EFFECT OF DUST DEPOSITION ON THE PERFORMANCE OF PHOTOVOLTAIC PANELS

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Abstract. *It is well known that the solar energy is converted into electrical energy directly using semiconductor materials used in photovoltaic (PV) panels. Despite great advances in semiconductor materials technology, panel efficiency has remained quite low in recent years. Panel performance is affected by many factors such as tilt angle, shading, dust, solar radiation, temperature and conductor losses. In this work, a preliminary study was conducted on the effect of dust deposition on the performance of a PV system. The research included indoor simulations of the panels as well as experiments with the panels in an outdoor test bed. The effect of dust on the performance characteristics of the panels was studied by obtaining the current-voltage characteristics of identical panels that were under the same conditions of insolation and ambient temperature, while one of the panels retained dust on its surface, and the other was cleaned of dust.*

Keywords: *power and current-voltage characteristics of a photovoltaic panel, Solar photovoltaic power plants, pollution, environmental parameters*

Introduction

Solar photovoltaic power plants are ideally located in regions with high levels of insolation. Photovoltaic performance is affected by high cell temperatures, contamination, mismatch and other losses associated with the balance of systems. It is critical to understand the implications of each of these losses on system performance. Contamination, which is largely dependent on installation conditions, is a complex problem that requires accurate quantification. Dust may or may not settle evenly on the surface of the panels depending on the terrain and environmental factors such as ambient temperature, wind and precipitation. It is important to investigate the impact of dust settling on the performance of PV systems to better understand the performance losses associated with pollution. The current-voltage (IV) characteristics of photovoltaic panels provide extensive information necessary for analyzing panel degradation. This paper attempts to understand the performance loss due to dust through a dynamic study of the IV performance of panels under different contamination conditions in an open-air experimental test rig. Additionally, this paper discusses the results of an indoor study simulating the performance of photovoltaic panels under different dust deposition regimes. Environmental parameters such as ambient temperature and local wind and dust patterns can significantly affect system performance. The influence of ambient and cell temperatures on PV system performance has been fairly well studied theoretically and validated by wind tunnel simulations. However, the productivity loss associated with dust deposition is an issue that has not been comprehensively addressed in previous studies because it is difficult to accurately quantify. Studies [1, 2] show that productivity can be reduced by 20% each month due to dust accumulation on dirty cell surfaces. Moreover, experiments carried out in [3] show that high wind speeds contribute to the accumulation of dust on surfaces. No studies have yet been conducted to correlate the amount of dust deposition and the resulting reduction in PV system performance.

Tropical regions such as southwest Central Asia are particularly vulnerable to dust accumulation in photovoltaic installations. However, the degradation of PV systems due to dust is greater in tropical regions where arrays are installed at shallower tilt angles. The settling of dust and sand on the surface of the cells can be uniform or uneven depending on the size of the photovoltaic arrays and the terrain. Smaller panels may have uniform dust accumulation, and the decrease in panel performance may be the same across multiple panels in an array. However, the dust accumulation pattern may not be the same for panels with a larger area or panels located at greater distances from each other in the module. Therefore, panel performance degradation due to dust deposition may not be uniform across the array and therefore more difficult to predict for such an installation. Ambient wind and precipitation are believed to be natural dust removers from photovoltaic surfaces. On the contrary, it can be seen that wind and rain often contribute to the deposition of dust on photovoltaic surfaces. High wind speeds increase the tendency for dust to settle on the surfaces of photovoltaic panels and cause a drop in the panel's power output. Rainfall promotes cleaning of photovoltaic surfaces when water helps remove dust particles as it flows off the surface [5]. However, if rainwater evaporates from the surface of the PV without draining, this results in greater dust adhesion to the surface. It is critical to investigate the impact of dust settling on PV system performance to understand the performance losses due to pollution alone. This would help assess the magnitude of the dust deposition problem in terms of potential losses when feeding power into the grid and estimate the economic loss to the power plant. Such an investigation would also facilitate feasibility studies of cleanup mechanisms and the development of appropriate cleanup schedules.

The performance of PV systems is highly influenced by internal and external factors such as design features, aging, radiation, shading, ambient temperature, wind, pollution and cleanliness. Any type of climate change causes changes in solar radiation and ambient temperature, which leads to adjustments in the output characteristics of solar photovoltaic systems [4]. Today, the economic consequences of dust pollution as a result of climate change have become one of the most important issues addressed by the governments of most countries in the world. Dust can be defined as a crushed form of tiny particles less than 500 microns in size. Dust can enter the environment from various sources, such as construction sites, industrial plants and dust storms. Dust consists of visible and invisible floating and fallen particles of solid material [1]. The term “dust particles” usually refers to aerosol particles in the atmosphere that cause artificial or natural air pollution. Natural sources in arid, semi-arid or eroded areas include dust storms that produce particles of varying sizes, typically larger than man-made particles. In most cases, these sources do not act locally and can export particles over several kilometers [2-4]. Artificial sources of pollution are mainly found in urban areas with industrial structures. They produce fine dust particles that act locally and have the most negative impact on the environment. At the moment, solar energy occupies a small share in global electricity production, but its role in the energy sector is growing rapidly. The recent spread of solar energy is caused not only by various government support measures, but also by the results of its implementation, for example, economic competitiveness. Russia cannot yet boast of “solar” gigawatts, since the industry under discussion is in the initial stage of development. For the construction of solar power plants, isolated energy regions are selected where their use is highly efficient, as well as regions characterized by the most favorable natural and climatic conditions [6].

The purpose of the work is to determine the effect of surface contamination of photovoltaic modules on the generation of electrical energy and to determine the period of dust covering surfaces to a critical value during comparative tests for regions with different climatic conditions. Particulate matter released into the environment poses a serious health hazard, causing millions of premature deaths each year.

Particulate matter is also widely known to influence incoming solar radiation and is therefore commonly included in climate change assessments. It logically follows that particulate matter will also affect solar energy production. We studied the effects of ambient and deposited particulate matter, including dust and anthropogenic particles, on the surface of solar panels. We collected dust samples from solar panels and placed them in clean, dry containers. Dust mass was determined using an electronic balance with a lower mass detection limit of 200 μg. The deposition area of the collected samples was 1000x1640 mm. The size distribution of water-insoluble particles was measured on the samples using a laser diffraction particle size analyzer. In this way, they were able to determine not only the total mass of deposited dust, but also the carbon fraction (as carbonate) associated with the dust. Figure 1 shows dust deposition on solar panels over 1 month. Partially cleaned solar panels show that particulates are covering the surface of the panel, thereby affecting solar energy production.

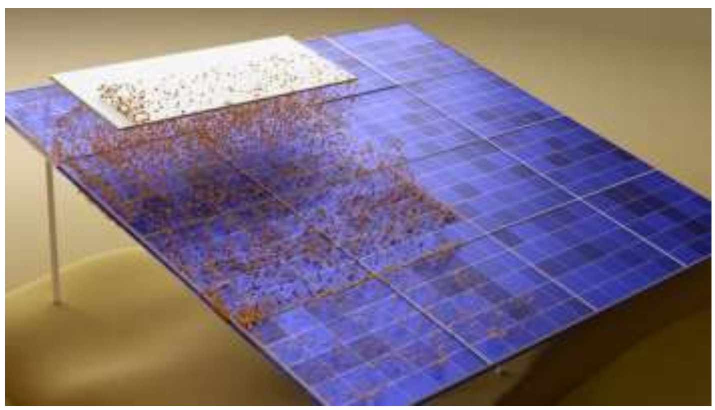


Figure 1 - Partially cleaned solar panels

Figure 1 shows that when cleaning the surface of solar panels every 25-30 days, electrical energy production increases by an average of ~55% after each cleaning. Most of the atmospheric particulate matter depends not only on winds, but also on anthropogenic sources of pollution, such as the burning of garbage, waste, industrial emissions and electricity generation through the combustion of fossil fuels. In this regard, there is a need to improve the operating efficiency of solar modules. In order to do this, it is important to promptly detect the presence of foreign objects and contaminants of various types on the surface of solar modules, and also remove them in a timely manner. The efficiency of solar modules and their service life mainly depend on the degree of their contamination. Since under an ideally clean surface and nominal conditions the generation of electrical energy is 18%, any contamination leads to shading of part of the surface of solar cells, which helps reduce their absorption of solar energy, and hence the amount of electrical energy generated. Therefore, it is very important to at least maintain the efficiency at the nominal level. To do this, you need to prevent mechanical particles from getting on the surface of solar photovoltaic modules, or regularly clean the surface of them. At the moment, there are several ways to protect and clean solar photovoltaic modules from mechanical particles. They all have their advantages and disadvantages.

Manual cleaning

The most common way to combat dust and contamination of solar modules is manual cleaning by maintenance personnel using modern equipment, which are long rods with stationary or rotating brushes, as well as a built-in hose for supplying washing liquid. The washing liquid must be cleaned and contain a minimum of impurities, in this case, after drying, there will be no streaks or traces of drops left on the solar modules, which otherwise will lead to a decrease in their performance. The method of manual cleaning of solar modules is rational and low-cost if the area of the power plant is small.

Automated cleaning

Automation of cleaning using robotic technology allows you to save on labor and increases cleaning efficiency by eliminating the human factor.

Small robots are mounted on tracks along a row of panels and move along the panels, cleaning them using a special brush designed so as not to damage the solar panel.

The direct impact of dust deposition on the performance of a PV system can be assessed by comparing the current-voltage (I-V) characteristics of panels with and without dust deposition on their surface. The I-V curve can be considered as a mirror of the photovoltaic cell under study, since each photovoltaic cell produces a unique I-V curve, the shape of which depends on insolation conditions, ambient temperature, cell operating temperature, wind exposure, pollution and mismatch losses, and other factors. losses associated with the balance of the system at the time of its tracking. Therefore, comparing the I-V curves of two identical panels, keeping all environmental factors the same but varying, allows us to isolate the effect of that particular factor on system performance. This comparative approach was adopted in the present study to study the effect of dust deposition on the performance of PV modules under the condition that the panels are exposed to the same environmental parameters but with different amounts of dust deposition.

2. Methods and equipment

A dual method was used to obtain the I-V curves from two identical panels: one panel with dust deposition and the other panel without dust. In the first method, I-V readings were recorded from panels placed indoors and illuminated by halogen lamps simulating sunlight. The second method consisted of recording current-voltage characteristics from identical panels installed on an open experimental stand and exposed to natural sunlight. Both panels in both installations were subjected to identical environmental conditions and differed only in dust deposits.

Electrical characteristics of solar modules PS - P 36 150 W	
Maximum power (Pmax)	37. 0 W
Voltage at (Vmm)	18 . 41 V
Open Circuit Voltage (Voc)	22.06 V
Current at (Imm)	2. 15 A
Short circuit current (Isc)	2. 63 A
Temperature coefficient Isc (KI)	0.058 A/°C
Number of cells in series (N)	36

To simulate indoor solar energy, two identical panels of the specified ratings were installed side by side parallel to the ground. The panels were placed in a dark room, and the only illumination of the panels was a pair of halogen sun lamps, the intensity of which could be varied, suspended vertically above each panel, as shown in Fig. 1. One of the panels remained free. dust throughout the solar simulation, while dust was deposited on the surface of the other panel. In Fig. 1 panel on the left is free of dust, but the panel on the right is not. The current-voltage characteristics were plotted and recorded using MECO solar module analyzers . The intensity of the lamps was measured and set using a TENMARS solar energy meter, and a CENTER infrared thermometer was used to measure the lower surface temperature, which is considered a good approximation of the operating temperature of the element [6]. The current-voltage characteristic for the internal solar array of the simulator settings was recorded in two batches of readings. In order to eliminate the influence of an increase in the operating temperature of the cells on the performance of the panels during operation, the first set of data was recorded while varying the intensity of light incident on the panels from 200 W/m2 to 800 W/m2 while maintaining the temperature of the panels constant. Thus, the I-V curves thus obtained in this first set are independent of the effect of element temperature on the performance of the two panels. In the second set of recordings, the incident light intensity was again varied from 200 W/m2 to 800 W/m2 in increments of 100 W/m2, allowing cell surfaces to reach maximum temperatures at these insolation levels. The test results conducted on the indoor solar simulator setup were presented and discussed in the next section.

Fig. 1. Indoor solar simulator setup.

Figure 2 - A leaned solar panels

3. Results and discussions

The indoor setup allowed for better control of the test conditions than the outdoor test bench. Because the indoor tests were conducted in a dark, enclosed room, the incident light on the panel could be adjusted to desired values and kept constant over a long period of time. Additionally, by turning off the lamps, the panels could be returned to ambient room temperature, which remained more or less constant throughout the study period. This allowed a more comprehensive study of the dust phenomenon affecting the performance of panel I - V . The indoor solar radiation simulation was repeated in an outdoor experimental test whether similar behavior could be observed under natural solar radiation and ambient temperature conditions. In both situations, the IV characteristics of the panel that had accumulated dust were compared with those of the clean panel.

3.1 Installing the solar simulator indoors

Of the two panels used for the indoor simulation, one panel was completely free of dust and the second panel had a visible amount of dust deposited on the surface. In the microscopic images in Fig. Figure 3 shows dust deposits on the panels. It can be noted that almost 70% of the surface area of the second panel was covered with dust particles. In the first set of readings, I-V curves were plotted at an intensity of 400 W/m2 at two different cell surface temperatures, viz. 40°C and 50°C (Fig. 4), and in the second case - when the temperatures of both panels were close to the ambient temperature in the room. The intensity of the halogen lamps was increased in steps of 100 W/m2, starting from 200 W/m2 to 800 W/m2, which was the maximum luminous intensity of the lamps. All readings were recorded when the panel temperature reached 30° C . The current-voltage characteristics obtained for two panels at 200 W/m2, 400 W/m2, 600 W/m2 and 800 W/m2 are reproduced here in Fig. 5-8 respectively. Table 2 above shows the records at various intensities of the average output power, short circuit currents, open circuit voltages and cell temperatures noted at that intensity.

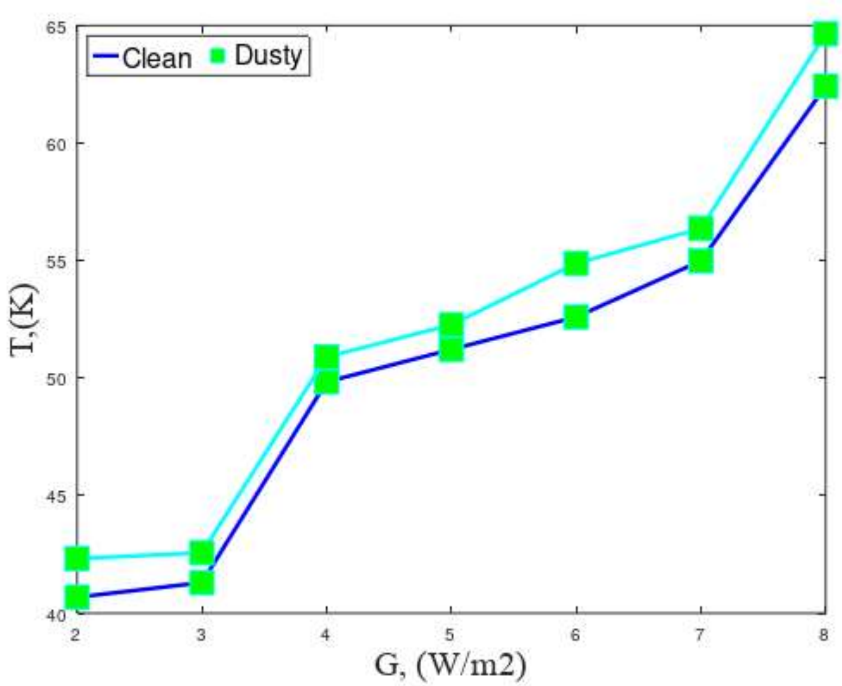
Table 2. Indoor simulation study records.

G(W/m2)	T (°C)		P (W)		I(A)		V(V)	
	Clean	Dust	Clean	Dust	Clean	Dust	Clean	Dust
200	40.68	42.32	0.84	0.58	0.073	0.048	17.72	17.64
300	41.30	42.57	0.98	0.64	0.082	0.054	17.86	17.69
400	49.84	50.90	1.84	1.11	0.157	0.097	18.26	18.07
500	51.22	52.27	2.83	1.69	0.233	0.136	18.59	18.33
600	52.60	54.88	3.31	1.96	0.269	0.158	18.63	18.38
700	54.99	56.37	3.86	2.33	0.312	0.181	18.62	18.39
800	62.42	64.65	3.97	2.47	0.339	0.195	18.36	18.13

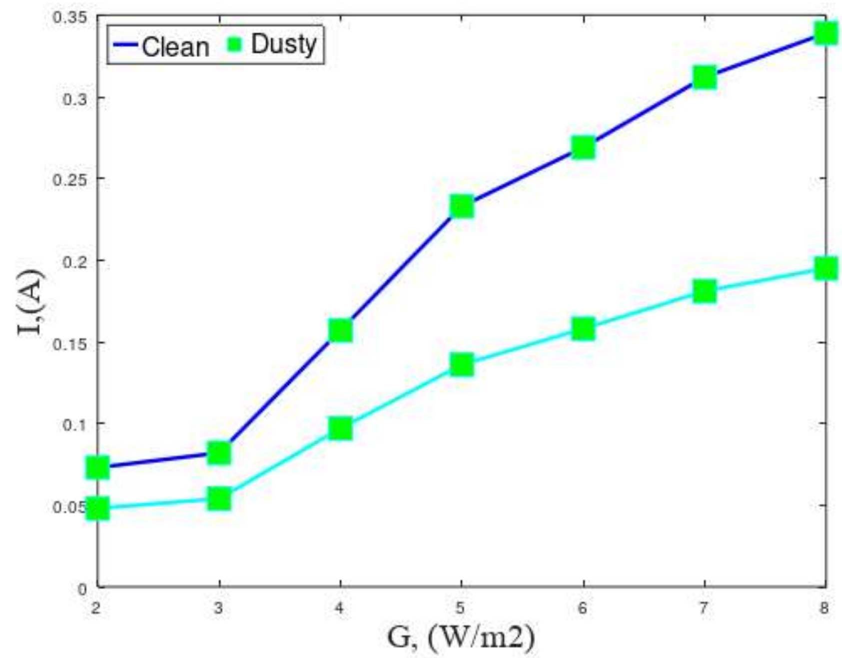
From the table and corresponding graphs the following observations can be made:

1. Dust deposits on the panels affect the operating temperature of the elements. It has been observed that a dusty panel performs 1-2° C higher than a clean panel at the same light incidence. This increase in element temperature due to dust further reduces the electrical efficiency of the panel. Increasing the cell surface temperature from 40°

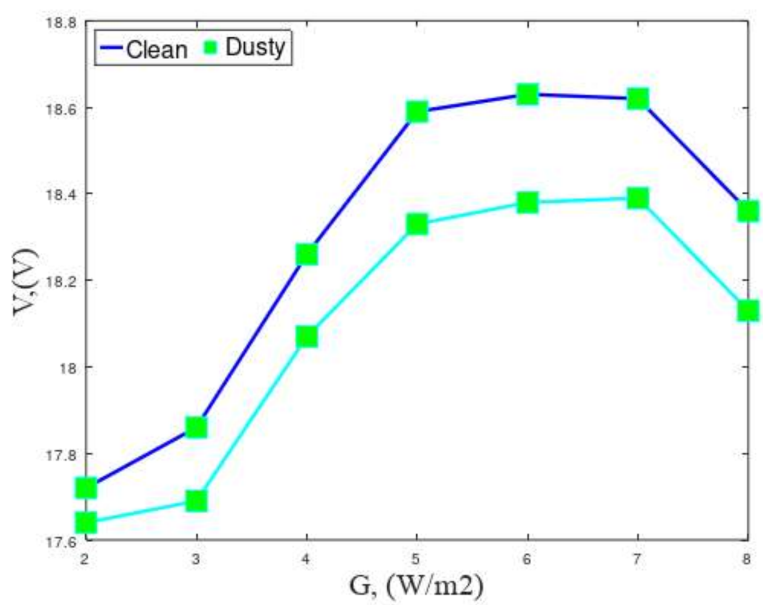
C to 50° C resulted in a slight increase in the short circuit current of both the clean and dusty panels, which was, however, accompanied by a large drop in open circuit voltage, causing an overall loss of power output due to the increase in operating temperature. Thus, the combined effect of dust deposition and increased cell surface temperatures further degrades system performance.



2. However, dust has a significant effect on the short circuit current generated by the panels. A clean panel always produced a higher output current than a dusty panel. This difference in current outputs increased as the incident light intensity increased from 200 W/m2 to 800 W/m2, i.e. The current power of the dusty panel decreased with increasing intensity of the incident light, as can be seen in the penultimate column of the table. Table 2, which shows the ratio of the short circuit current of a dusty panel to the short circuit current of a clean panel. Thus, dust deposition has a significant impact on the output current of PV systems.

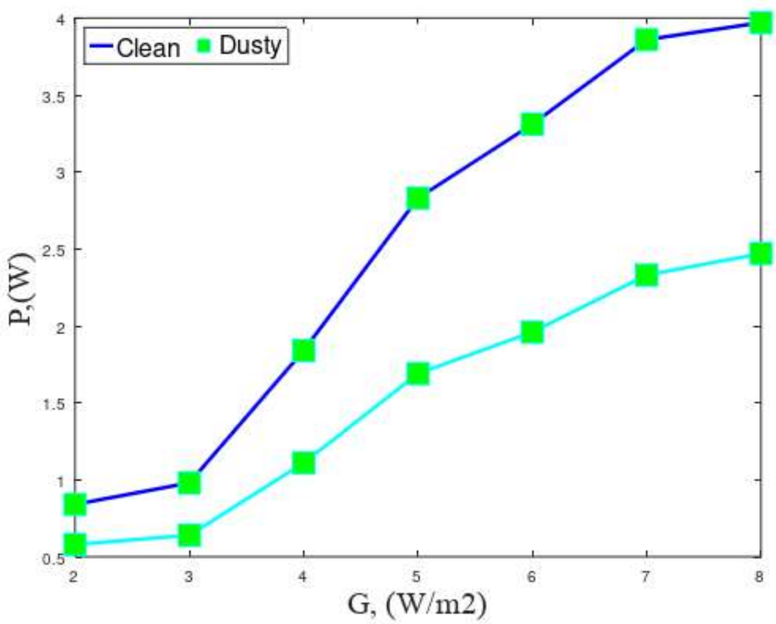


3. From the graphs it can be noted that dust deposition does not have a significant effect on the open circuit voltage of the panels. The open circuit voltage of a dusty panel is only slightly lower than the voltage of a clean panel at any light intensity.



This is confirmed by the last column of Table 2, which shows the ratio of the open circuit voltage of the dusty panel to the open circuit voltage of the clean panel. This ratio remains close to 100% for all light intensities. Thus, it is assumed that dust does not have a significant effect on system voltage.

4. There is a correlation between dust deposition density and power losses associated with dust deposition on photovoltaic panels. In the case of the outdoor experimental setup, where the dust density was 1.4 g/m2, the power loss due to dust was 5-6% of the maximum power output, while in the case of the indoor simulation setup, where the dust density was 7.155 g/m2, the associated power losses amounted to 45-55% of the maximum possible output power of the clean panel.



5. No significant differences in cell operating temperatures due to dust deposition on the test bench were observed.

4. Conclusions

In this work, a preliminary study was conducted on the effect of dust deposition on the performance of a PV system. The research included indoor simulations of the panels as well as experiments with the panels in an outdoor test bed. The effect of dust on the performance characteristics of the panels was studied by obtaining the current-voltage characteristics of identical panels that were under the same conditions of insolation and ambient temperature, while one of the panels retained dust on its surface, and the other was cleaned of dust. Comparative analysis of current-voltage characteristics led to an understanding of the phenomenon of power loss due to dust accumulation on photovoltaic surfaces. It has been observed that dust deposition does not significantly change the open circuit voltage of PV systems. However, the short-circuit current is affected by dust deposition: 30–40 % indoors and 4–5 % on an open stand. This drop in output current and the resulting drop in output power due to dust represents a huge loss of electricity and economic loss for PV power plants, given the scale of the power plants.

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