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An experimental investigation of Dust-Driven performance loss in solar photovoltaic systems in tropical regions of India

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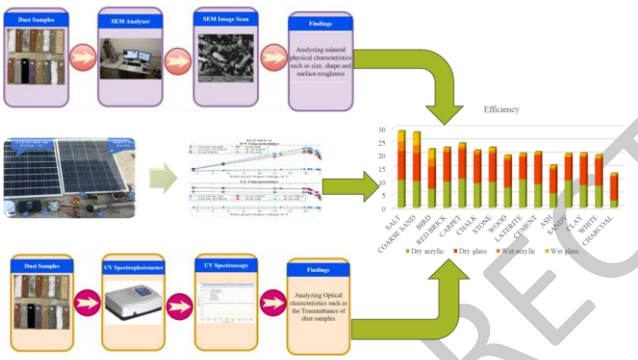
Graphical abstract



Abstract

Solar panel efficiency is significantly impacted by dust deposition. Due to exposure to the environment, the solar array becomes dust on its exterior surface, which diminishes the amount of sunlight that reaches the solar cell's surface and consequently reduces its output. The impact of 16 distinct dust samples collected from various sources is examined in the present investigation. Construction site dusts (laterite, sand, cement, white cement, red brick dust, clay soil, coarse sand, wood dust, stone dust, sandy soil, and loam sand), thermal power plants, the steel business, and the salt industry (ash, charcoal, and salt) are some of these sources. Natural sources, including bird droppings, are also considered. The significance of these dust samples on solar PV panel efficiency is the primary emphasis. The transmission of sunlight into the solar panel varies depending on the dust samples' morphological, optical, and dust density characteristics. This variation influences the solar photovoltaic power generation system's efficiency. Charcoal dust significantly disturbs the efficiency of solar PV systems more than any other sort of dust. The findings indicate that an effort were made to increase the solar panel's efficiency and that the regularity of the dust cleaning procedure is dependent on the deposition of dust samples. A wet wiper system enhances the efficacy of solar photovoltaic panels by mitigating the effects of dust accumulation and temperature fluctuations.

Keywords: Dust deposition, 16 different dust samples, SEM, morphological, optical properties, electrical energy, Solar panel

1. Introduction

Solar PV power generation is a significant renewable energy source. Solar Photovoltaics systems are economically efficient, ecologically sustainable, and hygienic. Solar panels produce electrical energy by using sun irradiation. Dust buildup on the solar panel can diminishes efficiency of solar PV panels by obstructing the sun irradiance penetrating on solar panel, increasing the sunlight reflection and heat dissipation over the panel surface.

Kumar *et al.* (2023) and Abdellatif *et al.* (2023) performed pioneering work where they devised an innovative model to assess the accumulation of dust on solar PV modules. Kazem *et al.* (2022) investigated the impact of dust on the performance of a photovoltaic/thermal (PV/T) construction in challenging environmental conditions. An analysis of the data showed that the energy and thermal efficiency of the solar PV/T system are significantly impacted by dust. It also turned out that the dust buildup on the device's surface reduced its ability to generate thermal and electrical energy.

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Using an artificial neural network-driven Internet of Things methodology, Mehmood *et al.* (2023) have proposed a method for calculating the soiling ratio of solar panel power systems. Alfaris (2023) that can recognize present an intelligent system without sensors and categories small particles of dust on solar photovoltaic (PV) panels to optimize the effectiveness of cleaning process. In 2023, Craciunescu and Fara investigate the impact of partial shading on solar photovoltaic, or solar PV and suggest an optimization approach that makes use of a high-efficiency fuzzy logic controller (FLC) algorithm. Tang *et al.* (2023) introduced a robotic arm designed to eliminate dust from solar panels. Adgüzel *et al.* (2023) utilized support vector machine (SVM) analysis to examine the impact of marble dust on the efficiency of solar photovoltaic (PV) panels.

The effect of dust on solar PV performance has been studied, but most of the research is only applicable to a particular region, such as Algerian Sahara (Sahouane *et al.* 2023), Morocco (Asbayou *et al.* 2023), Cyprus (Sharma *et al.* 2023 , Lopez-Lorente *et al.* 2023), Saudi Arabia (Alaboodi, *et al.* 2024), China (Liu *et al.* 2022, Abuzaid *et al.* 2022), Iran (Amirpouya Hosseini *et al.* 2023), Tehran, the Iranian capital (Amirpouya Hosseini et al (2023) and Vedulla et al (2023)), India (Chairma Lakshmi K R and Geetha Ramdas 2022), North African (Awadh 2023), oman (Girma T *et al.* 2024), Kathmandu (Hasan *et al.* 2022), Kuwait (Almukhtar *et al.* 2023), Qatar (Fahim *et al.* 2022), California (J. Goudelis *et al.* 2022), the Atacama Desert (Fernández-Solas *et al.* 2021), and Pakistan (Mahnoor Rashid *et al.* 2023). There is a lack of sufficient statistical data regarding the impact of soil dust deposition on specific regions of India, which restricts the appropriate layout and sizing of solar PV modules. Insufficient maintenance of solar PV systems can lead to energy loss due to a lack of understanding regarding the impact of dust.

This work aims to provide a more comprehensive experimental investigation to analyze the degradation in performance of solar PV module power production caused by 16 different types of specific industrial and domestic dust deposition under real time tropical area of Chennai, Tamilnadu, India. By merging SEM morphological analysis, UV spectrophotometer optical characterization, and electrical performance testing, the study offers a wider statistical basis for considerate dust-driven degradation in coastal tropical atmospheres. This combined method offers new insights into both the relative severity of different dust types and the efficiency of wet wiper dust cleaning mechanisms, thereby extending the applicability of dust– solar PV research to real-world maintenance strategies in India's tropical environment.

2. Materials and Methodology

2.1. Overview of the Research Area

The research is being carried out at R.M.K. Engineering College in Chennai, Tamilnadu, India. Chennai, located on the Coromandel Coast of the Bay of Bengal (longitude 80.270186°E, latitude 13.0836939°N), is a coastal metropolis in southeast India. Daytime highs in the city range from 30°C to 40°C (86°F to 104°F), and the summers are hot and muggy. India receives between 1,600 and 2,200 kWh/m^2 of solar radiation every year. Chennai has between 300 and 330 clear, sunny days annually.

Figure 1 Experimental Setup.

2.2. Description of Experimental Setup

A research setup comprising the following equipment is established to examine the impact of dust gathering on the efficiency of solar photovoltaic panels. The following are the major components for the experimental setup 1) Two similar 100 Watt polycrystalline modules whose specifications are given in **Table 2**, 2) Multimeter (MASTECH, MAS830L), 3) MECO SMP48 DC ammeter, 4) MECO SMP96 DC Voltmeter, 5) Infrared Thermometer, 6) Digital Weighing Machine, 7) Resistive load and 8) Solar irradiation meter whose conditions are specified in **Table 1**.

Table 1. Specification of Solar PV Panel (Chairma Lakshmi K R 2022)

Thermal and Mechanical Characteristics		Electrical Characteristics	
Number of Solar PV Cells / Module / Arrangement	**36 / (9*4)**	**P_m in Watts**	**100**
α (%/ºC)	0.068	I_{sc} in Amps	6.07
γ (%/ºC)	-0.384	V_{oc}	21.97
ß (%/ºC)	-0.294	I_{mpp} in Amps	5.73
Weight (kg)	≈10.15	V_{mpp} in Volts	17.46
Length x Width x Thickness (mm)	1150 x 675 x 35	ŋ in %	12.88

Figure 1 illustrates the experimental arrangement, with A denoting a clean solar panel and B denoting a dirty conventional solar PV panel. The dust's weight was measured by the weighting machine, denoted by C.

Sunlight irradiation is measured by the solar meter, represented by the letter D. For additional voltage and current measurements, the multimeter, denoted by E, is utilized. The F and G tags designate the digital ammeter and digital voltage meter, which are used to measure the output voltage and current of the solar panel. H is a representation of the variable resistance load. The resistive load of the solar panel serves as a representation to determine its current as well as its voltage.

2.3. Uncertainty Analysis

Analysis of uncertainty attempts to assess the impact of numerous factors on the overall effectiveness and output power of solar PV panel power-generating systems. Using the equations below, we can calculate the uncertainty of each piece of component used in the experiment. The range, accuracy, and uncertainty of each instrument are shown in **Table 3**.

Table 2 Measuring Devices Specification.

Apparatuses	Rating and Range	Purpose
Rheostat load	10 Ω Pure Resistive loads	Resistive load to monitor the solar panel's voltage and current.
SM – 206: Solar power meter	Accuracy: ±5% , Resolution: 0.1 W/m^{2}·, Range: 1-3999 W/m^{2}	Sun intensity / irradiance measurement
DC ammeter (MECO SMP48)	Resolution: 1mA, Accuracy: ± 0.5% of Full Scale Deflection, DC Current: 20 A	Solar panel output current measurement
DC Voltmeter (MECO SMP96)	DC Voltage: 200 V, Resolution: 1mV, Accuracy: ±0.5% of Full Scale Deflection	Solar panel output voltage measurement
Canyearn Infrared Forehead Thermometer (C01)	Accuracy: ±0.2°C / ± 0.4 °F, Measuring distance: 3 cm-5 cm, Response Time: 10 ± 1 s, Temperature Range: 32°C - 43°C	Solar panel temperature measurement
Digital Weighing Machine (EKW-07i)	Readability: 10 mg, Repeatability: 0.01 mg, Capacity: 600 g	Dust weight measurement.

Table 3 Uncertainty of Measuring Devices

Apparatuses	Range	Accuracy	Uncertainty
Solar power meter (SM – 206)	1-3999 W/m^{2}	±5% of reading	3.7%
Canyearn (C01) Infrared Forehead Thermometer	32.0°C – 43.0°C	±0.2°C to +/- 0.4 °F	0.37%
DC Voltmeter (MECO SMP96)	200 V	± 0.5% of FSD	3.1%
DC ammeter (MECO SMP48)	20 A	± 0.5% of FSD	2.94%

2.4. Description of Dust Sample Preparation

In this study, 16 different samples of household and industrial dust are investigated. As an example, airborne particles from automotive emissions, industrial facilities, fertilizers, or plant materials in agricultural areas can be found in metropolitan areas. This research study proposed to observe the effects of 16 different dust samples from various locations, including thermal power plants, the steel and iron industries, the salt industry (Ash, Charcoal, and salt), and natural dust like bird droppings on solar PV panels (including sand, laterite, redbrick dust, cement, coarse sand, white cement, sandy soil, clay soil, stone dust, wood dust, and loam sand). Depending on the area or immediate environment, the type of deposited dust, including its morphological structure and composition, differs. The 16 dust samples utilized in this investigation are visually represented in **Figure 2a** and dust deposition process is mentioned in **Figure 2b**. The key characteristics of the dust particles analyzed in the proposed study which is shown in **Figure 3**.

1) UV Spectrophotometer used for the measurement of the optical characteristics of dust which is described in **Figure 4**
2) SEM analysis utilized for morphological and elemental properties analysis, which is described in **Figure 5**
3) The P-V and I-V characteristics of solar panels help to explain their electrical properties.

The experiment is carried out by spraying dry dust and wet dust separately for all 16-dust samples. Using an analytical scale, the weightiness of the clean glass and acrylic plate is determined. Every dust sample is blended with water and evenly sprayed onto the surface of acrylic and glass plates. It is permitted to dry for some time. With the help of a UV spectrophotometer, the light transmittance is measured at different points on the materials. If the transmittance is not uniform across the cross-section dust is again sprayed until light transmittance is uniform.

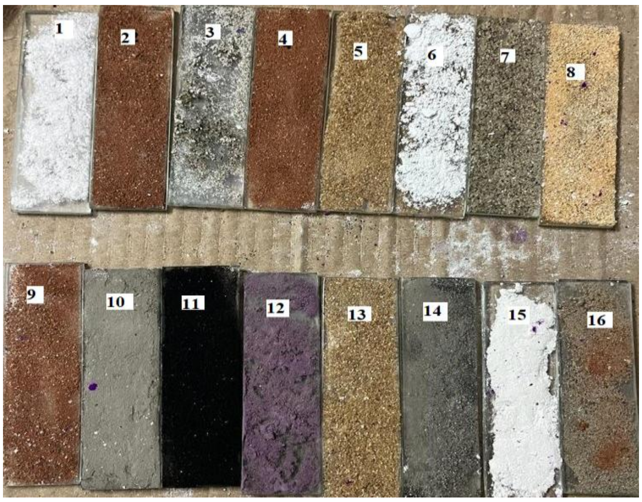

Figure 2(a) Visual Image of 16 Dust Samples

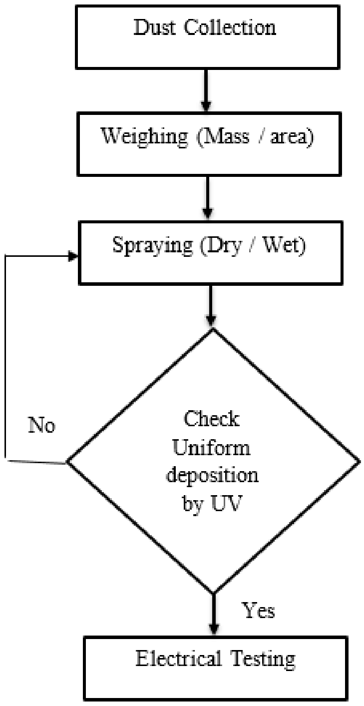

Figure 2(b). Process of Dust Deposition

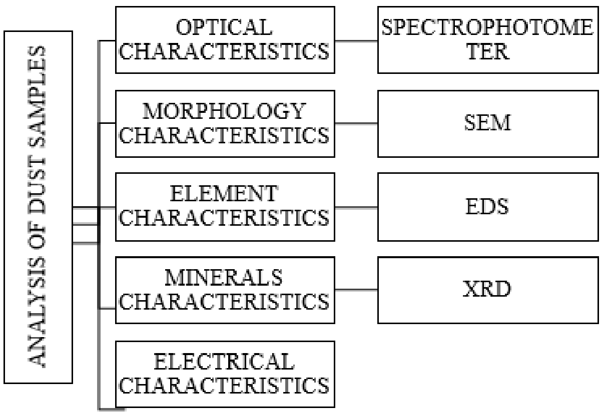

Figure 3 Characterization of Dust Samples

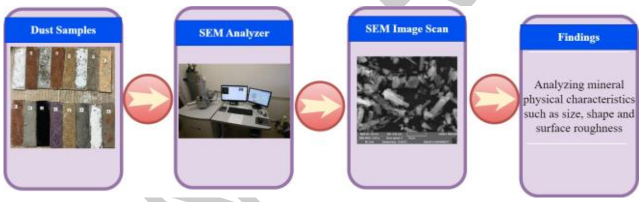

Figure 4 Image Characterisation using SEM analyses

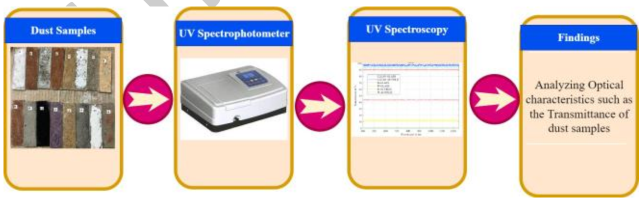

Figure 5 Optical Characterisation using UV Spectrophotometer

3. Result and Discussion

This segment presents spectrum transmission results, the electrical efficiency of solar PV panels, experimental discoveries on the effects of each dust type, and SEM images. SEM images of 16 different dust samples are shown in **Figures 6, 7, and Figure 8.** UV spectrophotometer analysis for 16 different dust samples is shown in **Figure 9 to Figure 16**.

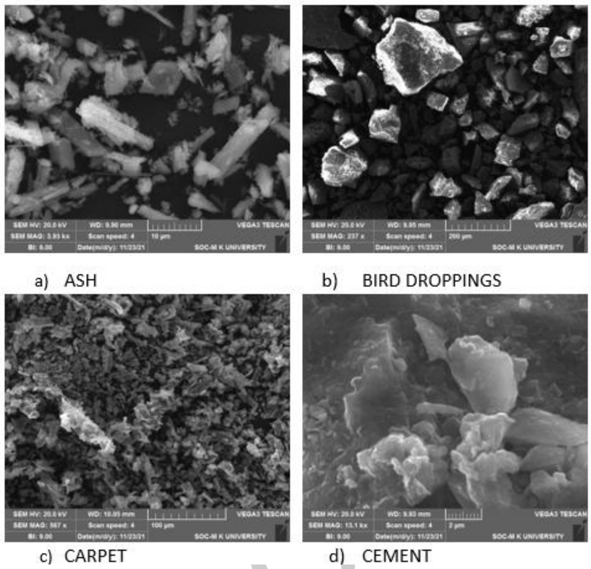

Figure 6 SEM image for dust samples a) Ash b) Bird dropping c) Carpet d) Cement

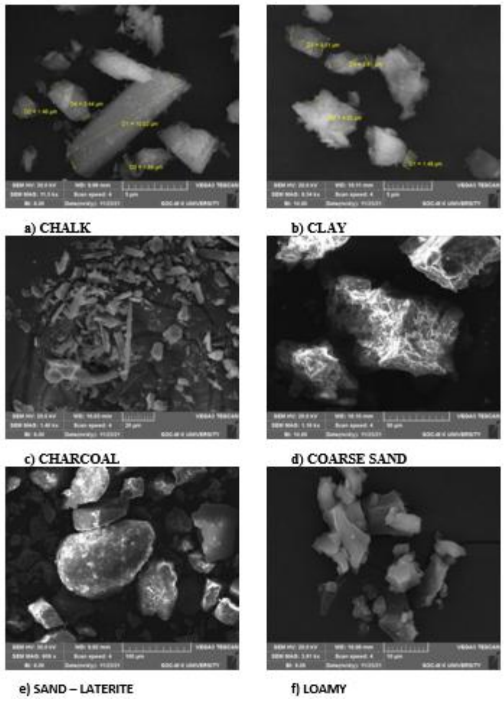

Figure 7 SEM image for dust samples a) Chalk b) Clay c) Charcoal d) Coarse sand e) Laterite f) Loamy

3.1. Findings from SEM images

Fly ash is a by-product of dry wood burning and is a common source of dust in developing nations where farm by-products are used for electricity generation. Both fly ash and bottom ash are produced when materials like wood are burned at high temperatures. Fly ash can be carried by the wind, leading to its dispersal over a wide area. Ash dust harmfully disturbs the electrical performance of solar PV modules by hindering the photovoltaic effect, which is responsible for converting sunlight into electricity. Analysis of ash dust using scanning electron microscopy (SEM) reveals that it is composed of small, opaque, dense minerals with an angular structure and a rough surface.

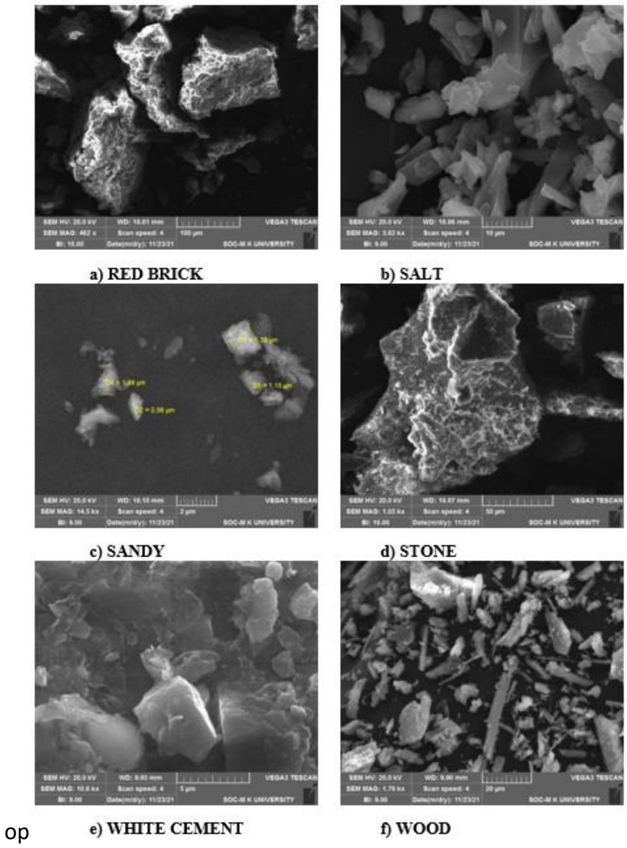

Figure 8 SEM image for dust samples a) Redbrick b) Salt c) Sandy d) Stone e) White Cement f) Wood

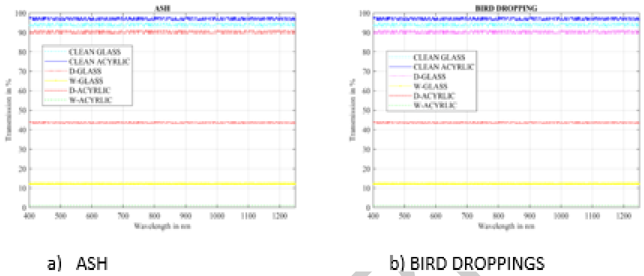

Figure 9 Spectral Transmittance Curve for dust samples a) Ash b) Bird dropping

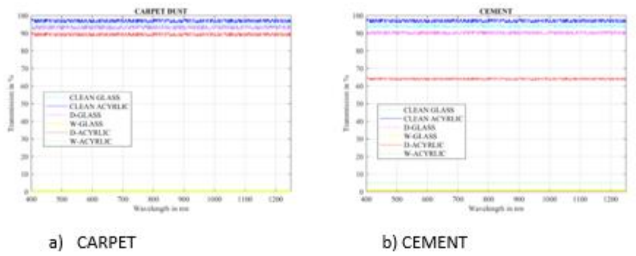

Figure 10 Spectral Transmittance Curve for dust samples a) Carpet b) Cement

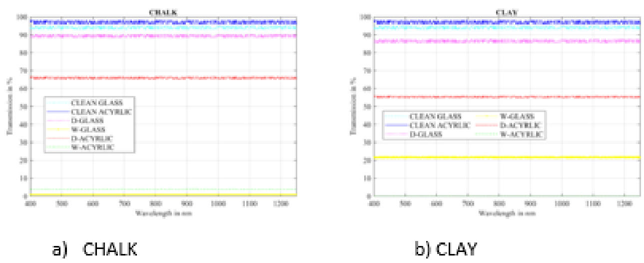

Figure 11 Spectral Transmittance Curve for dust samples a) Chalk b) Clay

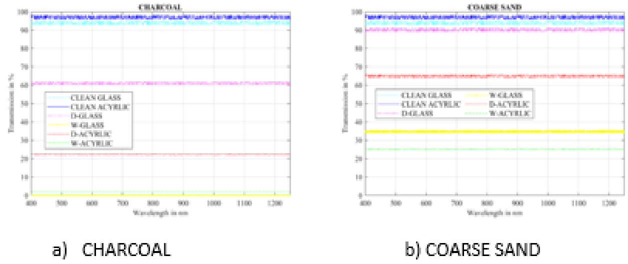

Figure 12 Spectral Transmittance Curve for dust samples a) Charcoal b) Coarse

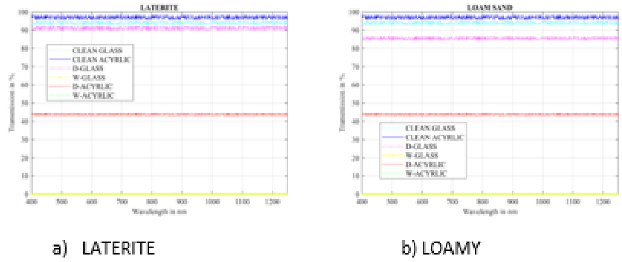

Figure 13 Spectral Transmittance Curve for dust samples a) Laterite b) Loamy

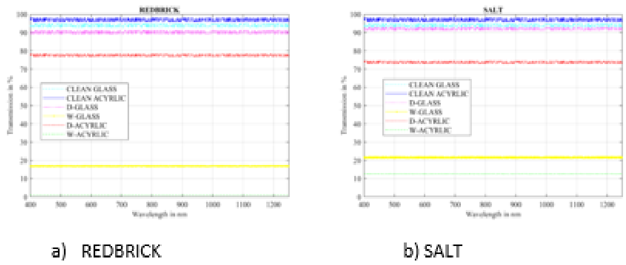

Figure 14 Spectral Transmittance Curve for dust samples a) Redbrick b) Salt

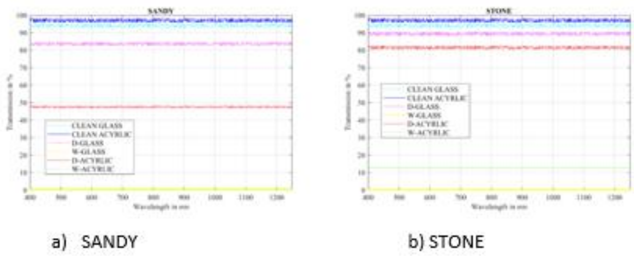

Figure 15 Spectral Transmittance Curve for dust samples a) Sandy b) Stone

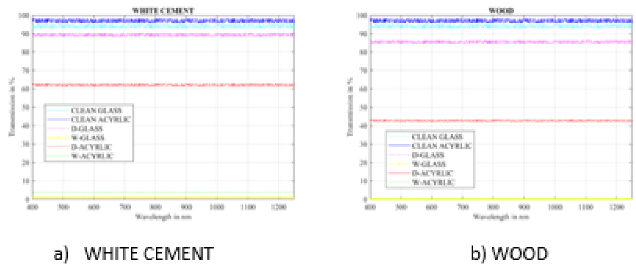

Figure 16 Spectral Transmittance Curve for dust samples a) White Cement b) Wood

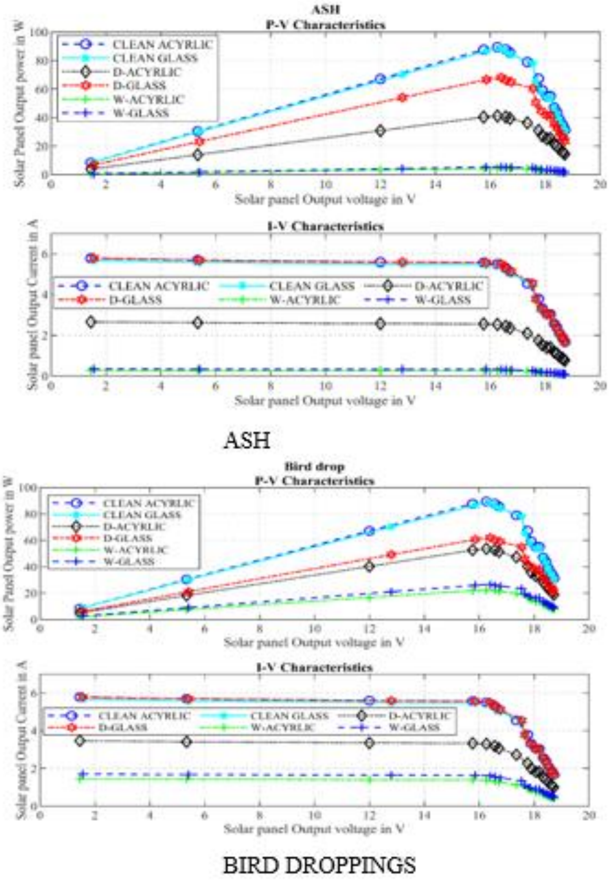

Figure 17 Electrical P-V and I-V Characteristics Curve of Solar Panel under dust samples a) Ash b) Bird dropping

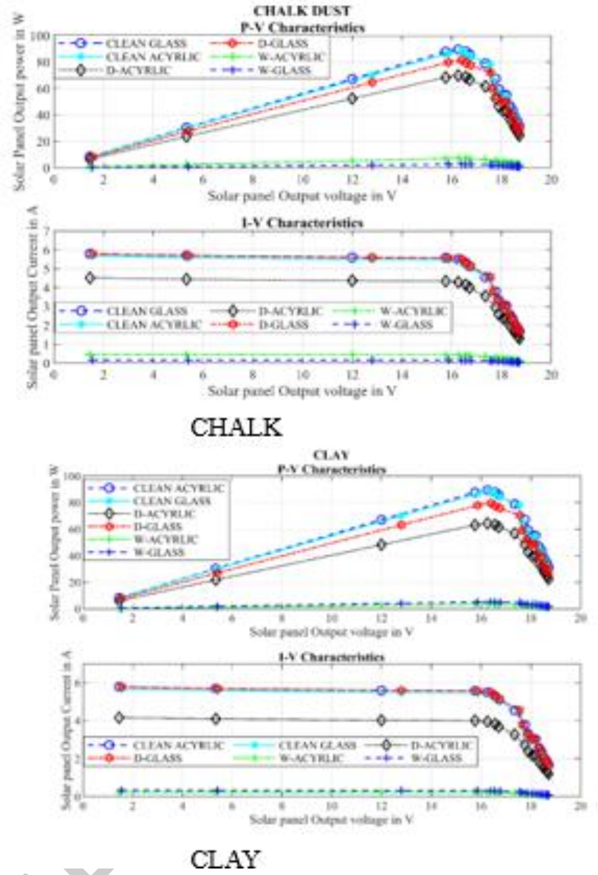

Figure 19 Electrical P-V and I-V Characteristics Curve of Solar Panel under dust samples a) Chalk b) Clay

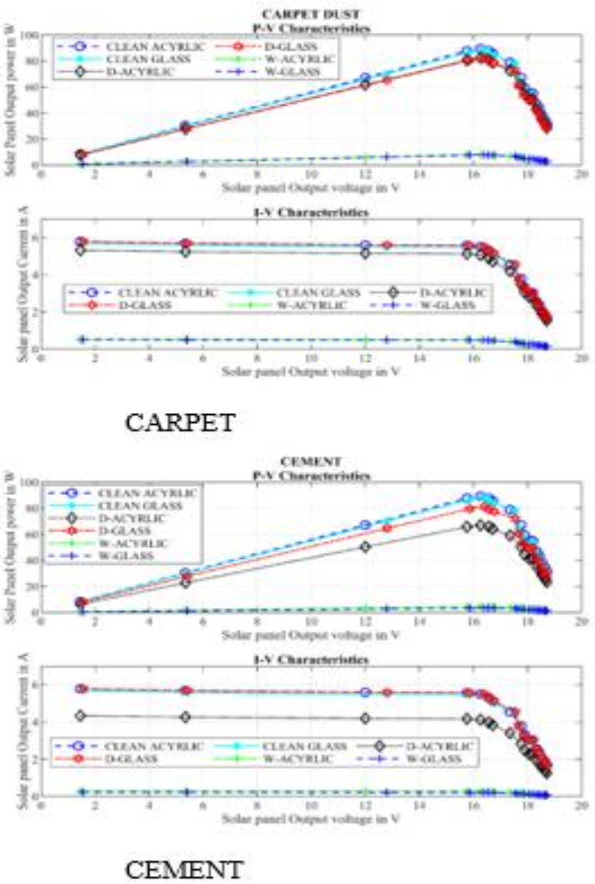

Figure 18 Electrical P-V and I-V Characteristics Curve of Solar Panel under dust samples a) Carpet b) Cement

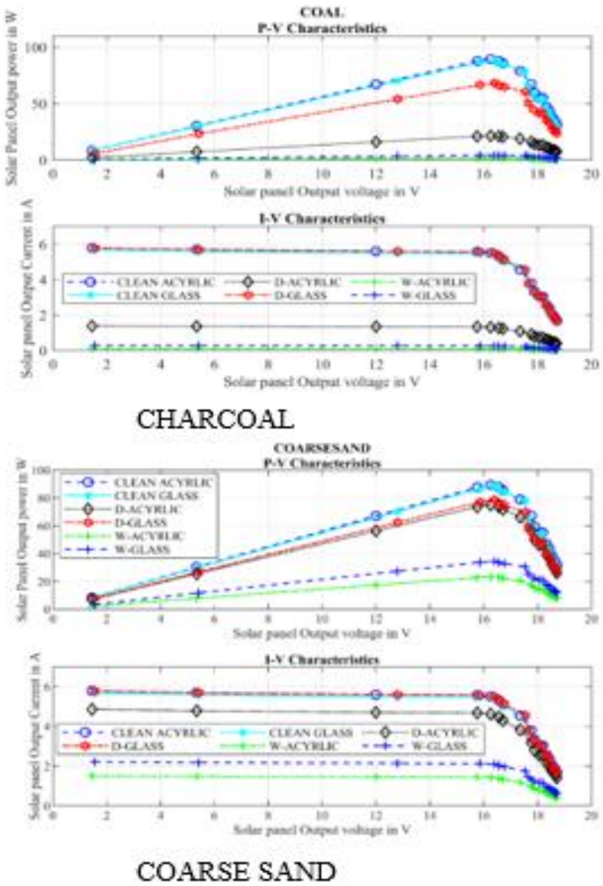

Figure 20 Electrical P-V and I-V Characteristics Curve of Solar Panel under dust samples a) Charcoal b) Coarse

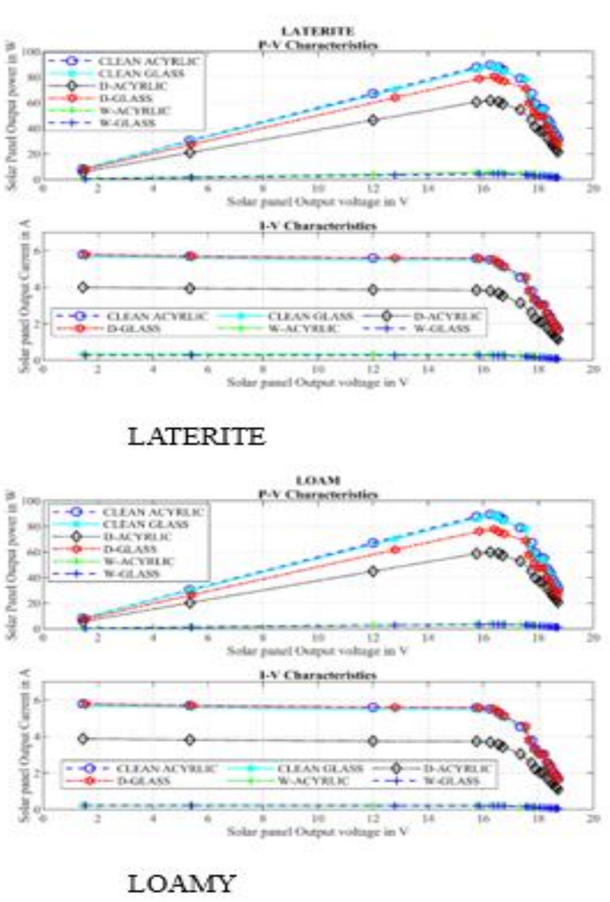

Figure 21 Electrical P-V and I-V Characteristics Curve of Solar Panel under dust samples a) Laterite b) Loamy

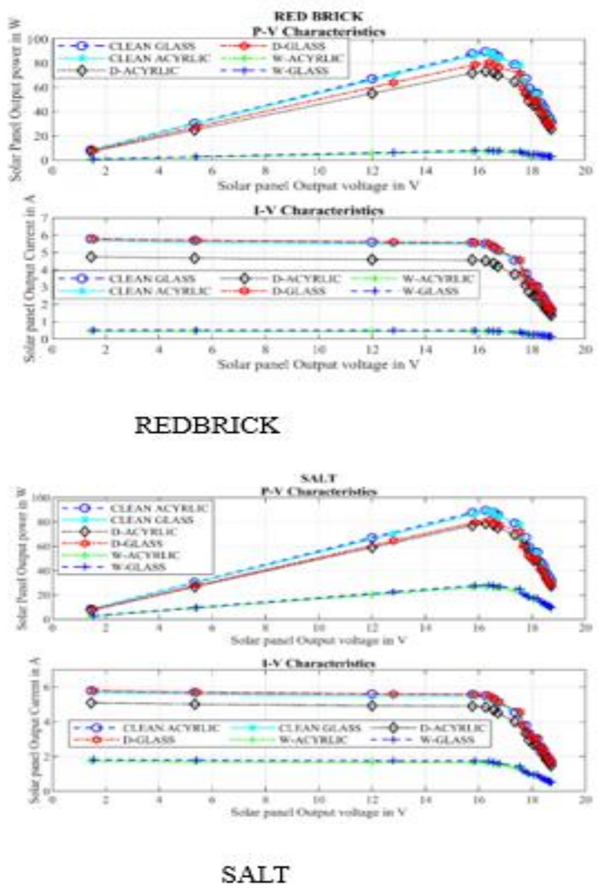

Figure 22 Electrical P-V and I-V Characteristics Curve of Solar Panel under dust samples a) Redbrick b) Salt

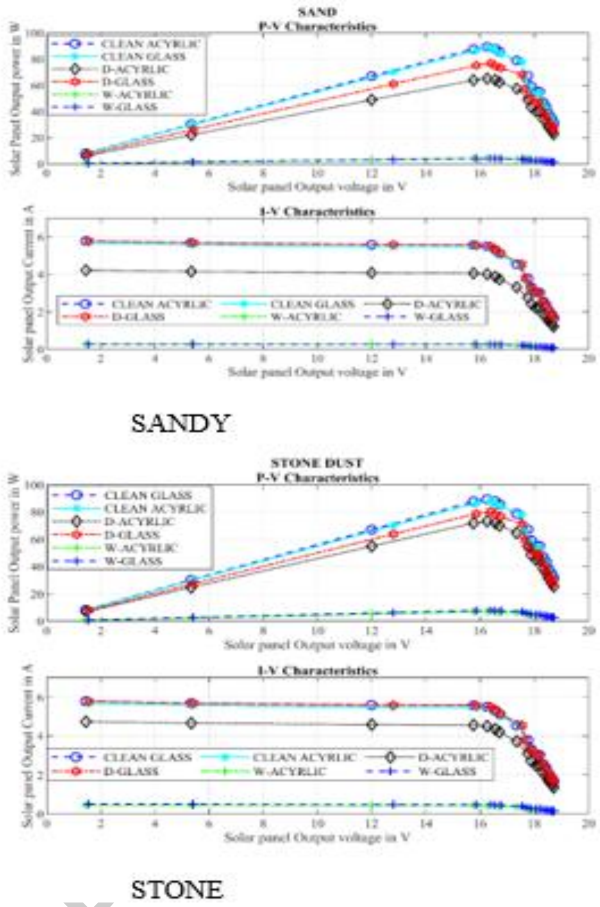

Figure 23 Electrical P-V and I-V Characteristics Curve of Solar Panel under dust samples a) Sandy b) Stone

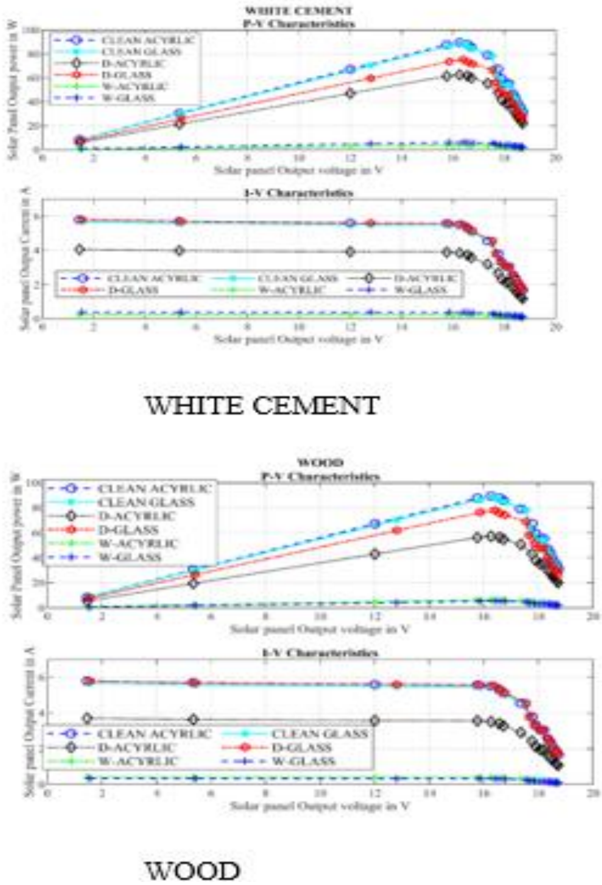

Figure 24 Electrical P-V and I-V Characteristics Curve of Solar Panel under dust samples a) White Cement b) Wood

The electrical performance of solar panels with clean glass and a clean acrylic plate under conditions of 930 W/m^2 of solar irradiation and 30^{o}C for the solar panel is shown in **Table 4**. **Table 5a** displays the values denote three investigational trials, with calculated mean and standard deviation to determine reproducibility and variability of the measurements of solar PV modules with various dust samples on glass and acrylic plates. **Table 5b** displays the electrical efficiency of solar PV modules with various dust samples on glass and acrylic plates.

Table 4. Peak Current, Voltage, and Power of a Solar PV Panel for Clean Glass Plate and Clean Acrylic Plate.

Dust sample	**CLEAN SOLAR PANEL**		
Electrical parameter	I_{MPP}	V_{MPP}	P_{MPP}
Clean glass	5.50	16.26	89.43
Clean acrylic	5.40	16.40	88.50

Table 5a Experimental output power values (Trial 1–3, Mean, SD) for solar PV modules for Various Dust Samples with Glass Plate and Acrylic Plate.

DUST SAMPLE	**CONDITION**	**TRIAL 1**	**TRIAL 2**	**TRIAL 3**	**MEAN**	**SD**
SALT	Dry Acrylic	78.5	78.9	78.7	78.7	0.2
SALT	Dry Glass	81.3	81.5	81.4	81.42	0.1
SALT	Wet Acrylic	26.7	26.9	26.9	26.83	0.1
SALT	Wet Glass	28.2	28.4	28.3	28.32	0.1
COARSE SAND	Dry Acrylic	75	75.3	75.1	75.12	0.15
COARSE SAND	Dry Glass	78.6	78.9	78.8	78.76	0.15
COARSE SAND	Wet Acrylic	23.1	23.4	23.3	23.25	0.15
COARSE SAND	Wet Glass	34.4	34.6	34.5	34.51	0.1
BIRD	Dry Acrylic	53.1	54.2	53.7	53.66	0.55
BIRD	Dry Glass	61.3	62.7	61.9	61.95	0.7
BIRD	Wet Acrylic	21.8	22.9	22.4	22.36	0.55
BIRD	Wet Glass	26.2	27.1	26.4	26.55	0.45
RED BRICK	Dry Acrylic	74.2	74.3	74.2	74.23	0.05
RED BRICK	Dry Glass	82.2	82.4	82.3	82.3	0.1
RED BRICK	Wet Acrylic	8	8.1	8	8.05	0.05
RED BRICK	Wet Glass	4.4	4.5	4.4	4.42	0.05
CARPET	Dry Acrylic	82.1	82.4	82.3	82.3	0.15
CARPET	Dry Glass	82.1	82.3	82.4	82.28	0.15
CARPET	Wet Acrylic	8	8.1	8	8.05	0.05
CARPET	Wet Glass	7.9	8	8	7.96	0.05
CHALK	Dry Acrylic	69.6	69.9	69.8	69.76	0.15
CHALK	Dry Glass	81.3	81.5	81.4	81.42	0.1
CHALK	Wet Acrylic	7.1	7.2	7.1	7.15	0.05
CHALK	Wet Glass	2.6	2.7	2.6	2.65	0.05
STONE	Dry Acrylic	73.2	73.4	73.4	73.34	0.1
STONE	Dry Glass	80.4	80.6	80.6	80.53	0.1
STONE	Wet Acrylic	7.1	7.2	7.1	7.15	0.05
STONE	Wet Glass	7.9	8	8	7.96	0.05
WOOD	Dry Acrylic	57	57.5	57.2	57.24	0.25
WOOD	Dry Glass	77.6	78.1	77.9	77.88	0.25
WOOD	Wet Acrylic	6.1	6.4	6.3	6.26	0.15
WOOD	Wet Glass	5.2	5.4	5.3	5.31	0.1
LATERITE	Dry Acrylic	80.4	80.6	80.6	80.53	0.1
LATERITE	Dry Glass	61.5	61.9	61.7	61.71	0.2
LATERITE	Wet Acrylic	5.2	5.5	5.4	5.37	0.15
LATERITE	Wet Glass	4.3	4.5	4.4	4.42	0.1
CEMENT	Dry Acrylic	67	67.2	67.1	67.08	0.1
CEMENT	Dry Glass	81.3	81.5	81.4	81.42	0.1
CEMENT	Wet Acrylic	4.4	4.5	4.5	4.47	0.05
CEMENT	Wet Glass	3.5	3.6	3.5	3.54	0.05
ASH	Dry Acrylic	40.5	41.8	41.1	41.14	0.65
ASH	Dry Glass	67.5	68.8	68.1	68.14	0.65
ASH	Wet Acrylic	4	5	4.4	4.47	0.5
ASH	Wet Glass	5	5.6	5.3	5.31	0.3

SANDY SOIL	Dry Acrylic	76.8	77	77.2	76.99	0.2
SANDY SOIL	Dry Glass	65.2	65.3	65.4	65.29	0.1
SANDY SOIL	Wet Acrylic	4.4	4.5	4.5	4.47	0.05
SANDY SOIL	Wet Glass	4.3	4.5	4.4	4.42	0.1
CLAY SOIL	Dry Acrylic	64.3	64.5	64.4	64.39	0.1
CLAY SOIL	Dry Glass	79.6	79.7	79.7	79.65	0.05
CLAY SOIL	Wet Acrylic	3.5	3.6	3.6	3.58	0.05
CLAY SOIL	Wet Glass	5.3	5.4	5.3	5.31	0.05
WHITE CEMENT	Dry Acrylic	62.5	62.7	62.6	62.6	0.1
WHITE CEMENT	Dry Glass	75.1	75.3	75.3	75.22	0.1
WHITE CEMENT	Wet Acrylic	3.5	3.6	3.6	3.58	0.05
WHITE CEMENT	Wet Glass	6.1	6.3	6.2	6.19	0.1
CHARCOAL	Dry Acrylic	21	22	21.4	21.46	0.5
CHARCOAL	Dry Glass	67.5	68.8	68.1	68.14	0.65
CHARCOAL	Wet Acrylic	1.7	1.9	1.8	1.79	0.1
CHARCOAL	Wet Glass	4.1	4.6	4.5	4.42	0.25

Table 5b. Output Power, Efficiency, and Power Loss of a Solar PV Panel for Various Dust Samples with Glass Plate and Acrylic Plate.

DUST SAMPLE	OUTPUT POWER P_{dust}				EFFICIENCY (%) η_{dust}				POWER LOSS (%) $P_{loss\ dust}$			
	Dry acrylic	Dry glass	Wet acrylic	Wet glass	Dry acrylic	Dry glass	Wet acrylic	Wet glass	Dry acrylic	Dry glass	Wet acrylic	Wet glass
SALT	78.7	81.42	26.83	28.32	10.56	10.92	3.60	3.80	12.00	8.00	70.00	68.00
COARSE SAND	75.12	78.76	23.25	34.51	10.08	10.57	3.12	4.63	16.00	11.01	74.00	61.01
BIRD	53.66	61.95	22.36	26.55	7.20	8.31	3.00	3.56	40.00	30.00	75.00	70.00
RED BRICK	74.23	82.3	8.05	4.42	9.96	11.04	1.08	0.59	17.00	7.01	91.00	95.01
CARPET	82.3	82.28	8.05	7.96	11.04	11.04	1.08	1.07	7.97	7.03	91.00	91.01
CHALK	69.76	81.42	7.15	2.65	9.36	10.92	0.96	0.36	21.99	8.00	92.00	97.01
STONE	73.34	80.53	7.15	7.96	9.84	10.80	0.96	1.07	17.99	9.01	92.00	91.01
WOOD	57.24	77.88	6.26	5.31	7.68	10.45	0.84	0.71	35.99	12.00	93.00	94.00
LATERITE	80.53	61.71	5.37	4.42	10.80	8.28	0.72	0.59	9.95	30.27	94.00	95.01
CEMENT	67.08	81.42	4.47	3.54	9.00	10.92	0.60	0.47	24.99	8.00	95.00	96.00
ASH	41.14	68.14	4.47	5.31	5.52	9.14	0.60	0.71	54.00	23.01	95.00	94.00
SANDY	76.99	65.29	4.47	4.42	10.33	8.76	0.60	0.59	13.91	26.23	95.00	95.01
CLAY	64.39	79.65	3.58	5.31	8.64	10.68	0.48	0.71	28.00	10.00	96.00	94.00
WHITE	62.6	75.22	3.58	6.19	8.40	10.09	0.48	0.83	30.00	15.01	96.00	93.01
CHARCOAL	21.46	68.14	1.79	4.42	2.88	9.14	0.24	0.59	76.00	23.01	98.00	95.01

From Table 5b, it is observed that, with dry ash accumulated on an acrylic plate, the output power loss occurred by around 54%, and by about 23% on the glass plate. When the sample is wet, an alarming increase is noticed, with degradation of roughly 95% on the acrylic plastic plate and 94% on the glass plate. Similarly, for salt dust, the output power loss is roughly 12% when dried salt is applied on an acrylic plastic plate and about 8% on a glass plate. An alarming increase is seen when the salt sample is wet, with a deterioration of nearly 70% on the acrylic plastic plate and 68% on the glass plate. The accumulation of charcoal dust caused a high power drop in the solar panel. On a glass plate with charcoal dust, the output power loss by around 35%, while it dropped by about 73% on an acrylic plastic plate. Wetly placing the charcoal sample on the different coupons caused an astonishing increase to be shown, with a deterioration of about 98% on the acrylic plate and 96% on the glass plate.

4. Efficient Improvement Technique- Wet Wiper System

In this research study, it is observed that large densities of dust reduce efficiency drastically and is unavoidable. A study with a cleaning mechanism using a wet wiper is carried out to test the impact of cleaning in improving efficiency. A wet wiper system consists of a micro fabric wiper unit with a stepper motor arrangement. Water is sprayed on the micro fabric wiper using a small tube arrangement placed on the wiper. A 3D model of the wet wiper system is shown in Figure 25. Based on the cleaning frequency given in the program, the microcontroller automatically starts to wipe the solar panel.

5. Conclusion

Solar power, being the most sought-after form of energy, needs a lot of in-depth analysis for improving its power conversion efficiency. The major reasons and parameters that contribute to the reduction in efficiency are irradiance, temperature, dust, incident angle, and shadow. In this investigation, sixteen distinct forms of dust are used to analyze the effects of different pollutants on the functioning of solar PV systems in both dry and wet circumstances.

With constant solar irradiance of 960W/m^2, all experiments are carried out in outdoor or real environment conditions. Clean solar PV modules delivered stable output power (~80 W) and efficiency (~11%), while dust deposition produced decreases extending from reasonable (10–30% for dusts such as sand, brick, and salt) to severe (>70–95% for uneven dusts such as charcoal, ash, and bird droppings).

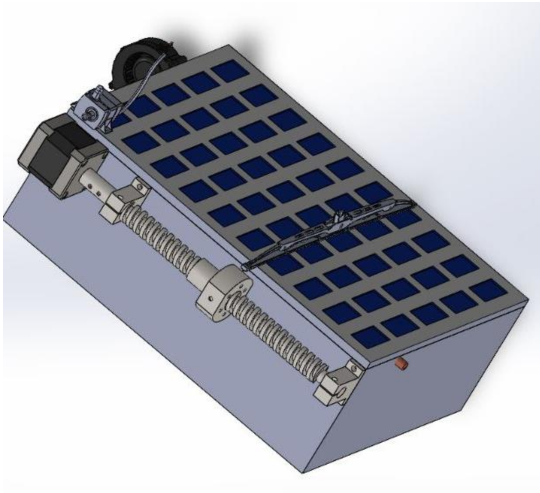

Figure 25. 3D Model of Wet Wiper System with Solar Panel.

Coal dust had the great impact on solar PV system efficiency out of all dust kinds, and the effects of cleaning with a wet wiper system were examined. It is observed that using a wet wiper cleaning technology at a specific frequency increases efficiency by 5%. From the results, it is recommended to maintain the solar panel under clean conditions by adopting an appropriate cleaning mechanism at the optimum frequency. By mitigating the combined effects of temperature and dust, the wet wiper system enhanced the average output power by up to 10.62W during the test period and improves the average efficiency of conventional solar panels from 9.87% to 12.49%.

To maintain solar PV efficiency, these findings emphasize the significance of dust-specific maintenance procedures, optimal cleaning intervals, and treatments for the surface (which include hydrophobic coatings). Future uses include self-cleaning surface integration, autonomous cleaning technologies, and forecasting of dust-driven losses to guarantee dependable solar energy production in dust-prone areas.

Consent to Publish

Not Applicable

Consent to Participate

Consent to Publication Not Relevant

Ethical Approval

Not Applicable

Authors Contributions

The following tasks were completed under Dr. Chairma Lakshmi K R's supervision: conceptualization, methodology, resources, formal analysis, inquiry, and preparation of the original text. dDr. Sheerin Banu M, Dr. S. Muthusundari, Mrs. V. Devi, Dr. Rajavel A, and Dr. Hariharan performed the supervision, formal analysis, visualization, and writing.

Availability of data and materials

Not Applicable

Competing Interests

There are no conflicting interests, according to the authors.

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List of nomenclatures

I_{MPP}	-	Clean Solar PV Panel Output Current in A
P_{MPP}	-	Clean Solar PV Panel Output Power in W
V_{MPP}	-	Clean Solar PV Panel Output Voltage in V
I_{sc}	-	Solar PV Panel Short Circuit Current in A
G	-	Solar Intensity / Irradiance in W/m^2
V_{oc}	-	Open Circuit Voltage of Solar PV Panel
I_{sc}	-	Short Circuit Current of Solar PV Panel
P_{MPP}	-	Output Power of clean solar PV Panel
$P_{loss\ dust}$	-	Output Power loss Under dusted condition
η_{clean}	-	Efficiency of Clean Solar Panel
η_{dust}	-	Efficiency of dust Solar Panel

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