archives
of thermodynamics
Vol. **44**(2023), No. 2, 49–68
DOI: 10.24425/ather.2023.146558

The performance analysis of dusty photovoltaic panel

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Abstract Solar photovoltaic power is widely utilized in the energy industry. The performance of solar panels is influenced by different variables, including solar radiation, temperature, wind speed, relative humidity and the presence of haze or dirt. Outdoor solar panels are particularly susceptible to a decrease in energy efficiency due to the accumulation of dust particles in the air, which occurs as a result of natural weather conditions. The extent of dust deposition is primarily determined by factors such as the tilt angle of the panel, wind direction, cleaning frequency as well as local meteorological and geographical conditions. The dust on the solar cell glazing reduces the optical transmittance of the light beam, causing shadowing and diminishing the energy conversion productivity of the panels. Sand storms, pollution levels and snow accumulations all significantly impact the photovoltaic panel performance. These circumstances reduce the efficiency of solar panels. The experiment was carried out on two identical dust-accumulated and dust-free panels. The evaluation was carried out in two different situations on the off-grid stand-alone system: in a simulated atmosphere and in an open space during the day. The current-voltage curves have been developed for both panels at various tilt degrees. The features provide sufficient information to analyse the performance of the panels under consideration. The measurements demonstrate that as dust collects on the panel's surface, the average output power and short circuit current decrease dramatically. The installation tilt angle affected the ratio of efficiency and average power outputs of dusty and clean panels.

Keywords: Dust accumulation; Tilt angle; Photovoltaics; Solar panel; Transmittance

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Nomenclature

G	–	irradiance, W/m^2
G_{ref}	–	irradiance at STC = 1000 W/m^2
I	–	output current, A
I_d	–	diode current, A
I_o	–	diode reverse saturation current, A
I_p	–	current in parallel resistance branch, A
I_s	–	source current, A
k	–	Boltzman constant, $= 1.38 \times 10^{-23}$ J/K
m	–	diode ideality factor
N_s	–	number of PV cells connected in series
P	–	power, W
q	–	electron charge, $= 1.6 \times 10^{-15}$ C
R_p	–	parallel resistance, Ω
R_s	–	series resistance, Ω
T	–	cell temperature, K
T_c	–	p-n junction cell temperature, K
V	–	terminal voltage, V

Greek symbols

ε	–	band gap, = 1.12 eV for silicon
μ_{sc}	–	temperature coefficient of short circuit current, A/K
η	–	efficiency

Subscripts

oc	–	open circuit
sc	–	short circuit
av	–	average

Acronyms

PV	–	photovoltaics
STC	–	standard test conditions

1 Introduction

Over the recent decades, the steady growth in the installed capacity of power generation by solar photovoltaics (PV) has been observed all over the globe. Photovoltaic generators produce clean energy by extensively using solar energy and converting it into electrical energy. Technological advancements, ecological and prise aspects have attracted a lot of special attention from governments, investors, and researchers. Several studies and research works have been done in associated areas.

The desert regions are the most popular locations for solar plant installations because of land availability and great solar potential. Different parameters influence the performance of PV generators in deserted areas, including the capability of the glass cover to transmit solar radiation, the intensity of solar radiation, the installation angle of the PV cell, the properties of the solar cell materials, the location of installation, temperature, etc.

For the panels installed in the open air, the factor responsible for the gradual degradation of transmittance is an accumulation of dust. Dust deposited on the glass top of the PV system reduces the transmission coefficient, which significantly results in a drop of energy conversion efficiency. The PV literature is concerned with the problems that occur due to dust and sand. The experimental study by Hassan *et al.* [1] provided information that the degradation is fast in the period of the first month and found a reduction of 33.5% in PV panel efficiency. It was analyzed by Rehman and El-Amin [2], Cabanillas and Munguía [3] that the dust deposited on the module cover may cause a significant reduction in the performance of PV. A reduction by 5% in one month was recorded in Saudi Arabia, by 1% in one month in Abu Dhabi, UAE and by 5.8% in 20 days in Hermosillo, Mexico. The operation of PV systems largely depends on the site location and weather conditions. The dust accumulation rate of 1–50 mg/m^2/day was reported in Colorado by Boyle *et al.* [4] and 150–300 mg/m^2/day in Egypt, undergoing visible variation, which is specifically due to the variable weather conditions. Furthermore, the impact of cooling on the PV electrical output was studied with the advanced cooling system in Pakistan by Bashir *et al.* [5] to have an insight into performance analysis. The deposition of dust is a challenge in the looming deployment of PV systems as shown by Javed *et al.* [6], Adinoyi and Said [7]. During the dust storm, the output of PV modules can even drop down to 20%.

The studies of the impact of dust accumulation on PV output performance play an important role in sustainable progress. The study by Mehmood *et al.* [8] showed that coarser dust particles have a more significant impact on PV panels' performance than fine particles. The dust particle size, chemical properties and thickness have been studied to better understand the physicochemical properties of dust depositions. For the study of the impact of dust sedimentation on PV performance, some work has been done to unearth the influencing parameters. The results showed that dust accumulation is highly dependent on the wind direction, pressure, tilt angle, azimuth angle, surface friction, humidity and the time duration for which the panels are placed in the environment. It elucidates the fact that the deposition rate significantly affects the decreasing efficiency, which is majorly dependent on the weather conditions.

Most recent broad and accurate experimental studies have been conducted and reported by Darwish *et al.* [9] on the impact of variable temperature dust particles in dust accumulation on solar PV panels. The comprehensive and satisfactory studies were conducted in controlled laboratory conditions under unnatural weather. But the natural weather environment has an enormous impact on dust accumulation; it is tedious to simulate and consider all the variables. So, to better simulate the natural environmental conditions of Tehran, researchers performed the study under external natural conditions. Middle east countries like Iran have a massive solar generation perspective, but dust deposition is an unavoidable circumstance. The performance and energy conversion in PV depend on different environmental factors, solar irradiance, installation tilt angle and wind direction as reported by Cabrera-Tobar *et al.* [10]. The studies powerfully depict that the dust clouds on the modules cause a significant reduction in efficiency, particularly during sand storms and in polluted areas. Therefore, cleaning PV surfaces is essential for maintaining the operating efficiency at a high level in the desert region.

There are several studies done on dust accumulation in PV. It was observed that the tilt angle strongly impacts the dust density. Also, the wavelength loss due to the accumulated dust has been studied. The effects of dust size and composition have been carefully investigated by Sanusi [11]. The necessity of cleaning the dusty or polluted module glass covers is observed in various studies, but cleaning issues remain a concern in desert regions where the water supply is limited and requires minimum cleaning frequencies for maintaining the system performance at a high level. Though, research on the frequency of cleaning dust from the PV module glass covers has been minimal. Kaldellis [12] conducted a study in Greece on panels tilted at 30° with red soil particles with a diameter of less than 150 μm, ash particles with a diameter of less than 10 μm and limestone particles with a diameter of less than 60 μm. The experimental study was conducted under the ambient temperature within the range of accumulated dust density from 0.12 g/m^2 to 3.75 g/m^2. The reduction in performance was observed from 2.3% to 7.5%. In Germany, Schill *et al.* [13] conducted tests at the optimal tilt angle for five months under visible light and found a reduction of 20% in efficiency. Klugmann-Radziemska [14] in Poland conducted a study for two years on the panels at a tilt angle of 37°. The particles settled over the panel were 50 μm in diameter, and few particles above 50 μm. The data collected indicated a reduction in efficiency by 0.8% per day. In Morocco, Azouzoute *et al.* [15] investigated the performance of the solar panels at an angle of 32°, for three months. The dust deposited on the unclean glass top panels was of density 1.6 g/m^2 and the resulting reduction in efficiency was equal to 35%. The dust particles of different sizes and different densities were investigated under laboratory conditions by Lu *et al.* [16]. The results of the eight week simulated environment experimentation in China have shown that under visible light of wavelength 350 nm to 800 nm, the reduction in the efficiency was from 28.8% to 43.41%. In India, Bergin *et al.* [17] conducted a performance evaluation for which the data was collected during continuous 30 days in the Gujrat state. After the analyses, a reduction in efficiency by 50% was observed. Al-addous [18] conducted an experimental study in Jordan for 16 weeks and observed a reduction from 1.37% to 5.02% per year. In China, Chen [19] collected the data for one week to check the performance of solar panels. The panels were under environmental conditions at an angle of 20°, the deposited dust density was found equal to 0.644 g/m^2, which reduced the efficiency by 7.8% per week. In the Bangladesh, Rehman *et al.* [20] conducted their study with the uncleaned panels under the natural conditions for one month to check the reduction in efficiency. The results showed a drastic reduction by up to 35%.

The latest new technologies are evolved with recent development in the field of neural network. Abdulghafor *et al.* [21] studied the modern seven artificial neutral network approaches, which are used to precisely estimate the thermal performance of a solar air heater based on input data such as mass flow rate, ambient temperature, plate temperature, wind speed and direction, relative humidity, and so on. Statistical error analysis with the mean square error and correlation coefficient was used to evaluate the neural network models. However, Mzad *et al.* [22] addressed the modelling of PV cooling employing a single nozzle with low temperature, minimal mass flow, and low pressure, with droplet velocity ranging from 0.1 to 1.7 m/s. The droplet size of the nozzle spray is a critical component that influences contact efficiency and panel cooling. The solar energy is a popular way of green energy generation but still there are some limitations. Węcel *et al.* [23] studied that the megawatt capacity photovoltaic power stations have a substantial negative indication in the energy generation capability of producing energy exclusively during the day. This needs the use of massive energy storage systems. The storage can be made more effective by combining optimised PV cells with an electrolyzer. The solar energy production can be more efficient if the solar radiation received at the earth surface can be predicted. Daghsen *et al.* [24] studied the two optimised regression models that are utilised to generate the Petela model and the ASHRAE method for energy conservation and solar energy forecasting, respectively. These models were used to create the universal patterns for solar radiation exergy accounting.

Various researchers from different countries studied the behaviour of the panels and analysed the reduction in efficiency. In India, there are many regions which are prone to sand and dust particles, but this is not the only factor which leads the dirt to be deposited. The urbanization has given birth to rapid development in the infrastructure and construction, and the building of concrete jungles gives rise to the deposition of nanoparticles. The burning of residual grass in the fields, the deposition of soot particles and festivals like Diwali are big contributors to polluting the panels.

In the paper, Section 1 gives a brief introduction with a literature review. The works of various researchers from different countries were studied. Section 2 gives the mathematical modelling of the solar panels, where the voltage and current equations are solved with the Matlab Simulink. Graphs of dependence between the voltage and current are also drawn at various radiation levels. The dust particles tend to reduce the radiation effect by providing the shadowing effect. Section 3 gives the experimental setup of the solar panels. Section 4 discusses the observations and results. It also gives a deep analysis of the obtained results. The conclusions of the paper are given in Section 5.

2 Mathematical Model

The photovoltaic panel can be shown as an electric circuit, as shown in Fig. 1, where the radiation (G) is incident on the panel, and the current generated is supplied to the resistances and the diode.

The current flow is given by the formula

$$I = I_s - I_d - I_p \,. \tag{1}$$

The diode current (I_d) is directly proportional to the reverse saturation current (I_0) and is given by

$$I_d = I_0 \left[\exp\left(\frac{qV}{mkT} \right) - 1 \right], \tag{2}$$

where m is the diode ideality factor, which is constant and depends on the PV cell technology, k is the Boltzman constant, q is the electron charge,

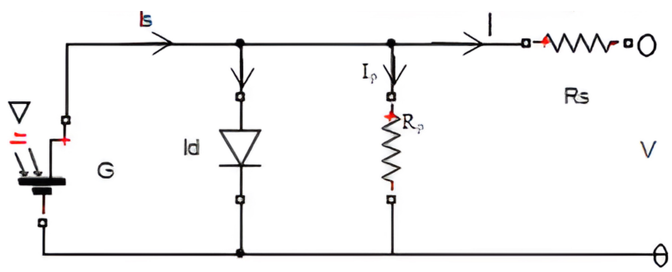

Figure 1: Single diode model with R_s and R_p.

T is the cell temperature and V is the terminal voltage). If we neglect the shunt resistance in the circuit, then the current can be written as

$$I = I_s - I_s \left[\exp\left(\frac{qV}{mkT}\right) - 1\right], \tag{3}$$

by putting the diode current equation. Under the short circuit conditions when $V = 0$ and open circuit conditions when $I = 0$, the short circuit current can be found from the given equation

$$I_{sc} = I = I_s - I_o \left[\exp\left(\frac{qV}{mkT}\right) - 1\right] \quad \text{at} \;\; V = 0, \tag{4}$$

and the voltage equation can be written as

$$V = V_{oc}\frac{mkT}{q} \ln\left(1 + \frac{I_{sc}}{I_o}\right) \quad \text{at} \;\; I = 0, \tag{5}$$

where V_{oc} is the open circuit voltage and I_{sc} is the short circuit current.

The diode current and current through the series resistance can be expressed in terms of voltage and current as

$$I_d = I_0 \left[\exp\left(\frac{V + IR_s}{a}\right) - 1\right], \tag{6}$$

$$I = I_s - I_0 \left[\exp\left(\frac{V + IR_s}{a}\right) - 1\right], \tag{7}$$

where

$$a = \frac{N_s mkT_c}{q}. \tag{8}$$

These equations are for the case when the shunt resistance is not present. If the shunt resistance is present, then the equation given below is considered:

$$I = I_s - I_0 \left[\exp\left(\frac{V + IR_s}{a}\right) - 1\right] - \frac{V + IR_s}{R_p}. \tag{9}$$

Various parameters are used in these equations and directly affect these values. The output current at the standard test conditions (STC) is given as

$$I = I_{s,\mathrm{ref}} - I_{o,\mathrm{ref}} \left[\exp\left(\frac{V}{a_{\mathrm{ref}}}\right) - 1\right], \tag{10}$$

where a_{ref} is the value of a at temperature 25°C .

If the PV cell is short-circuited the value of $I_{s,\mathrm{ref}}$ can be written as

$$I = I_{s,\mathrm{ref}} - I_{o,\mathrm{ref}} \left[\exp\left(\frac{0}{a_{\mathrm{ref}}}\right) - 1\right] = I_{s,\mathrm{ref}}\,, \tag{11}$$

which is valid during the ideal cases:

The source current depends on both the irradiance and temperature:

$$I_s = \frac{G}{G_{\mathrm{ref}}} \left(I_{s,\mathrm{ref}} + \mu_{\mathrm{ref}} \Delta T\right), \tag{12}$$

where $\Delta T = T_c - T_{c,\mathrm{ref}}$ and $T_{c,\mathrm{ref}} = 298$ K and μ_{ref} is the temperature coefficient of short circuit current in A/K.

The simulation was done based on the above equations using multi-paradigm programming language and numerical computing environment MATLAB Simulink – version 2020b [25]. The simulation was run to draw characteristics of the PV panel under various conditions. The irradiance (G) is the factor that is most affected by the dust particles. The panel under the dust does not receive its best radiation. Figure 2 shows the simulation

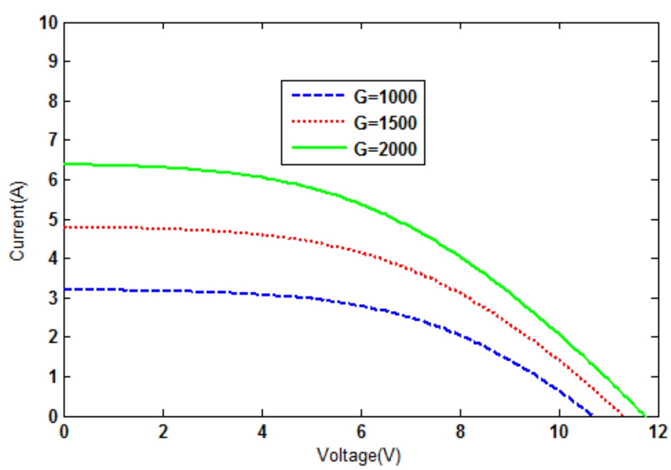

Figure 2: Simulink results under different radiation levels.

result under different radiation levels. The simulation models show that as the radiation level decreases, the short circuit tends to decrease too, decreasing with the voltage.

3 Experimental setup

The measuring techniques were utilized to get current-voltage curves from two similar PV panels, one panel is perfectly clean, and the other is polluted with dust as shown in Fig. 3. In the primary consideration, both panels are set under controlled indoor unnatural conditions in the laboratory. The tilt angle varied, and I–V qualities were recorded. In the second consideration, panels are put in the natural habitat outdoors under natural daylight. The study aims at analyzing the PV performance with the changing tilt angle and dust deposition. The identical panels are subjected to different ambient conditions and dust depositions in indoor and outdoor conditions. The dirt deposited on the PV surface depends on various parameters, which include the installation tilt angle, physical characteristics of the dust and local atmosphere. In general, the optimal angle for installation of the PV surface, which receives the maximum direct radiation, is highly dependent on the PV site. The best installation angle varies with the season and sun position, however, the regular angle adjustment is uneconomical. Therefore, the best tilt angle for engineering applications is approximately equal to the local latitude. In this study, in order to examine the impact of dust deposition, five various tilt angles (0°, 10°, 20°, 30°, 40°) have been considered. The indoor test setup has two comparable panels, one next to the other,

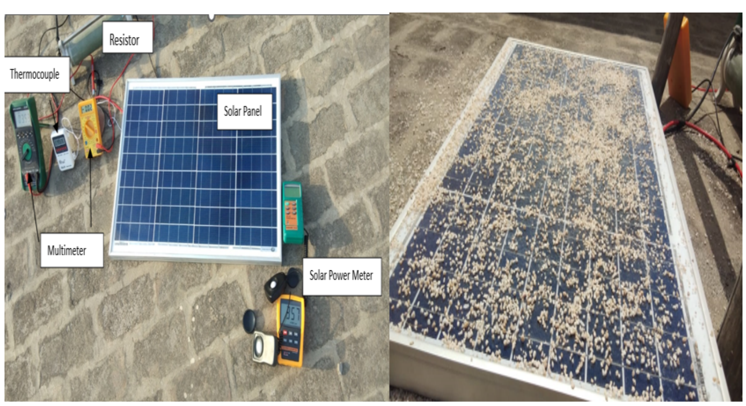

Figure 3: Experimental setup.

mounted parallel to the ground. The arrangements are made to change the light intensity of the sun-simulating lamps set over each panel.

The characteristics I–V were plotted using a data logger interfaced with the panels. A Tenmars portable solar power radiation measuring tester [26] is used to measure the intensity of light over the panel. In the indoor experimental setup, the bulb light intensity is kept at 500 W/m^2. The temperature of the solar module was measured from the back of the module with the platinum resistance thermocouple PT100. The cell operating temperature was maintained during the experiment between 35°C to 42°C. The fans controlled the panel temperature by cooling the back of the solar modules. The reading of voltage and current was recorded for various tilt angles. The I–V curves were obtained for both panels. During the dust simulation, sand was taken as the dust particle. The dust was spread over the panel non-uniformly, which covered 80% of the surface area. As the tilt angles assumed values above 20°, at 30° and 40°, 5.1% and 15.75% of sand dropped on the floor from the panel.

Outdoor experimental test arrangements were installed at a Gurugram roof-top location (latitude 28.45°N, longitude 77.02°E). The test had a roof-mounted polycrystalline PV panel with no shading effect, which was installed with an adjustable tilt angle parallel to the ground surface facing south. The two panels under consideration received the same insolation levels, kept in the same atmospheric natural conditions. The PV cell operating temperatures measured were recorded between 45°C and 65°C. The dust with non-niform distribution of covering density was set up in the experimentation. During the investigation, the insolation level was 950 W/m^2, the atmospheric temperature was 43°C, and the wind speed was 9.3 km/h.

4 Results and discussions

In the unnatural environmental conditions, the temperature, bulb light intensity and tilt angle of the installation were controlled for the comprehensive investigation. One panel with dust accumulated and the other with the clean surface were examined. The recording of readings started from 0° tilt angle at the light intensity of 500 W/m^2 and temperature 35°C. First I–V curves were plotted for the initial tilt angle. Then, the tilt angle was increased in steps of 10° starting from 0° up to 40°. The readings were recorded when the module temperature was 35°C to 42°C. The I–V curves for the two panels under study at different tilt angles are drawn in Figs. 4–8.

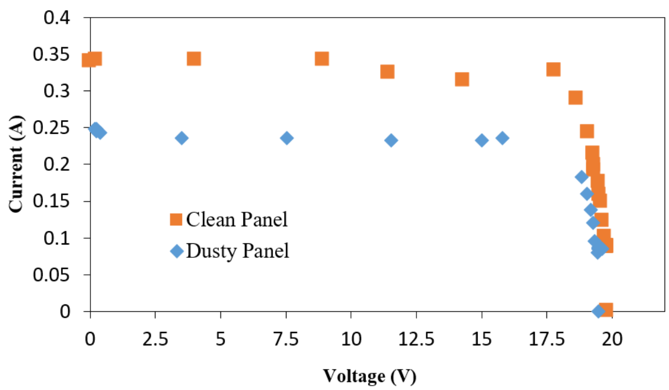

Figure 4: I–V characteristics at 500 W/m^2 and 0° tilt angle in laboratory conditions.

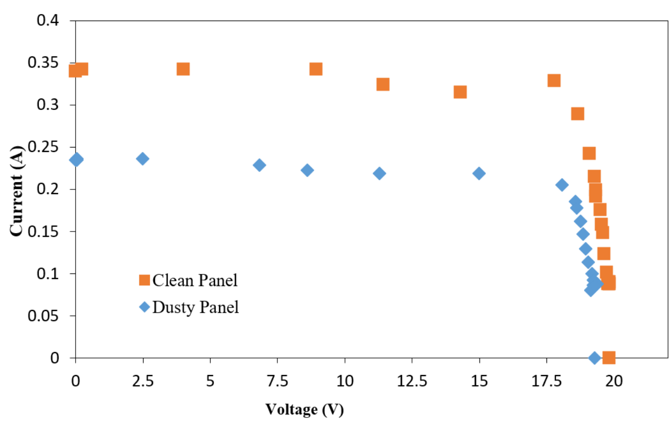

Figure 5: I–V characteristics at 500 W/m^2 and 10° tilt angle in laboratory conditions.

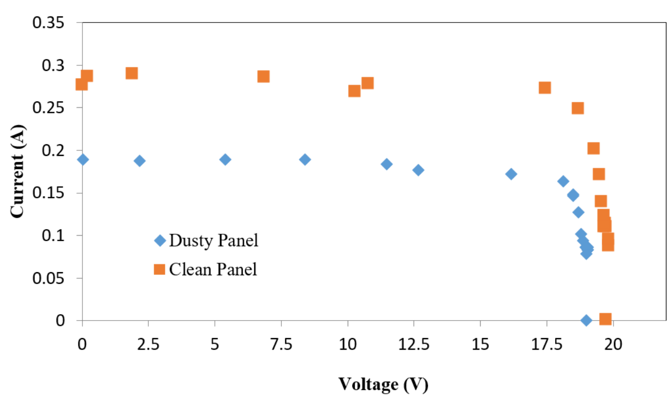

Figure 6: I–V characteristics at 500 W/m^2 and 20° tilt angle in laboratory conditions.

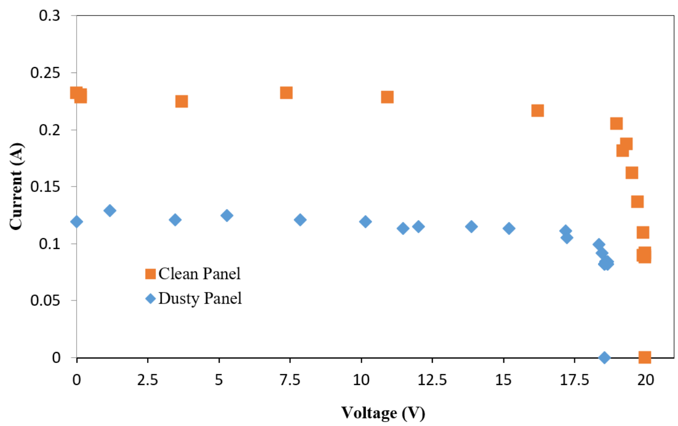

Figure 7: I–V characteristics at 500 W/m^2 and 30° tilt angle in laboratory conditions.

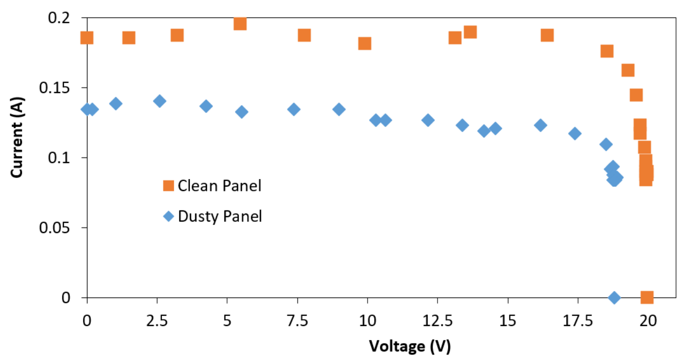

Figure 8: I–V characteristics at 500 W/m^2 and 40° tilt angle in laboratory conditions.

Tables 1 and 2 give the various parameters of dusted panels with respect to those of clean panels, including the voltages and currents. The power of the solar panels is determined from the product of open circuit voltage and short circuit current given as

$$P = V_{oc} I_{sc} \,. \tag{13}$$

The efficiency of the solar panel can be calculated from the given equation:

$$\eta = \frac{P}{G\,A} 100 \,, \tag{14}$$

where G is the irradiance and A is the total surface area of the solar panel.

Table 1: Ratio of open circuit voltage and short circuit current under controlled indoor conditions.

Tilt angle (°)	Solar module temperature (°C)		Ratio of short circuit currents (%)	Ratio of open circuit voltages (%)
	Clean	Dusty	$I_{sc\,\mathrm{dusty}}/I_{sc\,\mathrm{clean}}$	$V_{oc\,\mathrm{dusty}}/V_{oc\,\mathrm{clean}}$
0	35	35	72.57	99.52
10	37	35	69.14	97.78
20	35	39	66.89	95.58
30	37	42	54.06	93.39
40	37	40	72.00	94.62

Table 2: Ratio of efficiency and average power under controlled indoor conditions.

Tilt angle (°)	Ratio of efficiencies (%)	Ratio of average powers (%)
	$\eta_{\mathrm{dusty}}/\eta_{\mathrm{clean}}$	$P_{av\,\mathrm{dusty}}/P_{av\,\mathrm{clean}}$
0	64.14	62.87
10	63.56	69.85
20	62.63	76.62
30	49.12	66.17
40	62.67	71.05

The readings from the panels under investigation were obtained for different tilt angles. The following conclusions can be drawn:

- Sand-deposited panels were observed to have the operating temperatures higher by 2°C to 7°C than those of the sand-free panels under the same insolation level.

- The sand spread over the panel was non-uniformly distributed with a density of 12.5 g/m^2 at a zero degree tilt angle. As the tilt angle increased, the sand density decreased reaching 10.5 g/m^2 at 40°. The average power loss for the given sand densities is from 38% to 24%.

- It may be observed from the presented tables that accumulation of dust does not have a high impact on the open circuit voltage. The ratio of the open circuit voltages between dusty and clean panels varied from 93.39% to 99.52%. The values of the open circuit voltage of the clean and sand-accumulated panels were nearly identical. The voltage difference is visible at angles above 10°; the impact may be because of the module temperature increase.

- The short circuit current ratios varied from 54.06% to 72.57%. The dust deposited on the panels gives larger differences in short-circuit current ratios than in the open-circuit voltage ratios. The graphs show that sand has a sizable impact on the short-circuit current. The percentage ratio tends to decrease with the increase in the tilt angle, but for the largest angle, it suddenly increased. It was most likely due to the temperature increase and reduction of dust density over the panel by 15.75% due to the gravity and more radiation responsible for the power generation available on the panel.

- The ratio of efficiencies of dusty and clean panels is minimum at 30°, but no such correlation was found for this.

The experiment under natural conditions was conducted on the rooftop of a building in Gurugram in the month April. The sand spread over the panel was non-uniform. The sand density was nearly equal. The two panels were kept parallel to the ground, one with non-uniformly distributed sand and the other with a clean surface. During the outdoor investigation, the temperature of the sand varied from 40–45°C. The solar cells had experienced a temperature difference of approximately 10°C. I–V curves for clean and dusty panels at different tilt angles and at an increased radiation rate are shown in Figs. 9–13.

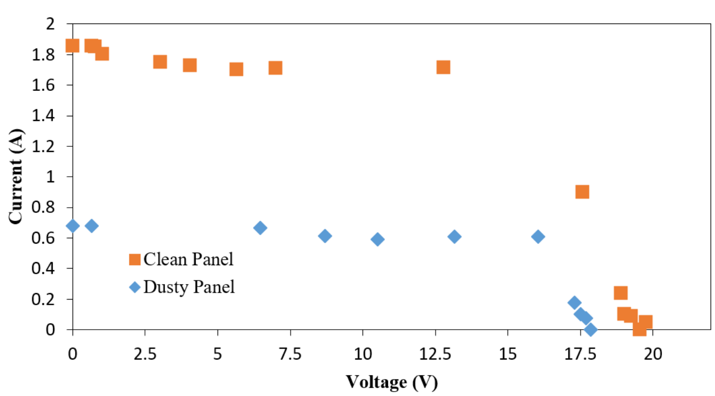

Figure 9: I–V characteristics at 950 W/m^2, 0° tilt angle in natural conditions.

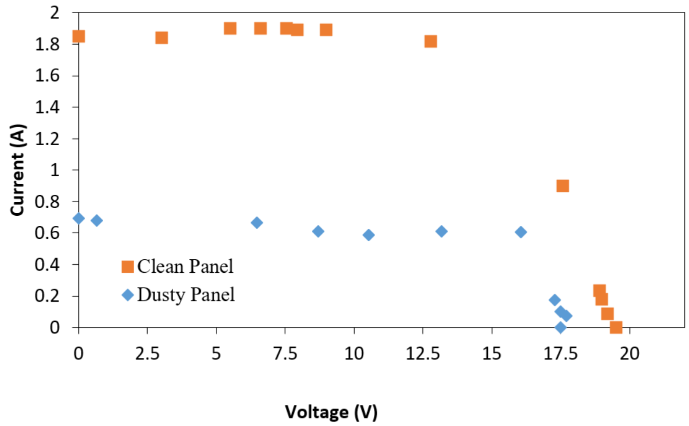

Figure 10: I–V characteristics at 950 W/m^2, 10° tilt angle in natural conditions.

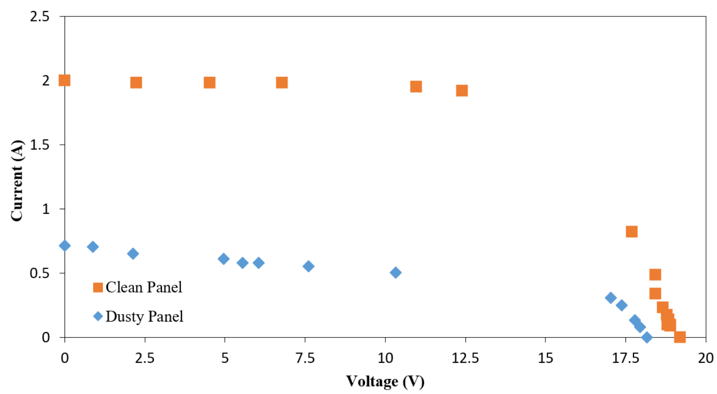

Figure 11: I–V characteristics at 950 W/m^2, 20° tilt angle in natural conditions.

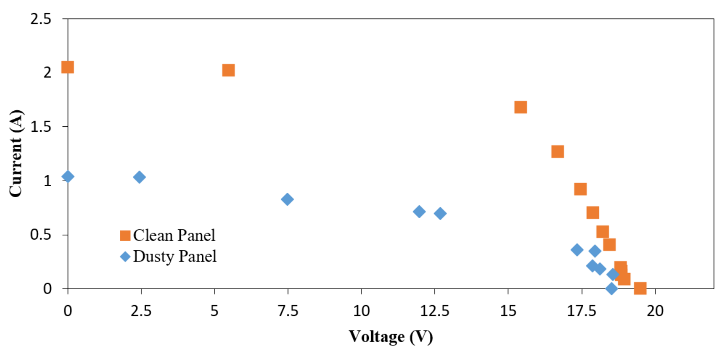

Figure 12: I–V characteristics at 950 W/m^2, 30° tilt angle in natural conditions.

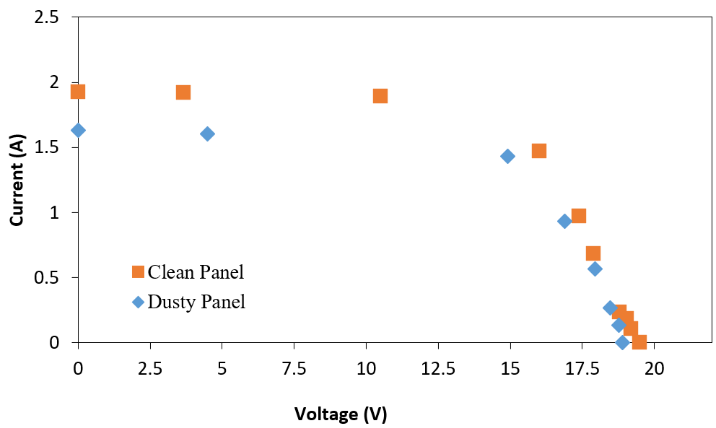

Figure 13: I–V characteristics at 950 W/m^2, 40° tilt angle in natural conditions.

The calculated ratios of short circuit currents, open circuit voltages, efficiencies, and average powers between the two studied panels are gathered in Tables 3 and 4. The outdoor experimentation was conducted at different insolation levels. The following observations were made:

- The non-uniform distribution of sand did not strongly impact the open circuit voltage ratio.
- A sizeable impact of sand accumulation was seen in the short circuit currents of the panels. In natural conditions, solar radiations have an adverse effect on the short circuit currents. In the clean panels, the short circuit currents were below 2 A for 0° and 10°, at 20°, 30° and 40°, approximately invariant. In the sand-deposited panel short

Table 3: Ratio of open circuit voltage and short circuit current of dusty and clean panels under natural conditions.

Tilt angle of the panel (°)	Ratio of short circuit currents (%)	Ratio of open circuit voltages (%)
	$I_{sc\,\text{dusty}}/I_{sc\,\text{clean}}$	$V_{oc\,\text{dusty}}/V_{oc\,\text{clean}}$
0	36.60	91.30
10	37.39	89.70
20	35.60	94.58
30	50.63	94.93
40	84.74	96.97

circuit currents were below 1 A for angles 0°, 10°, 20°, 30°, and the current rose above 1.5 A at 40°. This is due to the reduction in dust density over the panel.

- The average power ratio was between 45.19–52.63% for 0°to 30° tilt angles. For 40°, the ratio of average powers for the clean and dusty panels was quite different.
- The ratio of dusty to clean panel efficiencies is minimum at the tilt angle 20°, and no correlation was observed for this.

Table 4: Ratio of average powers and efficiencies of dusty and clean panels under natural conditions.

Tilt angle (°)	Ratio of efficiencies (%)	Ratio of average powers (%)
	$\eta_{dusty}/\eta_{clean}$	$P_{av\,\mathrm{dusty}}/P_{av\,\mathrm{clean}}$
0	41.99	52.57
10	42.79	52.63
20	29.80	45.19
30	34.15	46.03
40	90.59	86.47

5 Conclusions

The study was done to provide early insight into the effects of collected dust on the photovoltaic (PV) panel performance. The study describes the indoor controlled and outdoor natural conditioned experimental setups. The experiment yields the current-voltage characteristics curves for various tilt angles, temperatures and insolation levels, i.e., 500 W/m^2 indoors and 950 W/m^2 outdoors. The investigation was carried out on two similar panels, and a thorough analysis was conducted to determine the impact of dust accumulation on the panel performance. The monitored panel temperature was found to increase in dust accumulated PV panels, more in the natural open-air conditions than in the indoor conditions. The contaminated panel's short circuit currents were greatly decreased, whereas the open-circuit voltages had only slightly reduced values. The efficiencies and average powers of dusty PV panels were found to significantly decrease with respect to clean panels. The collection of airborne dust particles significantly lowers the optical transmittance of solar cell glazing.

The density of dust sitting over the panel with the particle dimensions and colour can be considered for future work. The dimension of the polydisperse particles with scanning electron microscopy and transmission electron microscopy can be useful in analysing the behaviour of the dust particles, which can be further used in designing the cleaning methodologies for specific locations. The horizontal panels amass dust with a high particle density. Panels with dust deposition suffer from substantial power loss, causing massive solar power-producing houses to suffer from electrical and economic power loss. The generation must be kept running by cleaning the panels regularly. Cleaning at regular intervals with self-cleaning technology may be implemented with solar panels to achieve optimal transmission through solar cell glazing. Because urban regions are more prone to pollution, it is recommended to employ auto-cleaning technologies to obtain optimal energy conversion efficiency from solar panels. The location of the site determines the frequency of cleaning.

Acknowledgements

The indoor experimental research work was conducted at the National Physics Laboratory, Delhi in the simulated environmental parameters – temperature, light intensity and tilt angles.

Received 7 February 2023

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