THE SENSITIVITY OF PHOTOVOLTAIC MODULES TOWARDS DUST IN AJMER, RAJASTHAN

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ABSTRACT

Electricity generation in off-grid or on grid solar power plant is appropriate in remote desert areas those are distressed by shortage or lack of continuous electrical power supply. However, their environment, adversely affects the optimal performance of PV systems. Prolonged drought, high wind speed and the widespread abundance of loose sand makes these areas the most common locations for sandstorms to form. Sand columns are an annual weather pattern seen in the western part of Rajasthan which are a prime agent for dust accumulation on solar PV module. High amount and heterogeneity in dust reduces the solar power by clogging the solar insulation. The prime objective of this study to investigate the property of dust found in local environment to explore the sensitivity of solar photovoltaic (PV) system towards dust in Ajmer Rajasthan. In this study different dust samples according to local site were investigated according to physical properties by the XRD and SEM-EDS interpretation. In the absence of dust, Silicon solar cell operating efficiency is at prime level under better terms. The results show that soiling loss is influentially site specific and subject to deposition density. The product of such study could be used by the new user in order to estimate the impact of dust on the future performance of PV modules in small and large installations in different regions of desert area. Maximum power up-to its installed capability can be produced if by several methods dust is removed.

Keywords: *Off-grid, Sand columns, Soiling loss, XRD, EDS*

1. Introduction

Among the numerous primary nonrenewable energy sources like fossil and nuclear energy and the renewable energy sources like wind, solar, biomass, geothermal and water power, Solar energy is a vast, renewable, pollution free, inexhaustible, and clean resource having economic, social and environmental profits with diverse application and low maintenance cost. In order to produce maximum power up-to its installed capability Photovoltaic solar plants require proper maintenance. They degrade with time of span due to various factors such as shortcoming in solar irradiance, high level of humidity, deposition of dust of several types and in large amount, high temperature, very fast or very low wind speed etc. and neglecting them will cause the plant to snuff early before the manufacturer warranty. The maximum power output of this technology is decided by various parameters as shown in Figure 1.

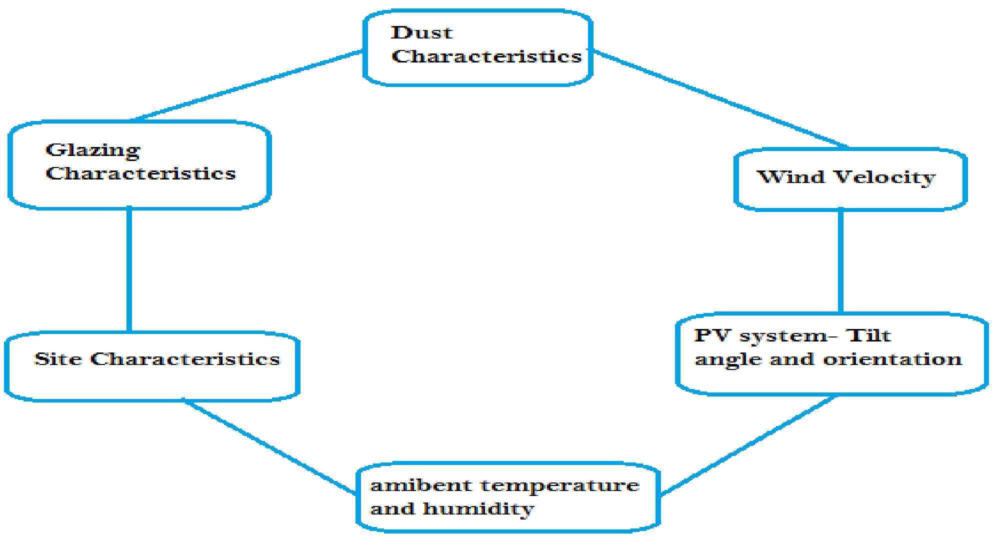


Figure1: Factors affecting the output power of the solar panel.

In this study, the soiling loss has been determined to investigate the effect of different dust particles found in local environment of Ajmer region of Rajasthan. Soiling consists of the deposition of contaminants over the photovoltaic (PV) modules and it is a site-specific phenomenon, strongly influenced by local climatic conditions [1-8]. Few causes for dirt on solar panel are mineral dust deposits, volcanic emissions, fly-ash particles from burning of Fossil Fuels, Industrial emission, bird droppings, Transportation, wildfires, construction and demolition, wear of tyres and brakes, erosion of agricultural soils, mosses, or fungi [9-11], plant debris, pollen [12], agricultural emissions such as feed dusts and they could alter greatly subject to the location. Depending on the area shaded by soiling particles over the PV modules results in optical losses due to light absorption or backward scattering,[13-14] however strongly addicted on the dust compositions and particle size distributions. Ajmer is the 5th largest city in Rajasthan and there are many activities that can generate dust around the city such as marble and stone industries, unpaved and paved road dust, construction sites, vehicular pollution, and large, medium and small industries. During the monsoon there is frequent heavy rain and thunderstorms which are unusual in terms of energy, frequency and their temperament, particularly in the western arid regions.

A typical dust soiling on the flat plate PV module in western Rajasthan after a dust storm which hits from north-west India is shown in Figure 2.

Figure 2. Soiling on the solar PV module in western Rajasthan after a dust storm

When the wind speed is higher or there is a sand storm, then the number of dust particles circulating in the air is higher than usual. In Aimer district the sandy soil, shallow soil and dark medium heavy soil are prevalent type of dust [15]. In India, as well as in other countries accumulated dust is an important factor that negatively affects the solar cell efficiency. This issue may vary by geographical locations. Numerous papers have endeavored to investigate the effect of dust deposition mechanisms on solar PV installations. Effect of dust on transmittance of glazing material for solar collectors under arid zone conditions of India was studied by many researchers [16]. They concurred that dust deposition increases with decrease in tilt from the horizontal. Under greater irradiation the effect of dust becomes reduced but not negligible [17]. Experiment concerning the effect of air pollutants including red soil, ash, sand, calcium carbonate and silica on the power generated were conducted and analyzed by H.A. kazem at al. [18]. They consolidated that the ash pollutant is the most effecting dust particle on the PV module. Several other researchers also worked on dust effect on solar cell module [19-24].

2. Dust on solar panel

2.1 Sources of dust

Dust is made of Small, solid, dry particles, visible and invisible, floating and fallen particles usually in the size range from about 1 to 100 μm in diameter. Silicon, Quartz, Feldspars, Calcite, Iron oxides and Apatite are the main minerals found in it. However, some other organic materials can be part of this composition [25]. Eolian process is the major source of dust in the atmosphere where wind assisted emission, transport and deposition of dust takes place [26]. Mineral-containing particles are emitted from erosion of agricultural soils, quarrying and building activities [27]. Metal-containing particles come from frictional sources, such as wear of tyres and brakes. Downward gravitational force of weight of particles is higher for heavy particles, responsible for depositing them quickly near their source, while very fine particles also deposit relatively fast because they are mobile. Due to small gravitational settling particles of intermediate size travelled long distances from desert to hill and from one country to another [28].

2.2 Soil layers

According to Cuddihy there are three layers for soiling. The first layer on the surface opposes removal by rain and artificial cleaning. Also, it might include either the chemical attachment or chemisorptions of soil, on that surface. The second layer on the surface also opposes the removal by rain, yet, it can be removed using the artificial cleaning. In fact, it is more physical than chemical, involving a high quantity of soil which results in a high energetic degree associated with the first layer and a low energy on the outer surface. Final or third layer located on the top of the surface, creates a set of loose soil matter, which during the dry periods has been gathered and thus, getting easily removed during the rainy periods [29].

2.3 Factors impressing dust agglomeration

Dust characteristics and the local environment is the main obstacle which badly affects the quality and efficiency of a solar panel. Dust characteristics comprise type of dust, size, shape and weight of dust particles. The local environment includes –location wise specific factors controlled by the nature of usual being activities, weather conditions (sand storm, rainfall, thunder storm, hail etc.), vegetation type, industrial activities, orientation and height of installation of solar panel. The reflection, dispersion, and absorption of incoming radiation on PV modules depend on the size of the accumulated dust particles. Coarse mineral particle is the major constituent by mass of desert dust [30-32]. Under the influence of gravity, they deposited by low wind speed. Violent countercurrent forces these particles to penetrate the viscous sub layer in windy environment making an inertial deposition grade additional to the gravity rate [33, 34]. Fine dust particles have a larger surface area and are more uniformly distributed than coarse particle. They also have less surface coarseness than large dust particles reducing the voids spaces between the particles through which light travels, so they cause more degradation in PV performance than larger particles [35]. So the size and specific mass of dust particles is highly responsible for the deterioration of the panel. Higher the mass of dust deposited, lower the power output and the efficiency while as the size come to be smaller, power output decreases since smaller particles occlude more radiation on PV module surface. So the size of the soil particles is very important. According to USDA each soils size class has given a name (Table 1)

Table 1. Classification of Soil according to particle diameter

Soil separate Name	Diameter(mm)	Comparison of visual size
Very coarse sand	1.0-2.0	House key thickness
coarse sand	0.5-1.0	Small pin head
medium sand	0.25-0.5	Sugar or salt crystal
fine sand	0.10-0.25	Thickness of book page
Very fine sand	0.05-0.10	Invisible to the eye
Silt	0.002-0.05	Visible under microscope
clay	<0.002	Most are not Visible even under microscope

3. Materials and Methodology

3.1 Apparatus specification

To study the effect of size and specific mass of different dust particles various equipments used. They are as follows-[1] a 20 W polycrystalline PV module(SM 20) , [2] fabricated lightening source having 4 set of electric lamps of 40 W,60 W and 100 W, [3] dust samples, [4] multimeter, [5] weighing machine,[6] a resistance load and [7]solar power meter. The system was installed in an indoor lab and the radiation energy was delivered by the fabricated lightening source. The number of electric lamps and their positions were varied depending on the requirements of experiments. The practical set up used in this investigation is shown in figure 3. The standards of used solar PV module and computation instruments are complied in Tables 2 and 3.

Figure 3. Practical set up.

Table 2. polycrystalline PV module	
Parameters	Standards
Module	SM 20
Rated Power Pmax(W)	20
Voltage (V)	12
Rated Current Impp (A)	1.15
Rated Voltage Vmpp (V)	17.5
Short circuit current Isc (A)	1.28

Table 3.Parameters of assessing instrument

Instrument	Rating and range	utilization
Digital Multimete r(Dt9205a Make)	Dc voltage: 200m/2/20/200/1000v Dc current:2/20/200n/2/20/200u/2/20m/200m/20a Resistance: 2/20/2000m/2/20/200k/2m	To measure the output voltage and current of PV Module
Solar irradiation meter	Measuring Range: 2000 W/m2 Resolution: 0.1 W/m2 Accuracy: Typically within +/- 10W/m2 +- 5% Temperature included error +/- 0.38 W/m2 / ºC	to measure the solar radiation falling on a horizontal surface in watts per square meter (W/m^2)

3.2 Procedure of the study

3.2.1 Electrical features: The study was carried out in the laboratory to control the climatic conditions and limit the variables only to the change of dust type and concentration. Specific amounts of dust collected from panel were uniformly scattered over the PV solar module using a stratified strainer with sieve size approximately 16–25 mm. Using an analytical balance of 0.1 mg accuracy the samples were weighted to get the mass of the deposited dust. After that the PV solar module is exposed under the artificial lightning source, at three radiations levels of 380, 400 and 480 W/m^2 and the voltage and current for dust samples of different weights have been measured. With increasing weight of scattered dust on the PV surface the data for power, power loss and power transferred were calculated and recorded. When light impinges on a dust particle on a solar cell, it is either scattered or absorbed as a result the amount of light received by the solar cell is decreased [36].

3.2.2 Dust sample investigation: Three dust samples taken in this work are dust collected from solar panel, Marble dust and dune sand because in Rajasthan wind blows most of the time, severe sandstorms usually occur, which spread dust found in local environment on the solar panel. Marble industry enhances the incidence of dust accumulation. Chalk powder, dust from roadside, fine pollen, dust from garden and bird dropping are very common forms of dust that can be found at any instructional institutes, playing fields etc. So proper understanding of the dust particle size and their impact on the various parameters of solar power should be investigated. The dusts samples taken in this study are as shown in Fig. 4. To maintain the uniformity of dust, dust samples were sieved with a fine mesh sifts. Little amount of sieved dust samples were used to understand the particle size distribution. To perceive the nature of the dust particles and chorography of the dust samples the SEM image analysis was carried out. SEM permits obtaining “bulk” images of fine particles, that is, 2-D images with some information regarding their volume. Mineral dust which has complex aggregates in the coarse fraction, SEM exploration is appropriate. It has a broad range of magnification as it recognizes the particle of diameter from decimal to tenths of micron.

Figure 4. [1] Dust sample collected from solar panel, [2] marble dust, [3] dune sand

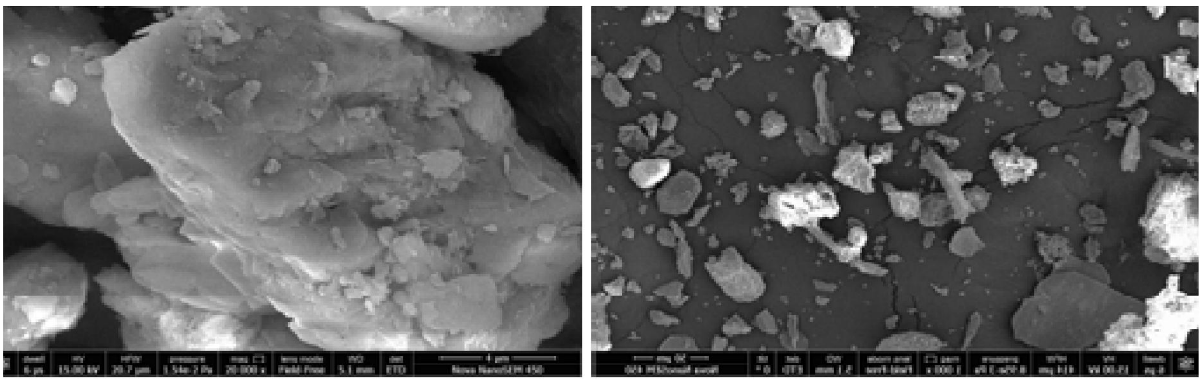
The SEM images for all types dust samples are shown in Fig 5and Fig.6. The SEM is also assembled with Energy dispersive X-ray spectroscopy (EDX) detector by EDAX, an x-ray technique used to identify the elemental composition of materials. EDX analysis peaks occur according to the energy values of elements in the spectra. This is apparent From the SEM depiction that heterogeneous mixture of particles with various morphologies present in the sample and small particles attached to large particles. However these small particles differ in shape and size and remain in the environment for prolong time than the large particles [37].

3.3 Observations for voltage and current with specific amount of dust and varying radiations

Impact of three different types of dust on the power, power loss of the panel and power transferred from the panel, with varying weight and increasing radiation were calculated and recorded. Power is measured from current and voltage readings measured from multimeter attached to module using the formula. P=I*V

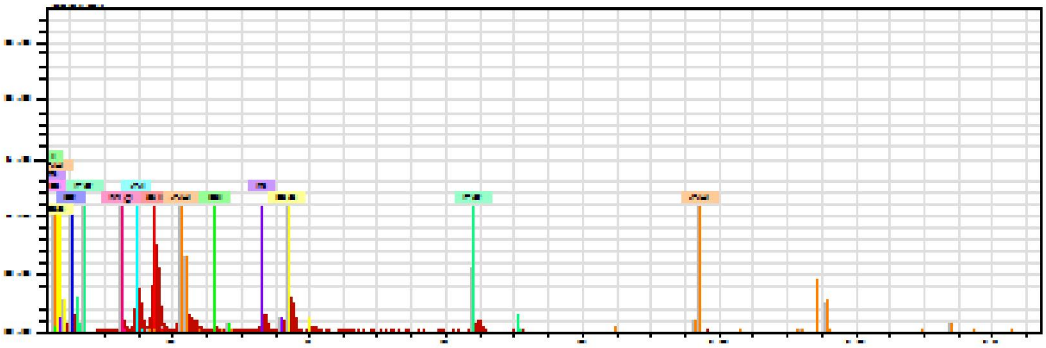
3.4 Graphical analysis of power and weight of artificially deposited dust

For displaying and reviewing large amounts of power and weight data and for showing trends, patterns, and relationships between them, graphs are plotted as in figure 7, 8 and 9. The data identified in the current study for the different types of dust samples at specific weights have been taken. Power has been estimated for the solar PV module at three radiation levels of 380, 400 and 480 W/m^2 for these dust samples. Here weight of dust on solar panel is an independent parameter and power output is a dependent variable. From the graph we conclude that for 480 W/m^2 of radiation data, power is high. Initially as dust density increases there is small variation in power output but for large amount of dust deposition power decreases rapidly. The power and dust data represented in graph pointed that the smaller size fine particle cover more surface area of the PV module and hence blocks more solar radiation. Minimum power value of 5.3 W is obtained for the dust collected from solar panel which has high density of fine particles comparative to other dust samples on PV module. Dust collected from solar panel has particle size of 4 µm as depicted in the SEM images.

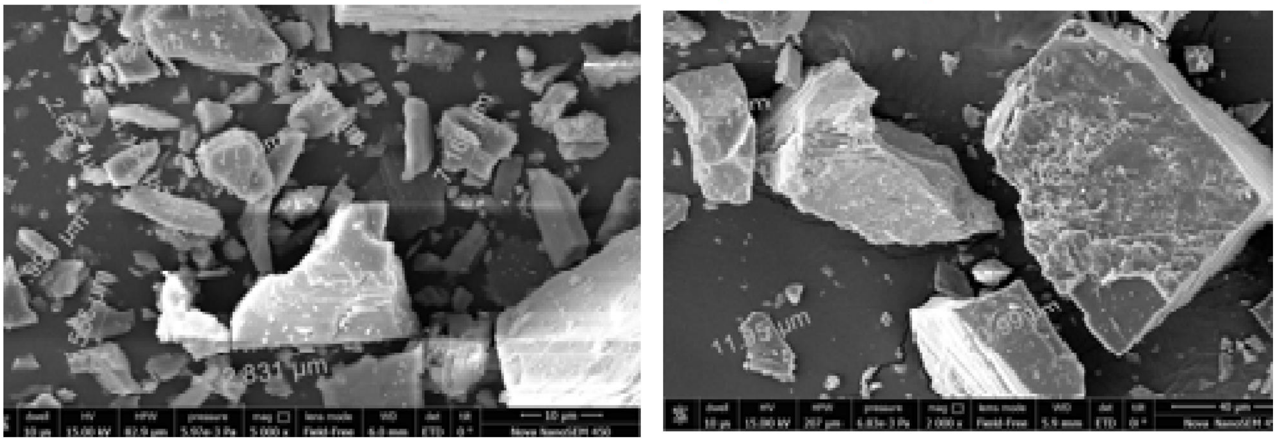


SEM image for dust collected from solar panel(4 µm and 50 µm)

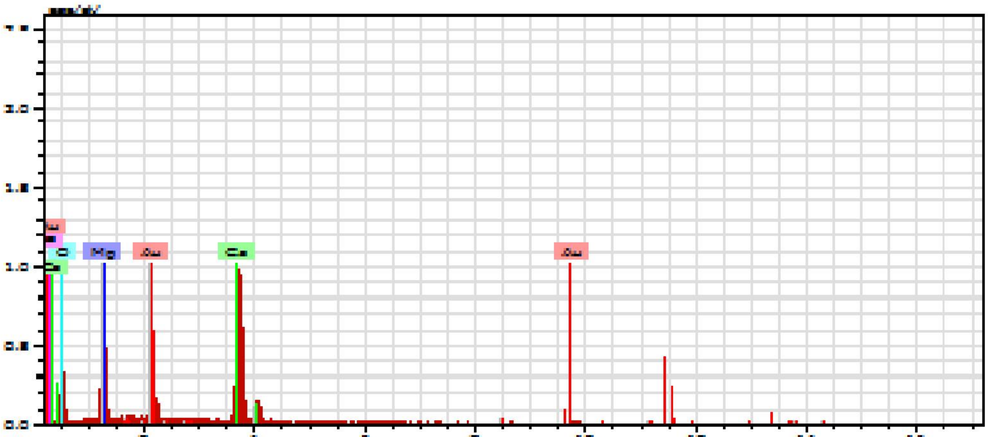
Figure 5. SEM images and EDAX spectra for dust collected from solar panel and for marble dust



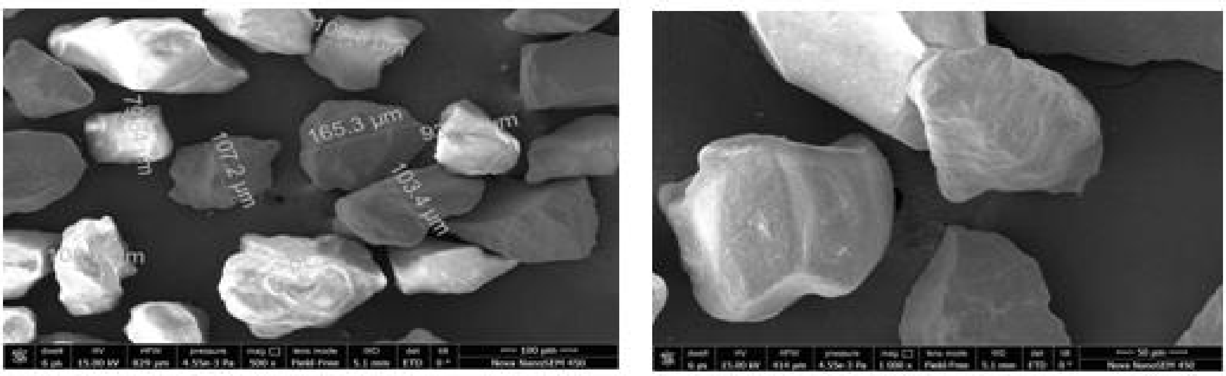
EDAX spectra of elemental analysis of the dust samples collected from solar panel



SEM image for the marble dust (10 µm and 40 µm)

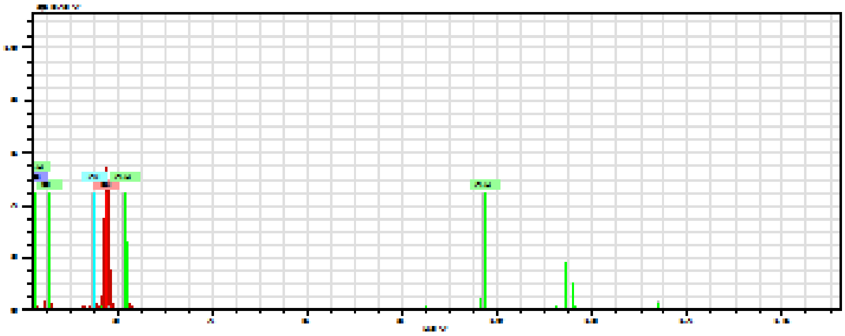


EDAX spectra of elemental analysis of the marble dust



SEM image for the dune sand (50µm and 100 µm)

Figure 6. SEM images and EDAX spectra for dune sand



EDAX spectra of elemental analysis of the dune sand

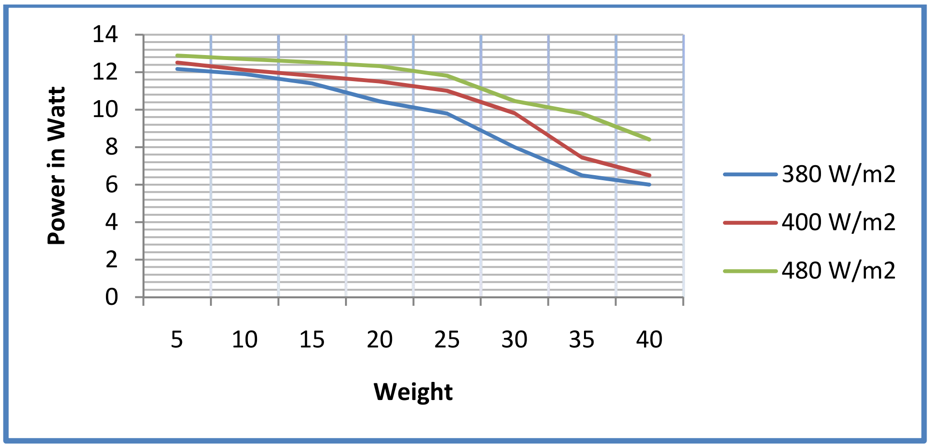


Figure 7. Power-to-weight relation for dust collected from panel

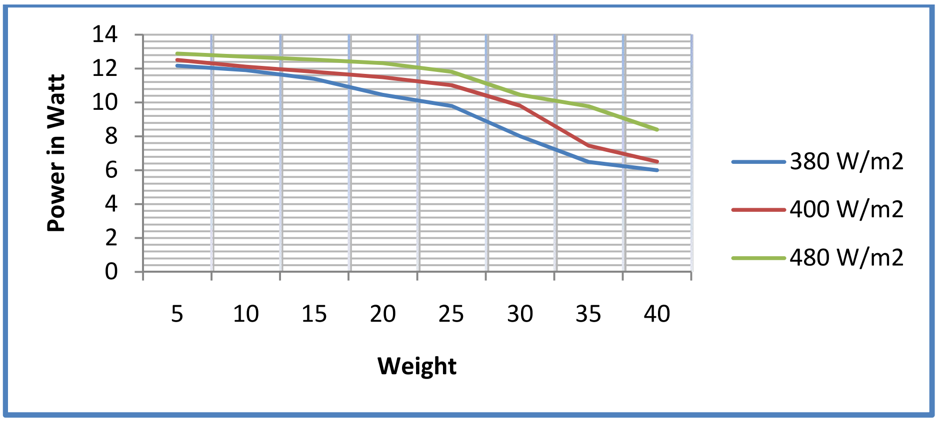


Figure 8. Power-to-weight relation for marble dust

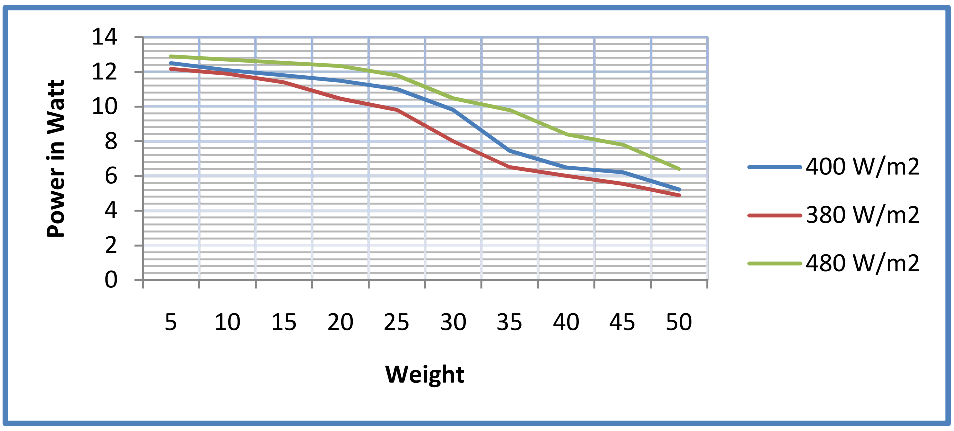


Figure 9. Power-to-weight relation for dune sand

4. Results and discussion

In a big city like Ajmer there are many activities that can generate dust around the city such as marble industries, unpaved and paved road dust, construction, landfill open burning, vehicular pollution and dust storms. To gain a clear insight into the dust deposition problem the physical properties of dust were analyzed. Dust grains are considered as spheres which homogeneously distributed on panel's surface. Since dust particles of every size are the obstacle between light and solar surface however smallest fine particle choke more sun energy and thus lower the performance of solar PV module. It is assumed that "solar is the nearest future"; hence, dust from different fields such as constructional sites, industrial area and desert will affect solar systems in coming time. At three radiations levels of 380, 400 and 480 W/m^2 for the 5gm of dust taken from the solar panel, power loss of 21.64%, 18.66% and 14.74% has been noted, respectively. Comparably for the 25gm of dust it was 40.45%, 38.27% and 34.64% and for the 35gm of dust it was 61.51%, 60.05% and 57.15% respectively. Experimental data shows that power losses are directly related to dust density while inversely related to radiation density. Again for 5gm of marble dust at radiations levels of 380, 400 and 480 W/m^2 power loss of 20.1%, 11.4% and 8.2% has been observed. For the same radiations levels but with 25gm marble dust it was 38.63%, 31% and 26.5% and for 35gm it was 56.42%, 46.11% and 40.30% observed respectively. For the dune sand of 5gm weight the power losses of 11.61%, 9.22% and 6.46% has been noted at radiations levels of 380, 400 and 480 W/m^2 respectively. For the same radiations levels but with 25gm of sand dune it was 28.83%, 20.11 and 11.8% and for 35gm it was 52.79%, 45.89% and 28.97% respectively. After exploring the data it results that as the size of dust grain reduces power loss increases since smaller particles fits into voids thus for the same weight of dust sample and same irradiation level power loss is maximum for fine dust collected from the solar panel, followed by marble dust and sand from dune . In the dirty solar panel any sphere of dust covers the panel thus blocking the light reaching it. However not all the radiation reaching the sphere is lost because of it is reflected and can be partially received again by the panel. From the graphical representation of the data it is concluded that the power loss gradually increased with the dust mass deposited and it follows the exponential trend line. This power loss is not only mass-dependent but also depends on the dust properties. From the experiment data it is reflected that electrical power output was compressed significantly (by up to 71%) when external resistances concealed the light path of the solar panel. As a consequence we may conclude that the windblown particles negatively affect the PV module performance and the level of degradation is non-negligible.

5. Conclusion

A comparative experimental study of a total three dust samples with specific weight and varying radiation levels has been performed. First Dust sample was collected from the solar panel installed at the rooftop of S.P.C.Govt College Ajmer. Marble dust was collected from a marble cutting and polishing factory in this region. The dune sand was collected from Pushkar district of Rajasthan involved in this study. From the study it is observed that the dust collected from the solar panel register considerably lower power and superior power loss because in this sample various fine particles were recorded which was proven by SEM analysis. It is concluded that a small layer of dust particles can reduce the PV output power to a large extent. Regular cleaning after every seven days recommended for efficient system performance.

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