 413-421
[11] Ilse, K. K., *et al*., Fundamentals of Soiling Processes on Photovoltaic Modules, *Renewable and Sustainable Energy Reviews*, *98* (2018), Dec., pp. 239-254
[12] Picotti, G., *et al*., Soiling of Solar Collectors – Modelling Approaches for Airborne Dust and Its Interactions with Surfaces, *Renewable and Sustainable Energy Reviews*, *81* (2018), Jan., pp. 2343-2357
[13] Chanchangi, Y. N., *et al*., An analytical indoor experimental study on the effect of soiling on PV, focusing on dust properties and PV surface material. *Solar Energy*, 203 (2020), Jan., pp. 46-68
[14] Kazem, H. A., *et al*., The Impact of Dust's Physical Properties on Photovoltaic Modules Outcomes. *Innovative Renewable Energy*, On-line first, https://doi.org/10.1007/978-3-030-18488-9_39, 2019, pp. 495-506

[15] Alnaser, N. W., *et al*., Comparison Between Performance of Man-Made and Naturally Cleaned PV Panels in a Middle of a Desert, *Renewable and Sustainable Energy Reviews*, *82* (2018), Feb., pp. 1048-1055
[16] Deb, D., Brahmbhatt, N. L., Review of Yield Increase of Solar Panels Through Soiling Prevention, and a Proposed Water-Free Automated Cleaning Solution, *Renewable and Sustainable Energy Reviews*, *82* (2018), Feb., pp. 3306-3313
[17] Said, S. A. M., *et al*., The Effect of Environmental Factors and Dust Accumulation on Photovoltaic Modules and Dust-Accumulation Mitigation Strategies, *Renewable and Sustainable Energy Reviews*, *82* (2018), Feb., pp. 743-760
[18] Alami Merrouni, A., *et al*., Large scale PV Sites Selection by Combining GIS and Analytical Hierarchy Process. Case Study: Eastern Morocco, *Renewable Energy*, *119* (2018), Apr., pp. 863-873
[19] Javed, W., *et al*., Modeling of Photovoltaic Soiling Loss as a Function of Environmental Variables, *Solar Energy*, *157* (2017), Nov., pp. 397-407
[20] Touati, F., *et al*., Long-Term Performance Analysis and Power Prediction of PV Technology in the State of Qatar, *Renewable Energy*, *113* (2017), Dec., pp. 952-965
[21] Abderrezek, M., Fathi, M., Experimental Study Of The Dust Effect On Photovoltaic panels' energy yield, *Solar Energy*, *142* (2017), Jan., pp. 308-320
[22] Mehmood, U., *et al*., Characterization of Dust Collected from PV Modules in the area of Dhahran, Kingdom of Saudi Arabia, and Its Impact on Protective Transparent Covers for Photovoltaic Applications, *Solar Energy*, *141* (2017), Jan., pp. 203-209

Paper submitted: November 11, 2022
Paper revised: January 20, 2023
Paper accepted: February 3, 2023