# EXPERIMENTAL STUDY TO ANALYSE THE IMPACT OF DUST ON THE PERFORMANCE OF PHOTOVOLTAIC PANEL

[1*]Minakshi Katoch, [2]Nitai Pal
[1] Department of Electrical Engineering,
Indian Institute of Technology (Indian School of Mines), Dhanbad, 826004, India
[2] Department of Electrical Engineering,
Indian Institute of Technology (Indian School of Mines), Dhanbad, 826004, India
* E-mail:minakshi2224@gmail.com

**Abstract:** Solar radiations are the free source of energy. The terrestrial radiations available in earth surface ranges between 0.29µ to 2.5µm are available for the energy generation from the solar cell. Photovoltaic generation is the most popular in renewable energy sources. Its installation has gained the speed in the last decades. The experimental investigation performed to study the power output response of the photovoltaic panels during the dust depletion. The performance of the PV panels gets profoundly impacted by the sand storms, pollution level, and snow accumulations. These challenges lower down the efficiency of the solar panels. The experimental study has been carried out on the dust accumulated and dust free, two identical panels. The assessment carried out in two different conditions on the off-grid stand-alone system: simulated atmosphere and under the open air in the day time. The I-V curves have been drawn for both the panels at different tilt angles. The characteristics provide sufficient information for analyzing the performance of considered panels. The observations have shown that the average output power and short circuit current reduces drastically as dust accumulates over the surface of the panel. The installation tilt angle showed an impact on the ratio of efficiencies and average power outputs of dusty and clean panels. The open circuit voltage parameter acted nearly inert in both the conditions. The experimental comparison of the clean and dusty panels for the natural and simulated conditions is carried out and is discussed in the paper.

**Keywords:** Dust Accumulation, Photovoltaic, Tilt angle.

## I. Introduction

Over the recent past decades, the steady growth in the installed capacity of power generation by solar photovoltaic has been observed all over the globe. Photovoltaic generators produce clean energy which extensively uses solar energy and converts that into electrical energy. The advancements in technology, ecological, and inexpensive aspects have attained lots of special attention from governments, investors, and researchers. Several studies and research work 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 generator in the deserted area: are 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, 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 a PV system leads to a reduction in the transmission coefficient, which significantly results in the drop in energy conversion efficiency. In the PV literature, the concern for the problems that occur due to dust and sand have been discussed. In Saudi Arabia, the study by Salim et al. (1988) prepared a PV experimental set up at a rural community near Riyadh, to analyze the impact of the deposition of dust on the energy output of PV. For the array installed at 24.6 degrees, the monthly energy drop for the dirty array was measured, and its performance compared with an identical panel, which was cleaned every day. In eight months, the dirty array had shown the energy output reduction of 32%. In the study, any parameters about the dust level of the experimental site and properties of dust are not considered. The experimental study by Hassan et al. (2005) provided information that the degradation was fast for the period of the first one month and found the reduction of 33.5% in efficiency. It was analyzed by Rehman and El-Amin (2012), Al Hanai et al. (2011) and Cabanillas and Munguía, (2011) that the dust deposited on the module cover may cause to a significant reduction in the performance of PV. The observations showed that in Saudi Arabia in one month 5 %, Abu Dhabi, UAE in one month 1% and Hermosillo, Mexico in 20 days, 5.8% reduction was recorded. PV system is largely depended on the site location and weather conditions. In Colorado by Boyle et al. (2015) and Egypt by Hegazy (2001) dust accumulation rate of 1–50mg/·$m^2$·/day and 150–300mg/$m^2$/day is reported with visible variation, which is specifically due to the variable weather conditions. In one more similar experimental set by Garg (1974) found the transmittance of direct solar radiation through the cover of PV and measured that over 30 days, the transmittance reduced by 60% for a horizontally mounted solar panel. The same investigations by Sayigh et al. (1985) were done in Kuwait and observed 64%, 48%, 38%, 30% and 17% of reduction in the glass plate transmittance after 38 days of disclosure to the environment at tilt angles of $0^0$, $15^0$, $30^0$, $45^0$ and $60^0$, respectively. In this case, the investigation was done on the dirty and clean panels on different days. Probably the complete experimental study in a laboratory set up by El-Shobokshy and Hussein (1993) the soiled PV panels with different types of dust and then measured the output of PV under various conditions. The analysis may be done from the research that the effect of dust on the output of PV cells no longer be related to the open air exposure time duration for a given location as recommended by many investigations. The results indicate that the parameters such as dust particle size, material, density, and distribution of deposited dust have a substantial impact on the reduction of output power from the PV panels. In this case, the experiment was conducted, and all the PV surfaces were covered with dust under unnatural conditions with zero wind speed. But under the natural situation, wind considerably affects the sedimentation of dust coatings on horizontal PV surfaces. In one of the investigations by Hottel and Woertz (1942), researchers conducted three months analysis of solar panels fixed at a tilt angle of $30^0$ in an industrial area, which was 92 meters away from the train track. From the experimental analysis, they analyzed that due to dust net reduction in performance was 4.7%, and from the calculations, a reduction of 2.7% has been observed in glass transmittance. They endorsed these observations for the self-cleaning action. Similarly, the data by Dietz (1963) gathered for tilt angles between $0^0$ and $50^{0,}$ and due to the dirt depletion, a fall of 5% in solar radiation reaching the collector was observed. These findings were confirmed by Michalsky et al. (1988) the investigations, which were conducted for two months in New York on two pyranometers, one cleaned daily, and the second one was never cleaned. The observations have shown that dirty pyranometer had 1% fewer values than clean pyranometer. The above studies indicate that the consequences of the deposition of dust on the glass covers of solar panels had not gained much attention, particularly in countries with desert locations and dusty climates. On the other hand, the partially available studies do not give adequate information about the dust deposition rate in the test site and also did not provide information about the physical properties. Therefore, sufficient data is required to design and to take a broad view of the drop in the performance of solar PV cells due to the accumulation of dust. The various types of PV modules had been investigated in different weather conditions. Furthermore, the impact of cooling on the PV electrical output is studied in Pakistan by Bashir et al. (2016) to have an insight into performance analysis. The deposition of dust is a challenge in the looming deployment of PV systems by Javed et al. (2017), Adinoyi and Said (2013) during the dust storm, the output of PV modules can drop up to 20%. Thus, the investigation shows that 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. (2017). had shown that coarser size dust particles as compared to fine, impacts less the performance of PV panels. The dust particle size, chemical properties, and thickness have been studied for a better understanding of physicochemical properties of deposition of dust. For the study of the impact of dust sedimentation on the PV performance; some work has been done to unearth the influencing parameters. The results had shown 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 sited in the environment. It could elucidate that deposition rate significantly affects the lessening of efficiency, is majorly dependent on the weather conditions. Most recent, broad, and accurate experimental studies have been conducted and reported by Darwish et al., (2016) the impact of variable temperature dust particles, in the dust accumulation process on solar PV panel. The comprehensive and satisfactory studies were conducted under unnatural weather in the controlled laboratory conditions. But natural weather environment has an enormous impact on dust accumulation; it is a tedious job to simulate and to take account of all the variables. So to attain better simulation of the natural environmental conditions Tehran, researchers performed the study under the outside natural conditions. The middle east countries like Iran has a massive solar generation perspective, but the dust deposition is an unavoidable circumstance. The performance and energy conversion in PV are dependent on different environmental factors solar irradiance, installation tilt angle, and wind direction by Cabrera-Tobar et al., (2016). The studies powerfully depict that the clouds of dust on the modules are a significant cause for the reduction in the efficiency, particularly in the sand storm and polluted areas. Therefore, the cleaning of PV surface is essential and crucial for maintaining the operating efficiency at a high level in the desert region. There are several studies done on the dust accumulation on 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. Moreover, the dust size, composition, and effect have been carefully investigated by Sanusi (2012). The necessity of cleaning the dusty or polluted module glass covers is observed in various studies, but the cleaning issues remain a concern in desert regions where 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 of dust from the PV module glass covers has been minimal.

## II. Experimental Set up

The measuring techniques were utilized to get current-voltage curves from two similar PV panels, one panel is perfectly clean, and the other polluted with dust. In the primary consideration, both the panels set under controlled indoor unnatural conditions in the laboratory. The tilt angle varied, and I-V qualities have been recorded. In the second consideration, panels are put in the natural habitat in outdoors under natural daylight — the aim of the study to analyze the PV performance with the changing tilt angle and dust. In the indoor and outdoor conditions, the identical panels are either subjected to different ambient conditions and dust depositions. The dirt deposited on the PV surface depends on various parameters, which include installation tilt angle, physiological characteristics of dust, and the local atmosphere. In general, the optimal angle for installation of PV surface, which receives maximum direct radiations is highly dependent on the global position of the location. However, the best installation angle varies with the seasons and sun positions, but regular adjustment of angle is uneconomical. Therefore a for engineering applications, the best tilt angle took is approximately equal to the local altitude. In the study to examine the dust deposition impact at five various tilt angles ($0^0$,$10^0$, $20^0$, $30^0$, $40^0$) have been considered. The indoor test setup has two comparable panels, one next to the other, mounted parallel to ground. The arrangements are made to change the intensity of the sun simulating lamps, set over each panel. The tilting edge might have differed, and the temperature of the panels can be controlled.

The characteristics I-V plotted using a data logger interfaced with panels. Tenmars solar power measuring device is used to measure the intensity of lamps over the panel. In the indoor experimental set up the lamp intensity kept at 500w/m$^2$. The temperature of the solar module was measured from the back with the platinum resistance thermocouple PT100. The cell operating temperature maintained during the experiment between 35$^0$C to 42$^0$C. The fans controlled the panel temperature provided for the cooling at the back of the solar modules. The reading of voltage and current recorded for the various tilt angles. The I-V curve obtained for both the panels. During the dust simulation sand taken as the dust particle. The dust spread over the panel non-uniformly, which covered 80% of the surface area. As the tilt angles varied above 20$^0$ at 30$^0$ and 40$^0$, 5.1% and 15.75% sand dropped on the floor from the panel.

Outdoor experimental test arrangements installed at a Gurugram location roof-top(latitude 28.45°N, longitude 77.02°E). The test had a roof mounted polycrystalline PV panels with no shading effect, which had installed in adjustable tilt angle parallel to the ground surface facing towards 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$^0$ to 65$^0$. The dust with non-uniform distribution covering density was set up in the experimentation. During the experimentation the insolation level was 950W/m$^2$ , the atmospheric temperature was 43$^0$ C, and wind speed was 9.3Km/hr.

## III. Results and discussions

In the unnatural environmental conditions, the temperature, lamp intensity, and angle of installation controlled for the comprehensive investigation. One panel with dust accumulated and the other with the absolutely clean surface is examined. The recording of readings started from 0$^0$ tilt angle at intensity 500W/m$^2$ and temperature 35$^0$ C. The I-V curves plotted for the initial tilt angle. The tilt angle was increased in steps of 10$^0$ starting from 0$^0$ and raising up to 40$^0$. The readings were recorded when the module temperature was between 35$^0$ C to 42$^0$ C. The I-V curves for the two panels under study have been drawn in figures 1-5 respectively.

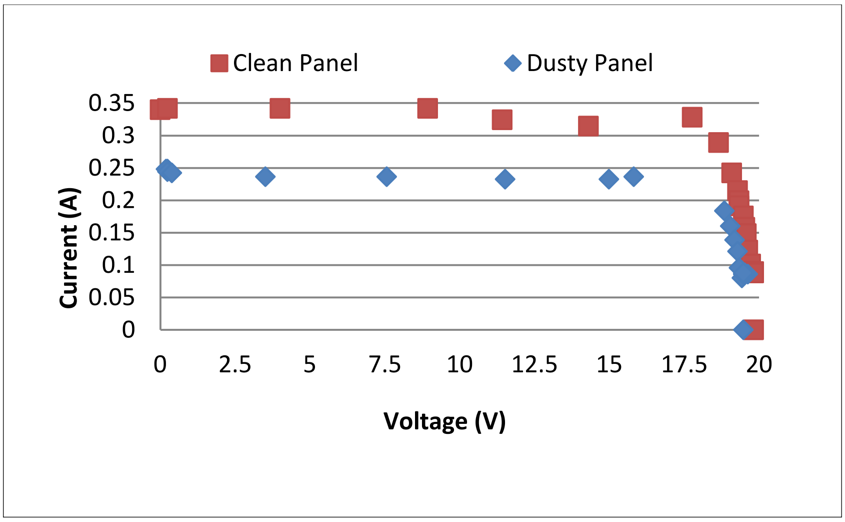

Fig. 1: I-V characteristics at $0^0$ in laboratory conditions

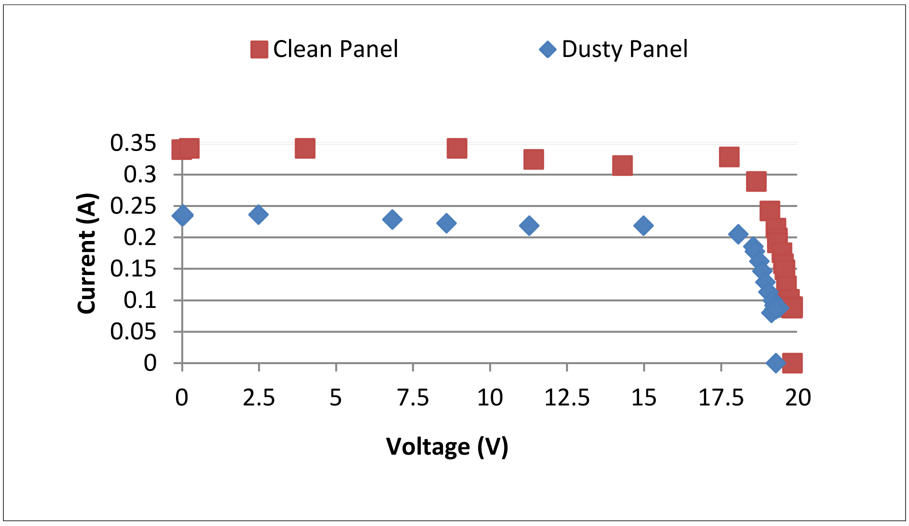


Fig. 2: I-V characteristics at $10^0$ in laboratory condition

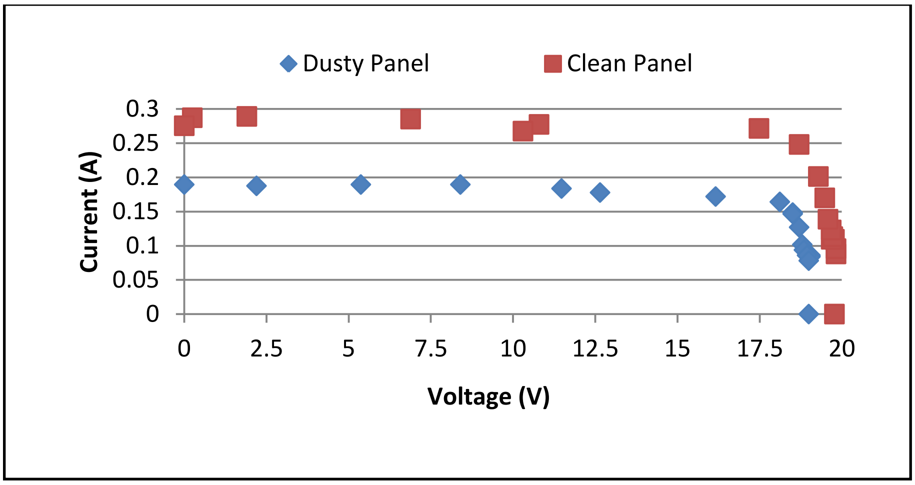


Fig. 3: I-V characteristics at $20^0$ in laboratory condition

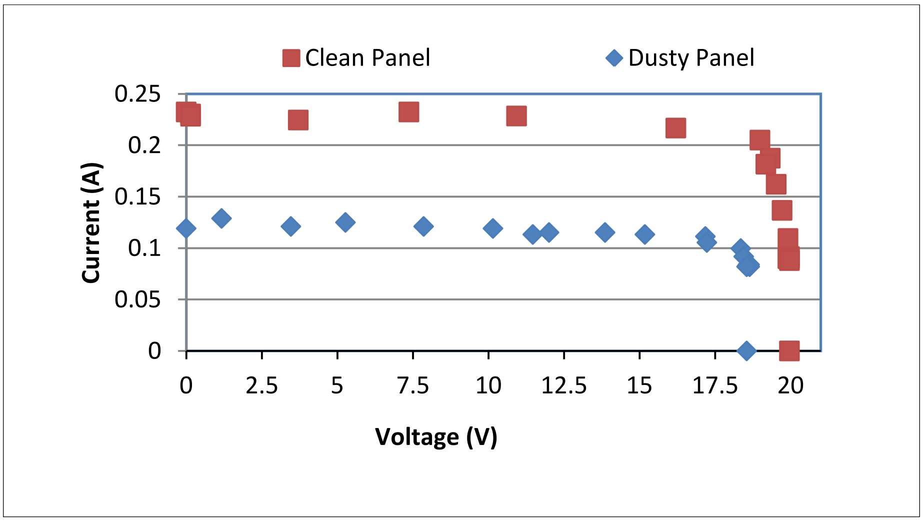

Fig. 4: I-V characteristics at $30^0$ in laboratory condition

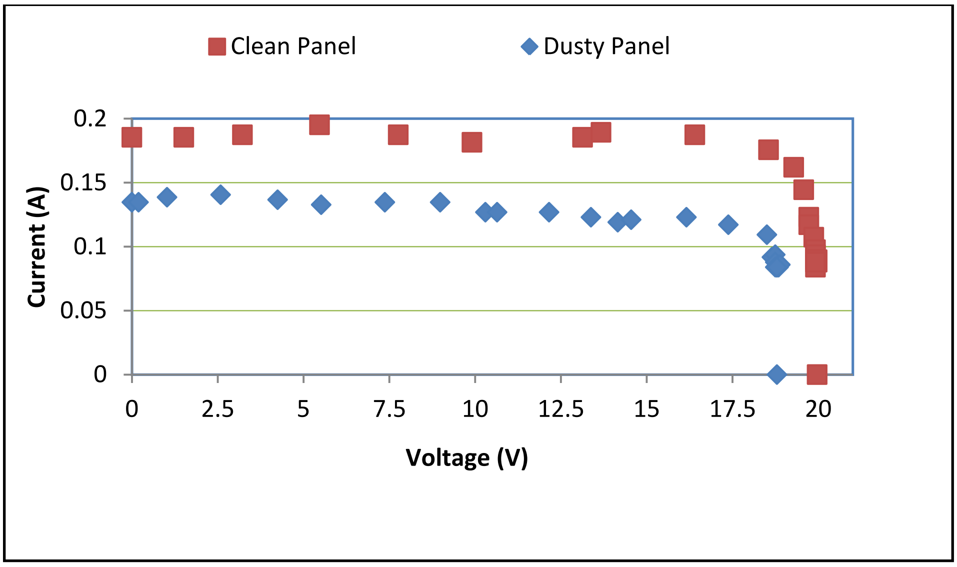


Fig. 5: I-V characteristics at in laboratory condition

The readings from the panels under investigations noted at different tilt angles. Table 1 give the various parameters, including the voltages and currents. The following conclusions can be drawn:

- Sand deposited panels observed with $2^0$C to $7^0$C higher operating temperatures than the sand free panels under the same insolation level.
- The sand spread over the panel was non- uniformly distributed with the density of 12.5g/m$^2$ at zero degrees tilt angle. As every tilt angle increased the sand density at $40^0$ was 10.5 g/m$^2$. The average power loss for the given sand density is 38% to 24%l.
- It may be observed from the various graphs that accumulation of dust does not have a high impact on the open circuit voltage. The ratio of open circuit voltage varied from 93.39% to 99.52%. The open circuit voltage of the clean panels and sand accumulated panels were nearly the same. The voltage difference is visible at angles above $10^0$; the impact may because of the increase in the module temperature.
- The short circuit current ratio varied from 54.06% to 72.57%. The dust deposited on the panels gives a higher difference in short circuit current ratios, then the open circuit voltage ratios. The graphs show that sand has a sizable impact on the short circuit current. The ratio decreased with the increase in angle but at last angle it suddenly increased. It may be due to the temperature increase , dust density over the panel reduced by 15.75% due to the gravity and radiation responsible for the generation are more available on the panel.
- The ratio of efficiencies of dusty and clean panels is minimum at $30^0$, but no such correlation found for this.

Tab. 1: Ratio of open circuit Voltage, short circuit current, Average Powers and Efficiencies under controlled indoor conditions

| Tilt angle | Solar Module Temperature ($^0$C) | Ratio (Short circuit Current %) | Ratio (Open Circuit Voltage %) | Ratio of Efficiency (%) | Ratio of Average Power (%) |
|---|---|---|---|---|---|

-6-

| | Clean | Dusty | $I_{scdusty}$ / $I_{scclean}$ | $V_{ocdusty}$/ $V_{oclean}$ | $\eta_{dusty}/\eta_{clean}$ | $P_{avdusty}$/ $P_{avclean}$ |
|---|---|---|---|---|---|---|
| 0 | 35 | 35 | 72.57 | 99.52 | 64.14 | 64.14 |
| 10 | 37 | 35 | 69.14 | 97.78 | 63.56 | 63.56 |
| 20 | 35 | 39 | 66.89 | 95.58 | 62.63 | 62.63 |
| 30 | 37 | 42 | 54.06 | 93.39 | 49.12 | 49.12 |
| 40 | 37 | 40 | 72.00 | 94.62 | 62.67 | 62.67 |

The experiment under natural conditions conducted at the rooftop of the building in the April month in Gurugram. The sand spread artificially over the panel was non-uniform. The sand density was nearly equal. The two panels kept parallel to 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 $40^0$ - $45^0$C. The solar cell had seen a temperature difference of approximately $10^0$ C. The load is varied to get I-V curves at different tilt angles, and the graphs had been shown in figures 6-10.

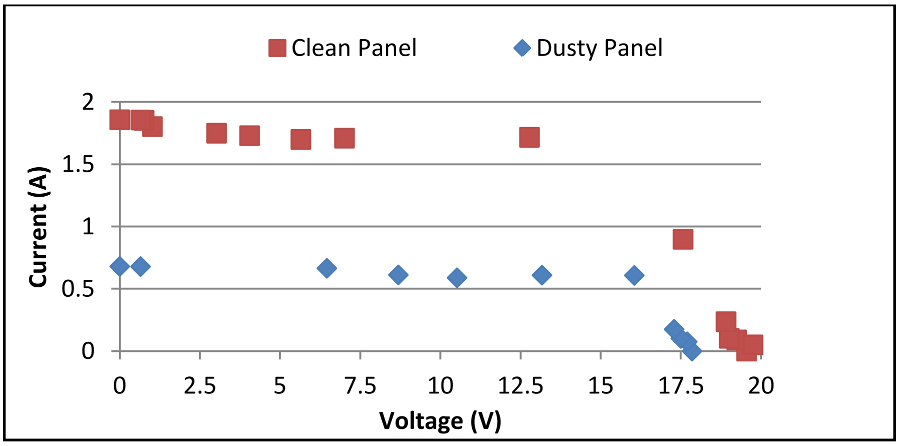


Fig. 6: I-V characteristics $0^0$ in natural conditions

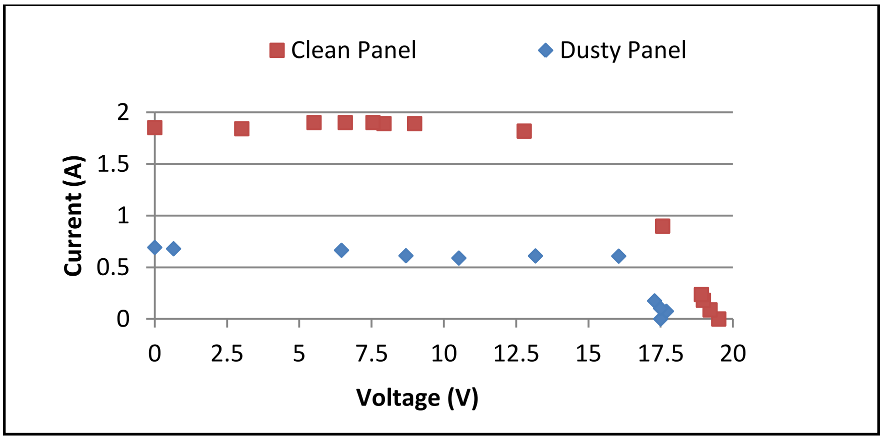


Fig. 7: I-V characteristics at $10^0$ in natural conditions

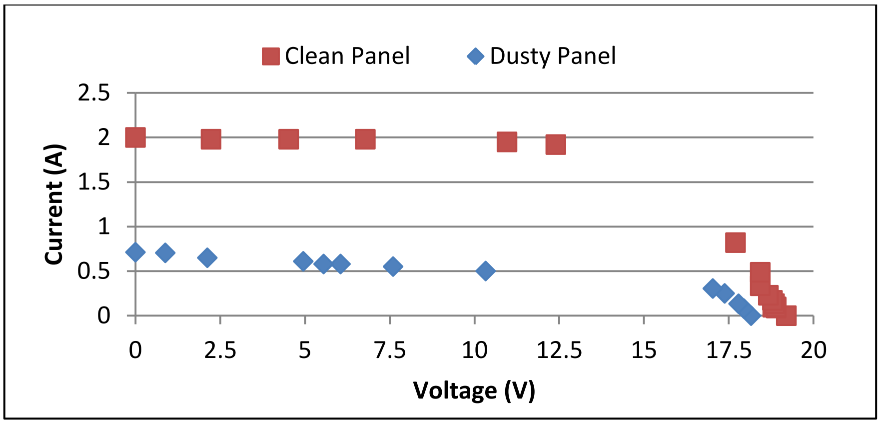


Fig. 8: I-V characteristics at $20^0$ in natural conditions

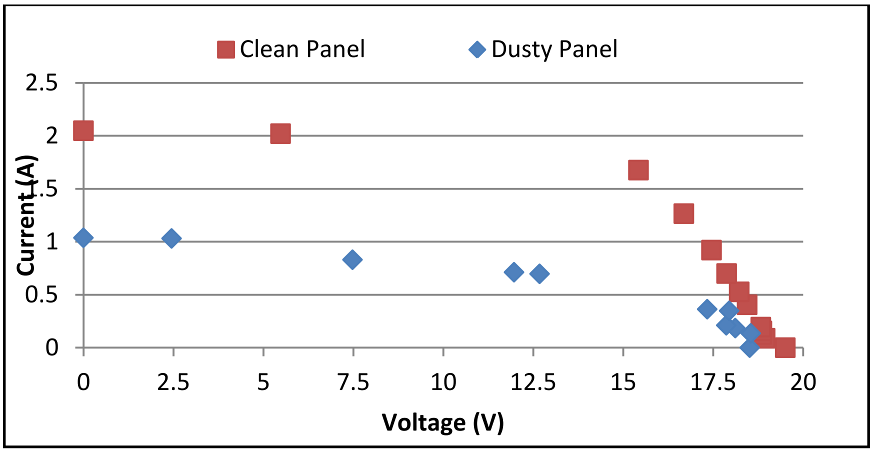


Fig. 9: I-V characteristics at $30^0$ in natural conditions

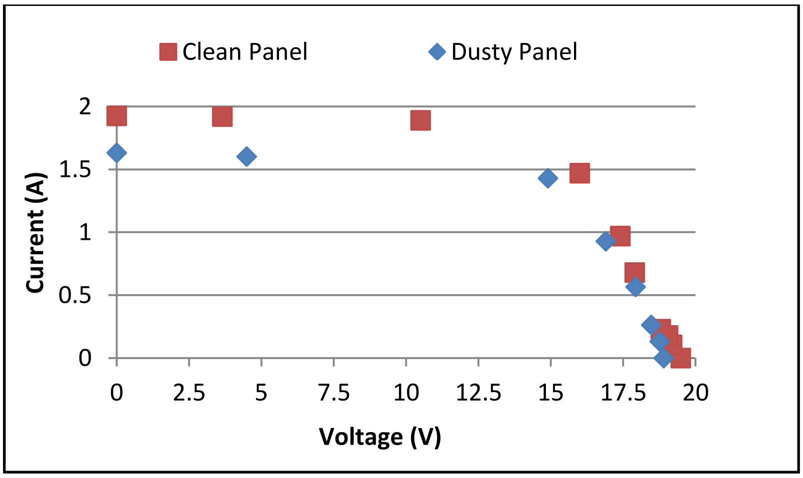


Fig. 10: I-V characteristics at $40^0$ in natural conditions

From the observations of two panels under study, the ration of short circuit currents, open circuit voltage, efficiency, and average power had been calculated in table 2. The outdoor experimentation was conducted at different insolation level. From the observations following points are noticed:

- The non-uniform distribution of sand had not impacted the open circuit voltage ratio very strongly. The ratios of open circuit voltage of dusty panel to open circuit voltage of clean panel lied between 89.70% to 96.97% for the experimental set up under study.
- A sizeable impact of sand accumulation had seen in short circuit currents of with sand and sand free panels. In natural conditions, solar radiations have an adverse effect on the short circuit currents. In the clean panels, the short circuit currents were almost constant, i.e., below 2A for $0^0$ and $10^0$, at $20^0$, $30^0$ and $40^0$ were approximately constant. In the sand deposited panel short circuit currents were almost constant, i.e., below 1A for angles $0^0$ , $10^0$, $20^0$ and $30^0$ the current rose above 1.5A at $40^0$. It is due to the reduction in dust density over the panel.
- The average power ratio lied between 45.19- 52.63% for $0^0$ to $30^0$ tilt angles. For $40^0$ the values of average powers for the clean and dusty panel were at a little difference.
- The ratio of efficiencies of dusty to clean panel is minimum at tilt angle $20^0$ and no correlation observed for this.

Tab. 2: Ratio of open circuit Voltage, short circuit current, Average Powers and Efficiencies under controlled indoor conditions

| Tilt angle | Solar Module Temperature ($^0$C) | | Ratio (Short circuit Current %) | Ratio (Open Circuit Voltage %) | Ratio of Efficiencies (%) | Ratio of Average Power (%) |
|---|---|---|---|---|---|---|
| | Clean | Dusty | $I_{scdusty}$ / $I_{scclean}$ | $V_{ocdusty}$/ $V_{oclean}$ | $\eta_{dusty}/\eta_{clean}$ | $P_{avdusty}$/ $P_{avclean}$ |
| 0 | 45 | 46 | 36.60 | 91.30 | 41.99 | 52.57 |
| 10 | 47 | 48 | 37.39 | 89.70 | 42.79 | 52.63 |
| 20 | 47 | 50 | 35.60 | 94.58 | 29.80 | 45.19 |
| 30 | 51 | 55 | 50.63 | 94.93 | 34.15 | 46.03 |
| 40 | 51.9 | 55.6 | 84.74 | 96.97 | 90.59 | 86.47 |

## IV. Conclusions

The current study conducted to have the preliminary insight of accumulated dust on PV panel performance. The investigation presents the indoor controlled and outdoor natural conditioned experimental setup. The experimentation results in I-V characteristics at the different tilt angles, temperatures, and insolation levels, i.e., 500W/m$^2$ for indoor and 950W/m$^2$ for outdoor. The study was done on the two identical panels; a comprehensive analysis has been done to get the impact of the performance of dust.

It can be concluded from the characteristics that

- open circuit voltage ratio was not much influenced by the dust, tilt angle, temperature, indoor, and outdoor conditions.
- The short circuit current ratio got the significant effect of the factors dust, tilt angle, temperature, and most importantly, insolation levels.
- The difference in outdoor conditioned short circuit currents, i.e., between dusty and clean panel is higher than the difference in indoor conditioned short circuit currents for the same tilt angles.
- In the indoor conditioned ratio of efficiencies is a constant line with a little sag at $30^{0,}$ and

after that, it increases again. In the case outdoor conditions line is constant for the initial $10^0$ and after that sudden increase is followed by the sag at $20^0$ as shown in figure 12.

- In the indoor conditions ratio of average power is a constant line with a little swell at $30^{0,}$ and again, it becomes a constant line. In the outdoor conditions, a constant relation is observed between the sand and dusty panel, as shown in figure 11.
- The indoor and outdoor results differ from each other may be due to the insolation level dissimilarity.
- The results observe at angle $20^0$ for the considered ratios has changed due to the incident angle of radiation taken in both the conditions.

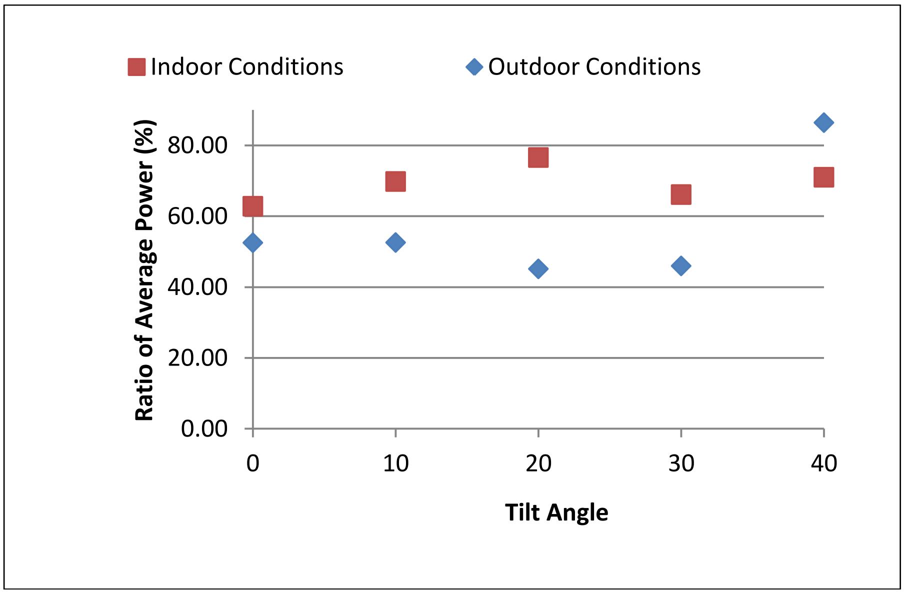


Fig. 11: Average power ratio at different angles

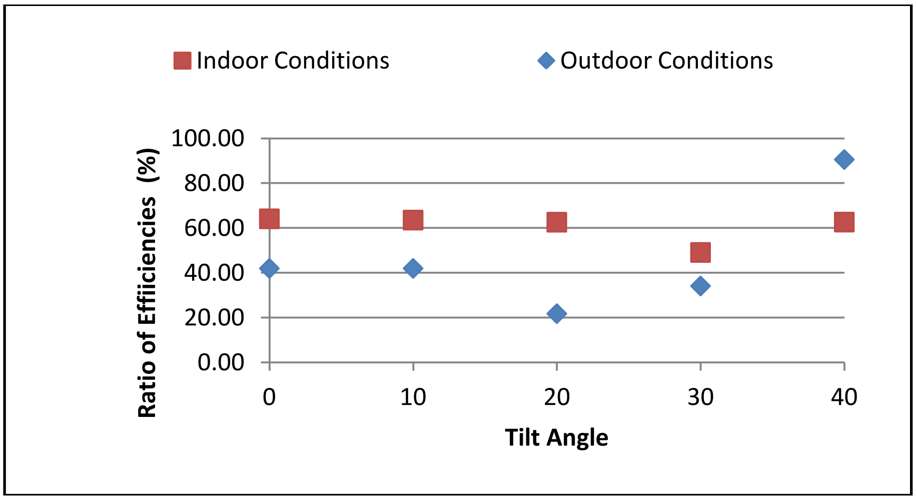


Fig. 12: Ratio of Efficiencies at different angles

The horizontal panels get accumulated with high dust density of particles. The panels with dust sedimentation have high power loss, which can make gigantic solar power generation houses suffer from electrical and economic power loss. The regular cleaning of panels is required for maintaining the generation. The cleaning frequency is dependent on the site location.

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

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