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Performance Evaluation of PV Panel Under Dusty Condition

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ABSTRACT. The performance of PV panel depends on the incoming sunlight on its surface. The accumulated airborne dust particles on panel surface creates a barrier in the path of sunlight and panel surface, which significantly reduces the amount of solar radiation falling on the panel surface. The present study shows a significant reduction in short circuit current and power output of PV panel due to dust deposition on its surface, whereas the reduction in open circuit voltage is not much prominent. This study has been carried in the field as well as in the laboratory. The reduction in maximum power output of PV panel for both the studies ensures a linear relation with the dust deposition on its surface. In the field study, the reduction in the power output due to 12.86gm of dust deposition on the panel surface was 43.18%, whereas in the laboratory study it was 44.75% due to 11gm of dust deposition.

Keywords: Dust, Photovoltaic, Power Output, Short circuit current, Open circuit voltage

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1. Introduction

The production of electrical energy is based on fossil fuels, nuclear and renewable energy sources. Among these, the renewable energy sources are considered as clean and environmental friendly energy source. There are different types of renewable energy sources, such as hydro, geothermal, biomass, wind and solar. Solar energy experienced a rapid growth and popularity in the last one decade because of its huge advantages, like availability of raw material, no emission of pollutants, can be used in remote areas, not generate noise problem and easy to install. Therefore, Solar energy is the most promising and vital energy source to produce electricity in a current scenario (Bayod-Rújula, Ortego-Bielsa, & Martínez-Gracia, 2011; Chueco-Fernández & Bayod-Rújula, 2010; Mekhilef, Saidur, & Safari, 2011; Oliver & Jackson, 2001). The Photovoltaic (PV) panel is a part of solar energy that converts solar radiation energy (solar energy) into electrical energy (Goetzberger, Hebling, & Schock, 2003). Whenever sunlight strikes on PV cell surface, which is made up of silicon type semiconductors, it separates electron-hole pairs inside the semiconductor material. This separation of electron-hole pairs inside the semiconductor material is the main cause for electrical power generation in solar photovoltaic system. The PV panels are operated in an open atmosphere, where it experiences a significant variation due to environmental parameters, such as wind speed, ambient temperature, solar radiation, humidity and dust pollutants (Jiang, Lu, & Sun, 2011). These environmental parameters affect the performance of PV panel in an open atmosphere. Among these parameters dust plays a significant role in reducing the performance of PV panel (Saidan, Albaali, Alasis, & Kaldellis, 2016).

The deposition of dust on PV panel surface is the main cause for its performance degradation (Adinoyi & Said, 2013; Klugmann-Radziemska, 2015; Mani & Pillai, 2010). Dust creates a barrier between PV panel surface and sunlight falling on its surface, which attenuates the part of the incoming sunlight (Kaldellis & Kokala, 2010, 2010). The attenuation of sunlight depends on the size of dust, density of dust and type of dust (Darwish, Kazem, Sopian, Al-Goul, & Alawadhi, 2015; Khatib et al., 2013). This attenuation of sunlight considerably reduces the performance of PV panel (Al-Hasan & Ghoneim, 2005; Sulaiman, Singh, Mokhtar, & Bou-Rabee, 2014). It was found that due to dust deposition on panel surface the power generation

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capacity and conversion efficiency of PV panel reduces up to 92.11% and 89%, respectively (Rajput & Sudhakar, 2013). A study shown, that the reduction in glass transmittance is ranging from 12.38% to 52.4% for 4.48 to 15.84 g/m^2 of dust deposition (Elminir et al., 2006). One more study reported that the reduction in conversion efficiency of PV panel due to dust deposition were 10%, 16% and 20%, respectively for 12.5 g/m^2, 25 g/m^2 and 37.5 g/m^2 dust density (Mohammad S. El-Shobokshy & Hussein, 1993).

The exposure time of PV panel in real atmospheric environment is even important for its efficient performance. Because the density of dust deposition on panel surface is also depends on exposure time other than the local climatic conditions of environment. It was found that the reduction in spectral transmittance and overall glass transmittance was 35% and 20% due to 5g/m^2 of dust deposition for 45 days exposure of PV panel in real atmospheric environment (Said & Walwil, 2014). Similarly, another study indicated that the reduction in glass transmittance of PV panel was from 90.7% to 87.6% after 33 days of its exposure into the outside environment (Hee, Kumar, Danner, Yang, & Bhatia, 2012). Further, one more study shown that the reduction in short circuit current and power output of PV panel was up to 28.6% and 30.6% after 12 days of its exposure into the atmospheric condition (M. S. El-Shobokshy, Mujahid, & Zakzouk, 1985).

Due to the fast industrialisation and urbanisation the effect of air pollution is becoming a very serious problem in the area of solar energy utilisation (Tian, Wang, Ren, & Zhu, 2007). As per the authors knowledge a very few studies have been reported w.r.t the effect of mass of dust deposition on the performance degradation of PV panel. In this regard, it is essential to study the effect of dust deposition on panel surface, especially in the dusty environment, at the time of installation.

In this paper the performance degradation of PV panel due to dust deposition on its surface is studied in the field as well as in the laboratory. The results obtained from both the studies (i.e. field and laboratory) have been compared and analysed to draw a scheme for systematic cleaning of panel surface in dusty environment.

2. Methodology

2.1 Field Study

The mine under study is located in Chitradurga District of Karnataka State, India. It is situated at the coordinate 14° 8' 55.4928" N and 76° 40' 1.1424" E. The site is enduring a good solar radiation profile throughout the year. During the sunny day (in the month of January) the peak solar radiation of 1180 W/m2 was recorded. Due to the high solar radiation, good atmospheric temperature (25ºC to 37ºC) and good wind profile (up to 4m/s) this site could be a good choice for the installation of PV plant.

To study the variation of solar radiation on panel surface at different tilt angle and time, a 100W polycrystalline solar PV panel was placed near the weather monitoring station, which is situated at 883m RL. The panel consists of 4 strings with 8 cells in each string (i.e. 8×4 cells). Solar radiation on the panel surface was measured using TM-207 solar power meter. The measurement was made from 9am to 5pm and the readings were taken at different tilt angle of the panel ranging from 0º to 90º (with horizontal), at an interval of 15º. For every tilt angle solar radiation was measured at each cell (in total 32 cells) and thereafter the average radiation falling on the panel surface was calculated. The variation in the pattern of solar radiation w.r.t the tilt angle at 12 noon is presented in Figure 1. Similarly, Figure 2 shows the typical variation in pattern of solar radiation with time at 30º tilt angle. As usual panel was kept facing towards south direction.

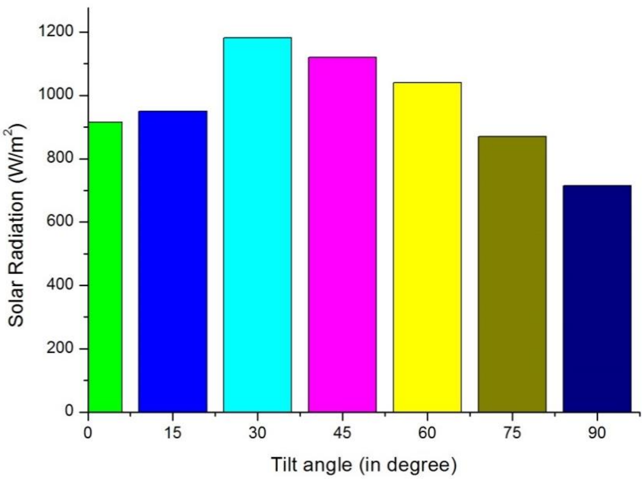
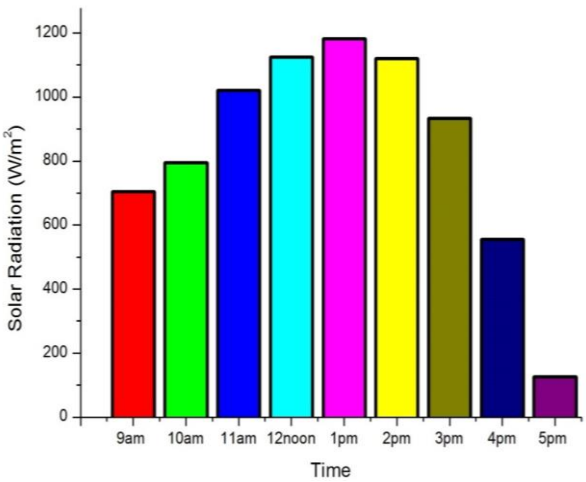


Fig. 1 Variation in solar radiation at different tilt angle at 12



noon

Fig. 2 Variation in solar radiation with time at 30º tilt angle

To study the effect of dust deposition on the panel performance, two identical 20W polycrystalline PV panels were installed near the weather monitoring station directing towards south and kept flat. The average solar radiation on these panels (for five days) was recorded as 1120 W/m^2. Among two panels one panel was kept dusty and other one was cleaned regularly. The electrical responses (i.e. power output, current and voltage) of both the panels were measured for five days using 320Ω rheostat and two digital multi-meters (one is used as ammeter and the other one as voltmeter of the circuit). The accumulated airborne dust particles on the panel surface were measured every day using fine filter papers (each of panel size) of known weight which were mounted near the panel. Table 1 gives the dust deposition on the panel surface for five days.

Table 1.
Dust deposition on panel surface

Day	Dust Deposition (gm)
First Day	2.58
Second Day	5.12
Third Day	7.69
Four Day	10.26
Five Day	12.86

2.2 Laboratory Study

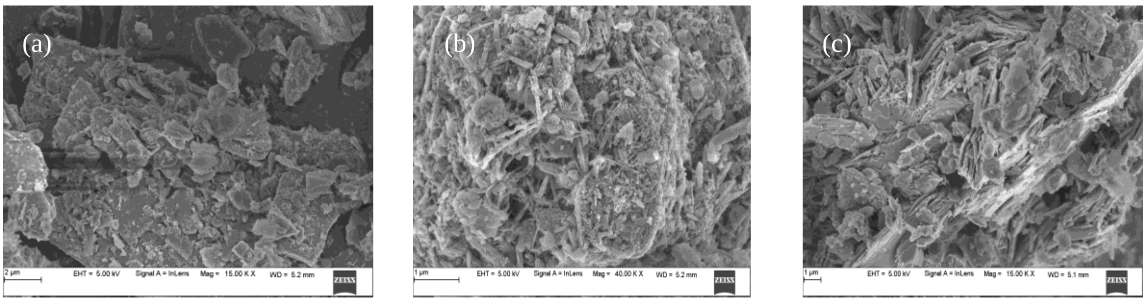
The laboratory experiments gives better control over the field study, as the laboratory experiment is carried out under the controlled environmental conditions, such as temperature, humidity, wind speed and solar radiation. In the laboratory study, a constant and required solar radiation could be generated with a set of solar simulators, which allows a comprehensive study of dust effect on PV panel performance.

In order to perform laboratory studies airborne dust particles were collected from the mines. The chemical and surface analysis of dust particles were carried out with the help of Energy Dispersive X-Ray (EDX) spectroscopy and Field Emission Scanning Electron Microscope (FESEM). A 20W polycrystalline solar PV panel was used for the laboratory study. The solar radiation during the study was maintained at 1082W/m2. The effect of dust on the panel performance was studied by uniformly spreading airborne dust which was collected from the mines on the panel surface and its electrical responses were measured for 3gm, 5gm, 8gm and 11gm mass dust distribution. This amount of dust was considered based on the field observation (Table 1), so as to make a glaring comparison between the field and laboratory studies.

2.3 Characterization of Reference Dust Particles

Surface morphology of dust particles

Field Emission Scanning Electron Microscope (FESEM) was used to examine the surface morphology of the collected dust from the mines. Figure 3 shows the FESEM images of collected dust samples with different magnification and orientation at acceleration voltage of 5kV. The images in the Figure 3 reveal that the surface morphology of the collected dust samples consists of plate, rod and agglomerated plate structures. From FESEM images it can be seen that the dust collected from the mines was dominated by very fine and silt particles. A study carried out by Sarver et al., have shown that the finer particle has a more significant effect in reducing the panel performance compared to coarser dust particles(Sarver et al, 2013).



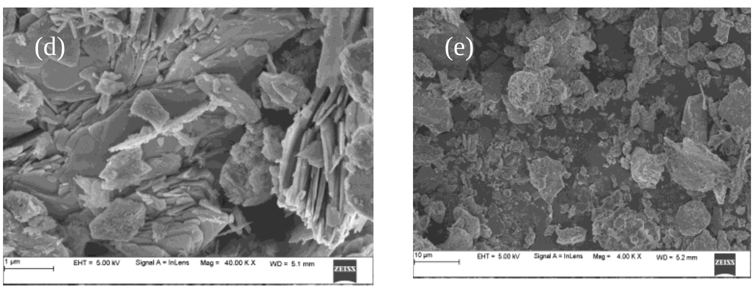


Fig. 3 FESEM images of the collected dust samples with the acceleration voltage of 5 kV and the magnification of (a) 15000x (b) 40000x (c) 15000x (d) 40000x (e) 40000x

Chemical composition of dust particles

Figure 4 shows the output of EDX spectroscopy which shows the chemical composition of collected dust samples. As per this analysis the major elements in the dust samples are oxygen, carbon and iron in the atomic percentage of 51.8%, 25.9% and 17.51%, respectively. In spite of this, the minor elements presents in dust sample are silica and aluminum with the atomic percentage of 2.7% and 2.09%.

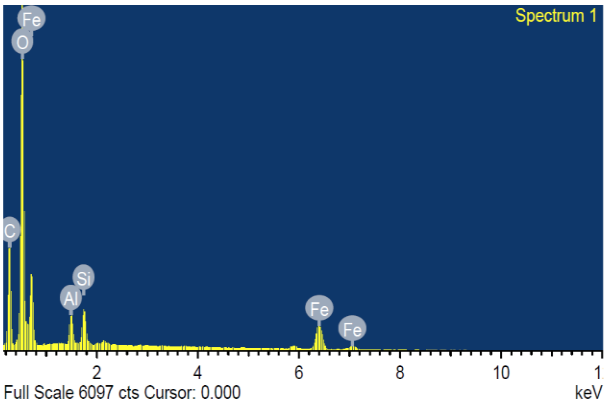


Fig. 4 Output of EDX analysis

3. Results and Duscussion

The effect of dust deposition on PV panel performance was studied in the field (under natural environmental condition) as well as in the laboratory (under controlled environmental condition). While performing the experiment in the laboratory as far as possible due attention was taken to replicate the field condition.

3.1 Field Study

The electrical responses of a clean and a dusty panel were recorded for five days and the readings of both the panels were compared to analyse the performance of PV panel under two different operating conditions (i.e. clean and dusty environment). Table 2 gives the measured electrical responses of both the panels for five days of observation. Based on the results as indicated in Table 2, the reduction in electrical responses of the panel due to dusty condition was calculated and presented in Tables 3. As observed from Table 3, the reduction in short circuit current (I_{SC}) and maximum power output (P_{MAX}) of a dusty panel compared to clean panel are respectively 39.58% and 43.18%, after five days of exposure. Similarly, the reduction in open circuit voltage (V_{OC}) of dusty panel is up to 4.35% with five days of exposure. This reduction in PV panel performance emphasize that the mitigation of open circuit voltage due to dust accumulation is meager when compared to short circuit current and maximum power output. The results of Table 2 and Table 3 dictate a severe and fast reduction in the performance of PV panel when it operates near the mine sites. Therefore, a frequent cleaning of panel surface is suggested for the PV panels which are located near the mines.

Figure 5 and Figure 6 shows the comparison of I-V and P-V characteristics of clean and dusty panel for all the five days of its exposure in the field. Based on the Table 3 the reduction in maximum power output (PMAX) of PV panel is plotted which is shown Figure 7. As highlighted in Figure 7 the reduction in maximum power output of PV panel increases as the number of days of exposure of panel into dusty environment increases.

The performance of PV panel in a dusty environment can be defined by the term normalised power output. The normalised power output of PV panel is the ratio of power output of dusty panel to the clean panel. It is denoted as PN and the percentage of normalised power output is given by the Equation (1). The normalised power output in the dusty environment indicates the performance of dusty panel w.r.t clean panel. The higher value of normalised power output indicates the good performance of the panel in dusty environment. The graphical representation of normalised power output w.r.t number of days of exposure of panel in the outside environment is presented in Figure 8.

$$P_N = \frac{P_d}{P_c} \times 100 \tag{1}$$

P_d = Power output of dusty panel
P_c = Power output of clean panel

Table 2.
Measured electrical parameters of two (clean & dusty) panels

Day	Clean			Dusty		
	V_{OC} (volt)	I_{SC} (amp)	P_{MAX} (watt)	V_{OC} (volt)	I_{SC} (amp)	P_{MAX} (watt)
1	20.62	0.65	8.82	20.37	0.53	6.84
2	20.51	0.51	7.96	20.06	0.45	5.32
3	20.57	0.60	8.51	19.80	0.43	5.47
4	20.60	0.80	10.94	19.77	0.53	6.53
5	20.65	0.96	13.38	19.75	0.58	7.60

Table 3.
Reduction in electrical responeses of dusty panel compared to clean panel

Day	Reduction in V_{OC} (%)	Reduction in I_{SC} (%)	Reduction in P_{MAX} (%)	P_N (%)
1	1.21	18.46	22.41	77.55
2	2.10	22.41	30.00	70.00
3	3.74	28.33	35.71	64.27
4	4.02	36.75	40.28	59.68
5	4.35	39.58	43.18	56.80

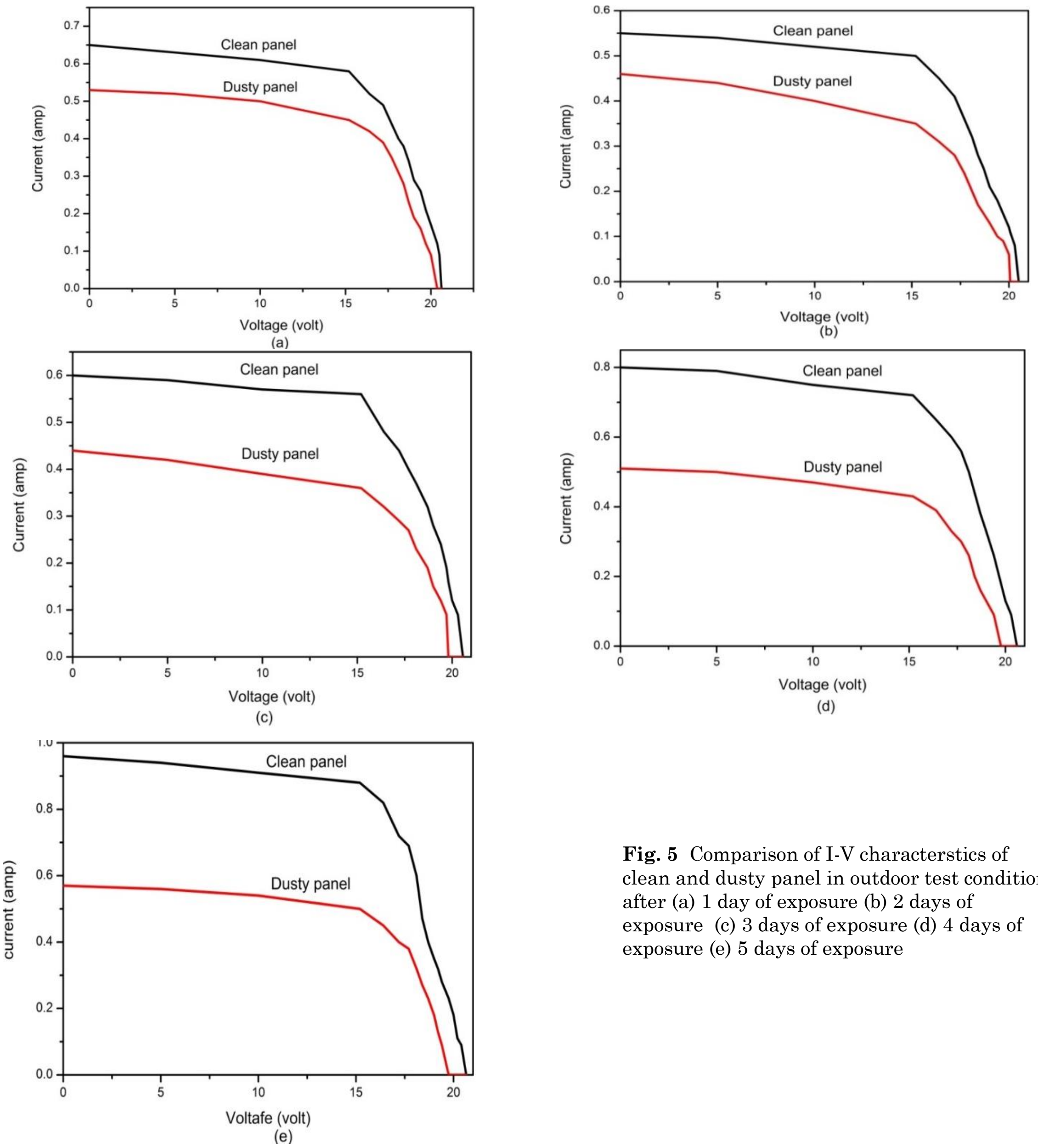


Fig. 5 Comparison of I-V characterstics of clean and dusty panel in outdoor test condition after (a) 1 day of exposure (b) 2 days of exposure (c) 3 days of exposure (d) 4 days of exposure (e) 5 days of exposure

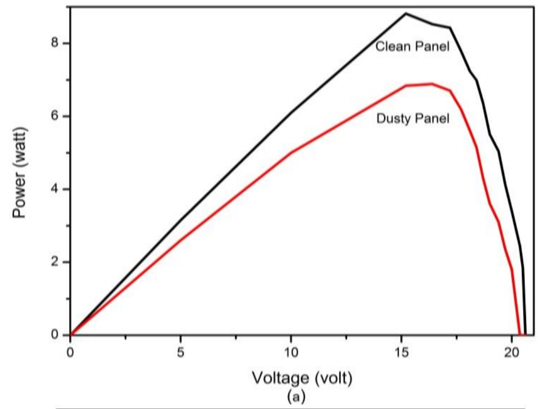
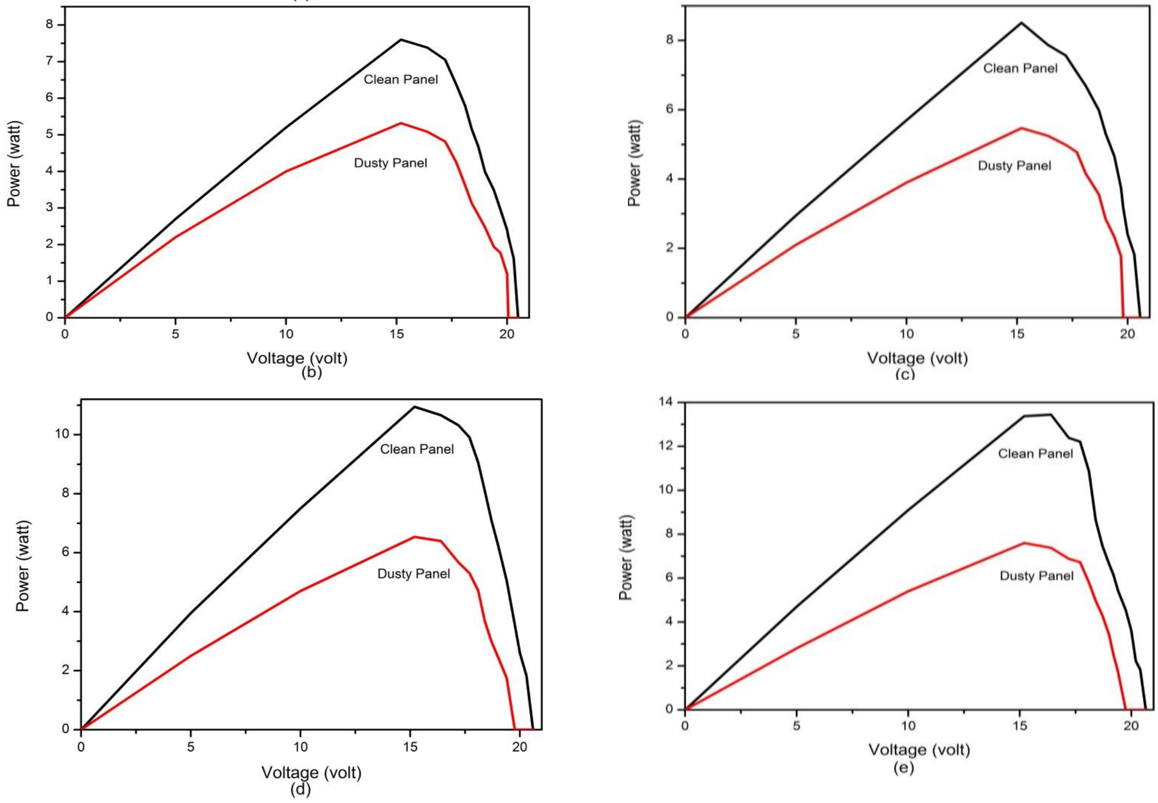


Fig. 6 Comparison of P-V characteristics of clean and dusty panel in outdoor test condition after (a) 1 day of exposure (b) 2 days of exposure (c) 3 days of exposure (d) 4 days of exposure (e) 5 days of exposure



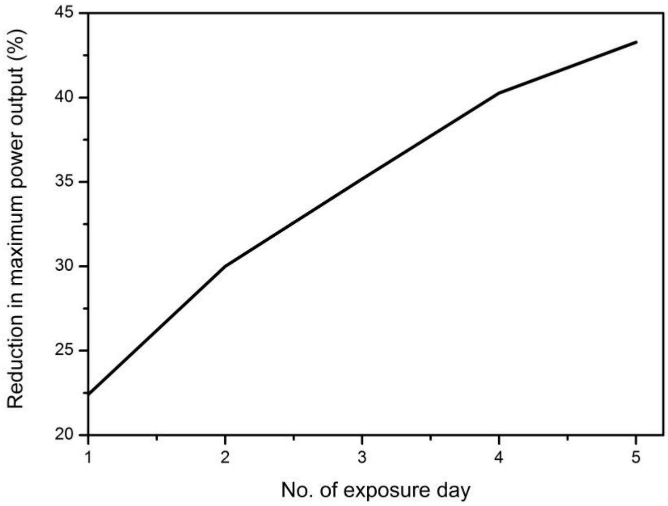


Fig. 7 Reduction in maximum power output of PV panel w.r.t number of exposure day

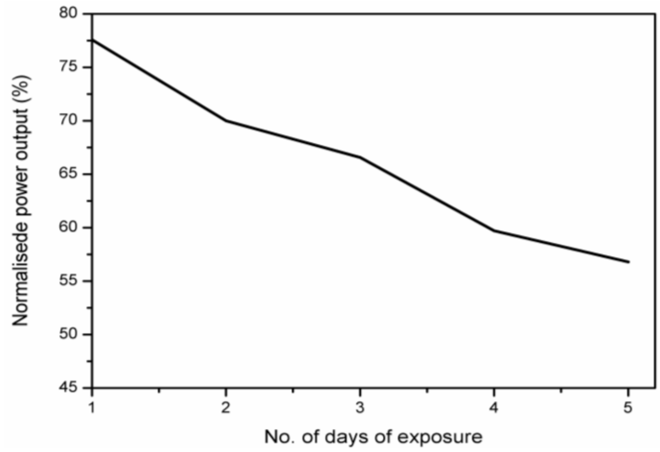


Fig. 8 Variation in the normalised power output w.r.t number of day of exposure

As depicted in Figure 8, initialy the reduction in the panel performance is predominant, where as it reduces gradually with the exposure time. There was a sudden decrease in the panel performance in the first day (i.e. 22.45%) which is evidenced by the steep gradient of the curve in Figure 8. The gradient of the curve gradually reduces with time, which represents a slow down in the reduction of panel performance. This is mainly happening due to overlapping of dust particles rather than settling on the panel surface. The reduction in maximum power output reduces with increases in deposition of dust on the panel surface.

3.2 Laboratory study

The electrical responses of a PV panel were recorded by varying amount of dust deposition on panel surface (based on field condition as shown in Table 1). Table 4 gives the measured electrical responses of the panel under varying dust deposition condition. Based on the recorded electrical responses the electrical characteristics are plotted, which are shown in Figure 9 and Figure 10. The reduction in I_{SC}, V_{OC} and P_{MAX} were calculated from Figure 9 and Figure 10, which are shown in Table 5. As indicated in Table 5, the reduction in short circuit current and maximum power output are respectively 40% and 44.75% with 11gm of dust deposition on PV panel surface. However, the reduction in open circuit voltage (i.e., 5.20%) was not found much significant when compared to short circuit current and power output. The reduction in panel performance was observed severe in laboratory compared to field study. This is because of the controlled environmental condition, (such as solar radiation, wind speed and temperature) and uniformity in distribution of dust particles on panel surface during the laboratory study.

Table 4.
Measured electrical responses with varying dust deposition

Dust deposition (gm)	I_{SC} (amp)	V_{OC} (volt)	P_{MAX} (watt)
0	0.50	19.2	7.24
3	0.41	18.50	5.70
5	0.38	18.35	5.24
8	0.34	18.28	4.62
11	0.30	18.20	4.00

Table 5.
Reduction in electrical responeses of dusty panel compared to clean panel

Dust deposition (gm)	Reduction in V_{OC} (%)	Reduction in I_{SC} (%)	Reduction in P_{MAX} (%)	P_N (%)
3	3.64	18	21.27	78.72
5	4.42	24	27.62	72.37
8	4.79	32	36.18	63.81
11	5.20	40	44.75	55.24

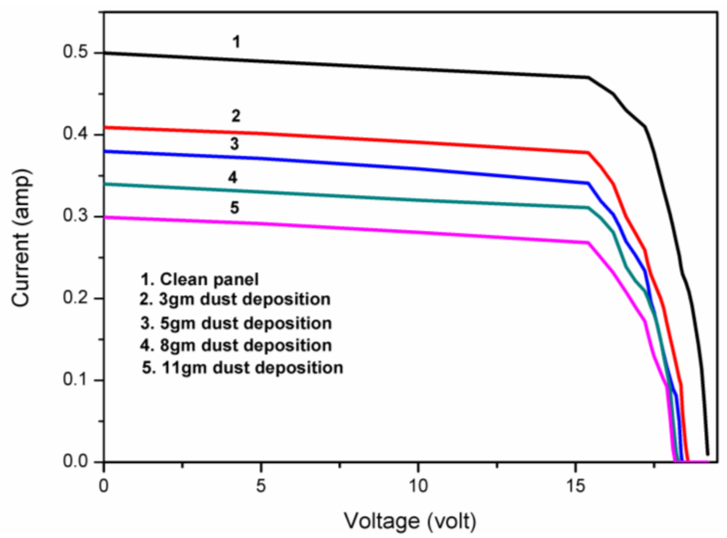


Fig. 9 I-V characteristic of PV panel under varying dust deposition condition

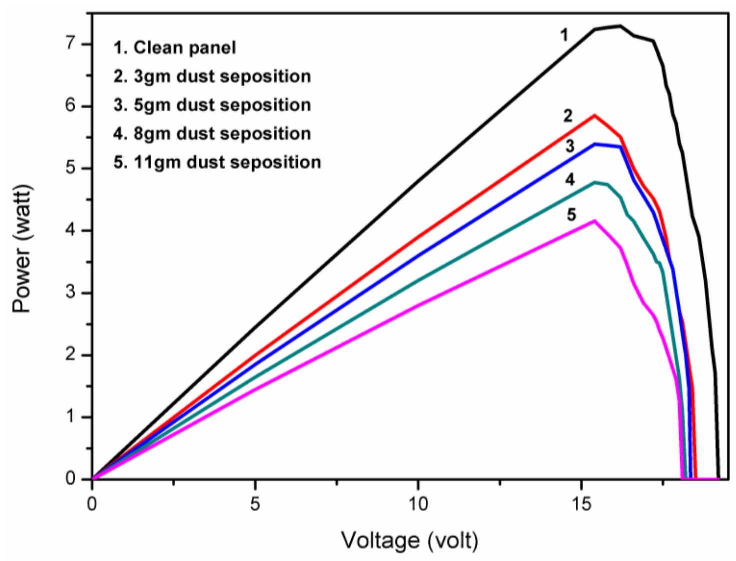


Fig. 10 P-V characteristic of PV panel under varying dust deposition condition

4. Conclusion

The accumulation of dust on the panel surface leads to the degradation of its performance. The reduction in open circuit voltage of PV panel due to dust deposition is negligible when compared to its short circuit current and maximum power output. This study has been carried out in the filed as well as in the laboratory. The field study revealed that the mitigation of short circuit current and maximum power output were respectively 39.58% and 43.18% for 12.86gm of accumulated dust deposition on the panel surface, whereas the open circuit voltage shows a meager reduction of 4.35%. The results of field study also corroborate with the results of laboratory study. In case of laboratory study, the reduction of 40% in short circuit current and 44.75% in power output were reported due to 11gm of dust deposition on panel surface. The reduction in open circuit voltage was 5.20%, which is quite low when compared to respective reduction in short circuit current and power output. These obtained results indicate a severe and fast reduction in the performance of PV panel when it operates near the mine sites. Therefore whenever PV panel are mounted near the mine sites or in the dusty environment, a proper cleaning mechanism should be adopted, so as to maintain the steady performance of panels. Since in dusty environment the degradation in maximum power output and short circuit current is reaching around 40% with 5 days of exposure, it is suggested to clean the panel surface at least at 5 days of interval whenever the panels are operated in heavy dusty environment.

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