Effects of Dust Grain Size and Density on the Monocrystalline PV Output Power

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Abstract

An important part of the Jordanian government strategy to overcome the energy challenge is to diverse to renewable sources, such as photovoltaic (PV) solar power. In this context, many projects have been initiated by both government and private sector. The southern part of the country has an outstanding potential for such projects. This study investigates the most suitable location for PV solar power station located in Al-Hussein Bin Talal University (AHU). In this study, the performance of Mono crystalline PV panels was evaluated, and the influence of dust grain size and mass deposition density (g/m^2) on the maximum output power point (P_{MAX}) was yielded. The dust samples were collected from three different locations at AHU, and then tested in the laboratory under steady conditions. The deposited dusts were adhered to PV panels' surfaces, which in turn; reduced the amount of solar radiation that reaching PV panels and decreasing the panels' efficiency significantly.

Keywords: Mass deposition density (g/m^2); Photovoltaic; Maximum output power point (P_{MAX}); Dust grain size

1. Introduction

Photovoltaic (PV) solar power is a promising renewable energy technology worldwide. It significantly reduces pollution sources; it can greatly reduce the contribution to global warming as there is no methane, carbon dioxide, nitrous oxide or other greenhouse gases that can absorb and emit any radiation within the thermal infrared range; and its production cost is decreasing as technology develops as well as having low running costs (WREC, 2000; McCaffrey, 2006).

As a public higher education institution, Al-Hussein Bin Talal University initiated a sustainable development strategy aiming to: rationalize resources management and usage, enhance the educational institutional role, and create a societal change in the area of sustainability. And since the university located in a high annual direct irradiation city; Ma'an, southern Jordan, at latitude 30.2° and longitude 35.4°, it will provide a fertile site for solar energy project. In the same vein, technically it is crucial to select the most suitable location for the project within the university environment, taking in account the effect of different type of dust on the panels' performance. Consideration in this study has been given only to the dust mass density and grain size distribution in different locations, since the weather's effect in the three locations are almost the same?

The most common efficiency indicators for PV solar cells are the maximum power point and their energy conversion efficiency (η). The maximum power point (P_{MAX}) is the point where the array can generates the maximum electric power, while the energy conversion efficiency (η) is measured by the percentage of maximum electrical power produced to the incidence of total solar energy on the cells (Goetzberger and Hoffmann, 2005).

The maximum power point and the cell conversion efficiency can be calculated using Formulas 1and 2 below, respectively, where V_{mp} (the voltage at the maximum power point), I_{mp} (the current at the maximum power point), A is the panel area and measured in (m2); and (E_{TOT}) is the total incident irradiance under standard test conditions (STC) and measured in (W/m^2) (Goswami and Kreith, 2007).

$$P_{MAX} = V_{mp} \times I_{mp} \quad . \; . \; . \; . \; . \; . \; (1)$$

$$\eta = \frac{P_{MAX}}{E_{TOT} \times A} \times 100 \quad . \; . \; . \; . \; . \; (2)$$

The PV solar cells cannot achieve 100% energy conversion efficiency. The reason behind that refers to the fact that, the PV solar cells are usually not able to respond to the wide spectrum sunlight. Which means that the photons with energy less than the energy for the PV solar cells material's Band Gap (BG) are not absorbed (Kasap, 2006), and that waste around 25% of the incoming energy (Goswami and Kreith, 2007). The best laboratory efficiency for silicon solar cells is almost 25%, while the PV modules are available with an overall efficiency of about 20% (Goetzberger and Hoffmann, 2005).

Dust deposition on the photovoltaic modules surfaces is a significant factor in decrease the incoming irradiance to the cell, and thus, produces power losses (Zorrilla-Casanova, *et al.*, 2011). Dust deposition relies on multi factors, some related to the dust properties (e.g. chemical properties, size, shape, weight), and other related to the environmental conditions (e.g. site-specific factors, environmental features and weather conditions) (Mekhilefa, *et al.*, 2012).

Different studies demonstrated the affect of altered type of dust on the power gradation in different environments (see for example, Lawrence and Neff, 2009; Darwish *et al.*, 2015; Mastekbayeva and Kumar, 2000; Hegazy, 2001; Elminir *et al.*, 2006; Mejia e*t al.*, 2013; Adinoyi and Said, 2013; Kazem *et al*., 2013; Abhishek Rao *et al.*, 2013; Ali *et al*., 2015). Relying on the previous literature outlined above, it could be concluded that the accumulation of dust particles on the PV solar cells affects the PV solar cells' efficiency. The main reasons for this can be summarized in the following points. First, the particles cause a light scattering and reduce the amount of light transmittance to the PV solar cells' surface. Second, fine particles are capable of spreading and covering uniformly over the PV solar cells' surfaces, thus decreasing the amount of transmitted light to the PV solar cells. Finally, increasing the tilt angles will reduce the amount of dust get accumulated on the panel surfaces and so decreasing the power's drop.

Generally, the dust may be classified according to grain size into fine grain less than 0.05mm (predominantly clay and silt size), medium grain size 0.05-2 mm (predominantly sand size), and coarse grain size 2-57 mm (gravel size predominant) – as the range of particle size can be very large (Hillel, 2004).

The main objective of this study is to evaluate the effect of different types of dust (from the university's surrounded environment), on the performance of Monocrystalline PV panel. The dust effect was classified according to the grain size, and the mass deposition density (g/m^2) of the dust. In addition to the introduction presented above, the flow of this paper is divided into several parts as follows: experiment methodology; experimental results and discussion; and conclusion of the study.

2. Experiment Methodology

All experiments were conducted indoor where a constant light source with constant zero value tilt angle (horizontal panel), and constant radiation was used to prevail over the variation in radiation that may experience under the sunlight. A halogen lamp of 100watt was used as a light source through over the experiments. The output power for the panel was measured before and after the dust deposition. The different samples of the tested dust were geographically site dependent. It is related to the pollution in the suggested location to install the panels.

The experimental tools were consisted of Monocrystalline silicon photovoltaic module, monitoring system, and basic electronics trainer M30 kit. The monitoring system was consisted of two DM-9080 digital multimeters. The investigation was carried out for different mass deposition density (g/m^2) for each dust sample separately. The electrical specifications for Monocrystalline panel as measured in the laboratory are illustrated in Table 1 below.

Table 1: Monocrystalline Electrical Specifications

Monocrystalline Silicon	
P_{max}	2.97W
V_{mp} (voltage at the maximum power point)	11.60V
I_{mp} (current at the maximum power point)	25.60mA
V_{oc} (open circuit voltage)	15.50V
I_{sc} (short circuit current)	36.10mA

To investigate the current voltage relation (I-V), the power voltage relation (P-V), and the maximum power point P_{MAX}, the current and voltage for the panel were measured by supplying power to variable resisters as shown on Figure1 below. All measurements were taken under the same testing conditions (temperature, irradiance source and tilt angle).

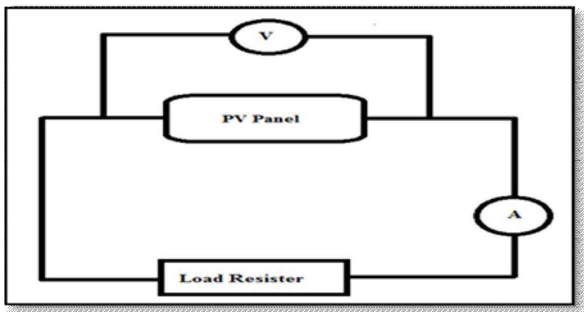


Figure 1: PV panel test circuit Schematic diagram

Figures 2 and 3 summarize the I-V and P-V curves for different variations of current and voltages of the Monocrystaline PV panel under the test. The key points for the curves are the short circuit current I_{SC} (at zero volt), open circuit voltage V_{OC} (at zero current), and the maximum power point which can be founded at the knee of P-V curve.

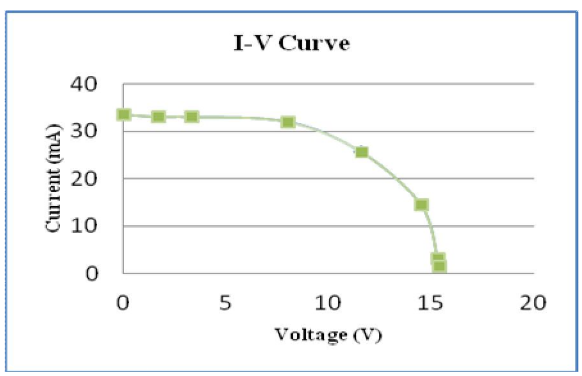


Figure 2: I-V Curve for Monocrystalline PV panel

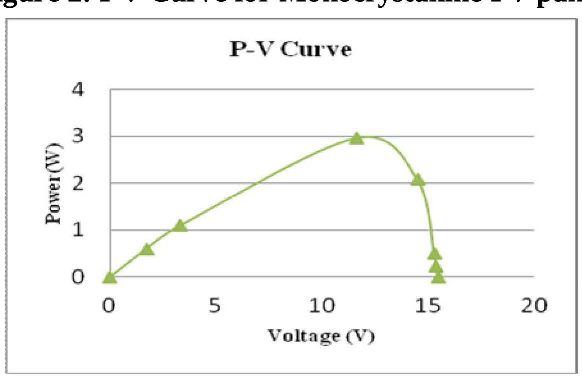


Figure 3: P-V Curve for Monocrystalline PV panel

Same amount of dust samples were collected from the three suggested locations for the project in AHU, each sample was investigated separately before use to coat the panels. All samples were dried in the university laboratory using oven, and then subdivided using rifle box. Different sieve opening sizes were used to classify the dust grain according to their sizes.

For testing purposes, a constant mass dust deposition density was used for the panel during each experiment. The following dust mass deposition densities tested were 5, 2.5, 1 g/m^2 respectively, an equal distribution (33.33%) from different grain size was taken. The maximum output powers from the panel were measured before and after the dust mass deposition in the laboratory.

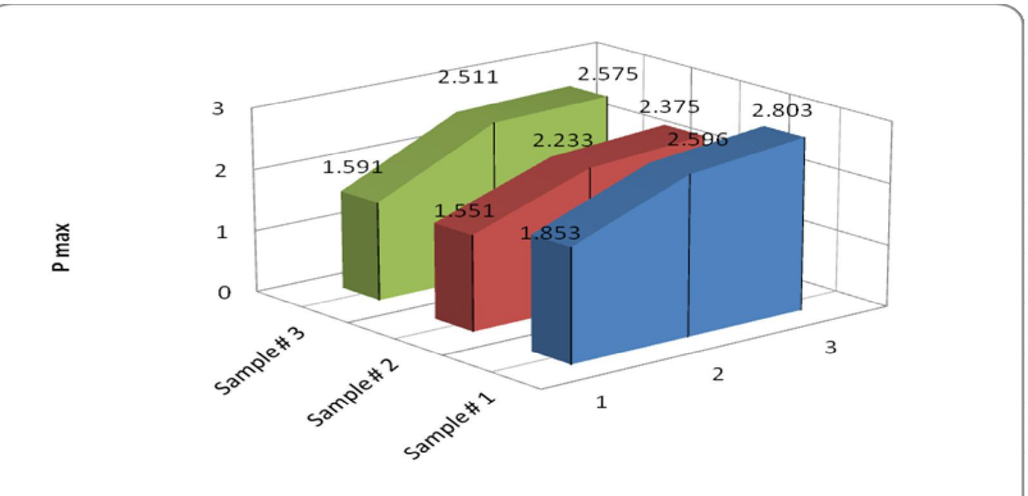
3. Experimental Results and Discussion

This section exhibits and discusses the results obtained throughout the experiments. Table 2 below illustrates the grain ranges for the three dust samples (the ranges were classified according to the sieve opening in mm). For each sample, the percentages of dust distribution according to the grain size were given in the Table below.

Table 2: The Grain Ranges for the Three Samples

Sieve Opining	**Mass retained in the sieve**					
(mm)	**Sample 1**		**Sample 2**		**Sample 3**	
2-19	398.45g	26.61%	248.45g	16.60%	288.01g	19.23%
0.05-2	648.50g	43.30%	577.70g	38.57%	603.40g	40.29%
<0.05	450.60g	30.10%	671.40g	44.83%	606.14g	40.48%

Based on the results presented in Table 2 for the three dust samples, it is observable that the first sample has the larger percentage of coarse dust grain (26.61%) and less percentage of fine grain (30.10%). Furthermore, for the second and third samples, the percentages for the grain size distribution are closer to each other. Although, sample three got 2.63% and 1.72% more coarse and medium grain size than sample two respectively, while sample two got 4.35% more fine grain dust particles than the third sample. A 3D (three dimension) graph in Figure 4 shows the P_{max} obtained from the Monocrystalline PV panel, after being coated with the dust samples by different dust mass density per time. The numbers 1, 2 and 3 on the third dimension represent the three amount of dust mass density that were used (5, 2.5 and 1 g/m^2), respectively.



	1	2	3
Sample#1	1.853	2.596	2.803
Sample#2	1.551	2.233	2.375
Sample#3	1.591	2.511	2.575

Figure 4: 3D Graph for the Pmax with Different Dust Mass Density for the Research Samples

By utilizing the maximum power point for the panel as a reference point (2.97W), the reduction percentage where obtained for each sample, under the different dust mass density. Table 3 below illustrates these reduction percentages.

Table 3: The Reduction Percentages for each Sample under Different Dust Mass Density

Sample	Pmax Reduction Percentages		
	$5g/m^2$	$2.5g/m^2$	$1g/m^2$
1	37.61%	12.60%	5.62%
2	47.78%	24.81%	20.03%
3	46.43%	15.45%	13.30%

Relying on the data presented in Tables 2, 3 and Figure 4, it could be indicated that increasing the dust mass density from 1 g/m^2 tox $5g/m^2$ value, would have a noticeable effect on the maximum output power obtained from the PV panel. By revising each sample separately, the researchers found that the maximum reduction percentages on the Pmax were obtained at 5 g/m^2 dust mass density. These percentages were 37.61%, 47.78% and 46.43% for samples 1, 2 and 3, respectively. Moreover, the minimum reduction percentages on P_{max} obtained at $1g/m^2$ dust mass density, these were 5.62%, 20.03% and 13.30% for sample 1, 2 and 3 respectively.

By revising each mass deposition density (g/m^2) that were tested separately, the researchers found that the minimum reductions on the P_{max} where recorded after coated the panel using the first sample with different mass deposition density, which were 37.61%, 12.60% and 5.62% for 5, 2.5 and $1g/m^2$ respectively. For this sample the dust grain distribution result shows larger percentage of coarse dust grains and less percentage of fine grains, while the capability of fine particles for spreading and covering uniformly over the PV solar cells' surfaces are much more than the large ones.

The power reductions were more for the second and third dust samples, and the dust grain distributions were much comparable for the two samples. Moreover, the reductions percentages for the second sample were a bit higher (47.78%, 24.81% and 20.03% for 5, 2.5 and $1g/m^2$ respectively). The variation in these results is related to the deference in the grain size distribution between the second and the third sample. The percentage of medium and soft grain size for the second sample was 2.63% more than it was for the third sample, which in turn, could explain the maximum power reduction that obtained from the second sample through over all the experiments at the different dust mass density. Thus, it could be stated that there is an inverse relation between the reduction on the output power and the dust grain size.

4. Conclusion

This study investigated the effect of dust grain size and mass deposition density (g/m^2) on the maximum output power point (P_{MAX}) for Monocrystalline PV panels. Three samples of dust were collected from three different locations in AHU, and then tested in the laboratory under steady conditions.

The obtained results proved that increasing the mass deposition density (g/m^2), result to increase the reduction on the PV panel P_{MAX}. The results also confirm that the fine and medium particle size has more ability of spreading and covering uniformly over the PV panel surface, thus decreasing the amount of transmitted light to the PV solar cells and reduce the maximum power point obtained from the panel.

Finally, based on the current research findings, a recommendation for a best location to construct a PV station in Al-Hussein Bin Talal University (AHU) could be presented. This location is the one where the first sample was obtained, since the least reductions were resulted from that geographical site.

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