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An Indoor Experimental Study on the Effect of Dust on a Solar PV Panel

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Abstract – This study investigates the effect of soiling on the performance of a solar photovoltaic (PV) panel at controllable indoor conditions. The investigation took a dynamic study approach into the I–V characteristics curve at the National Energy Research Center (NERC), Soba, Khartoum state, Sudan. The soiling used dust samples collected from the premises of NERC. The experiments were conducted using some of the prepared dust samples' particles distributed on a mono-crystalline silicon solar PV panel with a constant power light source. At different dust layers the solar PV was characterized by computing the resulting power generated of the PV panel. It has been found that the accumulation of the dust on the surface of the solar photovoltaic panel, 14.6 µm and 43.9 µm thicknesses, can reduce the panel's generated power by 17.1% and 67.6%, respectively. In addition, a full blockage of the solar photovoltaic panel's characteristics has been reported at 109.8 µm thickness of the dust layer.

Keywords: Photovoltaic, Solar, Soiling, Dust, Dust Layers.

1. Introduction

Renewable energy sources such as the sun, the wind, water, the Earth's heat, and plants are continually replenished by nature. Renewable energy technologies turn these resources into usable forms of energy most often electricity, but also heat, chemicals, or mechanical power NREL [1].

Sudan is very rich in solar radiation and has long sunshine hours all over the country, Osman [2] and Rabah et al. [3]. It is one of the top solar energy regions of the world. It has an average sunshine duration ranging from 8.5 to 11 hours per day, solar radiation from 20 to 25 MJ m^{-2} day^{-1} on the horizontal surface, and an annual daily mean global radiation ranges from 3.05 - 7.62 kWm^{-2} day^{-1}, Omer [4]. Nevertheless, according to the study by Rabah et al. [3] addressing Sudan's energy supply, transformation and demand; it was found that the Sudan's energy consists of oil (39%), biomass (56%), and hydroelectricity (5%). The study showed that solar energy, mainly photovoltaic, contribution is very little. The striking evidence that; despite of the high intensity of solar radiation and long sunshine hours across the country Sudan's solar energy is untapped. It is prudent that Sudan should focus on the utilization of this unlimited free renewable energy resource.

There are many reasons to choose solar energy in Sudan as a substitute for fossil fuels. It is a continuous source of energy, not subjected to political control, environment friendly, easy to convert to electricity and store, and at a very competitive cost with the present technology, Elzubeir [5]. However, one of the challenges that face the optimum usage of this fast-emerging technology, in places like Sudan, is the reduction of the solar PV systems performance due to the accumulation of dust on the PV panels' surfaces. An experimental setup was developed to investigate the effect of the dust accumulation on the solar PV performance.

The main objective of this study is to measure the effect of dust on the performance of solar PV panel. The study measured and constructed a solar PV panel I-V characteristics chart subjected to samples of dust collected from NERC, Soba, Khartoum state, Sudan.

2. Literature Review

Deterioration in the performance of a solar PV panel is subjected to different factors, e.g. the type of PV material, solar radiation intensity received, cell temperature, shading effects, dust, module orientation, weather conditions, geographical location …etc, Vidyanandan [6]

One of the most and critical factors affecting the performance of PV solar panel is dust. It is defined as the minute solid particles less than 500 µm in diameter. Dust settlement on PV solar panel mainly relies on the dust properties (type,

chemical, biological and electrostatic properties, size, shape, weight, etc.) as well as on the environmental conditions (environmental factors and weather conditions). Mani et al. [7].

There were a wide range of studies investigating the impact of dust worldwide subjected to different settings, environments and time frame. An important factor to evaluate this study is to construct the I-V characteristic curve in which it describes the solar PV panel energy conversion capability at the existing conditions of irradiance (light level) and temperature, [8], see figure 1.

In India an indoor study made by Rao et al. [9], attempts to understand the influence of dust deposition on PV solar panel. Two identical poly-crystalline panels were exposed to halogen lamps. An amount of 0.363 grams of dust was distributed over a surface area of 0.258 m^2 to one of the panels and maintaining the other one clean. By analyzing the I-V curve characteristic it's concluded that the short circuit current is affected by dust deposition, to the tune of 30-40% consequently, a drop in power output as well. A reduction in the power generation capacity of the poly-crystalline silicon solar cell was also recorded by Dadas et al. [10] using seven different layers of dust as a screen.

Moreover in India another study was done by Hussain et al. [11]. Seven dust samples with different weight were experimented (Badarpur sand 1, Badarpur sand 2, fly ash, rice husk, chalk powder, brick powder, and sand) and subjected to three radiation levels of 650, 750 and 850 W/m^2. It's found that, small layer of dust can affect the performance of PV solar panel. In addition, the efficiency of solar panel in terms of power can be reduced by up to 60%.

Ibrahim [12] studied the effect of dust and shadow in Egypt. The experiment included a silicon solar cell (10 cm * 6 cm in dimensions) and a solar-simulator (a 100W Halogen lamp). A reduction of 2.78% and 0.863% were recorded on both Isc and Voc respectively due to dust accumulation.

An experimental study was carried out in Jaipur, India by Kumar et al. [13] to inquire the impact of dust of solar PV panel. The experimental work was conducted for 20 days under constant halogen lamp's radiation. Obtaining the data from the I-V curve characteristic, it was found that, the reduction in power and short circuit current by up to 31.1 % and 27.24 % respectively. Moreover, degradation from 7.2% to 5% in the efficiency of solar PV panel was recorded.

In Malaysia the influence of dust soiling was studied using artificial dust (mud and talcum) under a constant light radiation conducted in an indoor lab. It was found that the accumulated dust on the surface of photovoltaic solar panel effect negatively on its performance. The system's efficiency and peak power reduced by up to 50% and 18% respectively, Sulaiman et al. [14].

In Oman, a group of different samples of pollutant (red soil, ash, sand, calcium carbonate, and silica) are used to investigate the soiling impact on multi-crystalline PV module in indoor and outdoor conditions. From the gained results it's derived that, firstly, the degradation on multi-crystalline PV module is totally depended on the type of pollutant and the level of accumulation. Secondly, the increase in temperature has a negative effect on the performance of PV module. Thirdly, 25% is the highest reduction when ash pollutant is used, Kazem et. al. [15]

The effect of pollutants was further investigated on PV solar panel by using three Iraqi construction pollutants (cement, plaster, and borax) in controlled conditions. It's recorded that a reduction of 25.8% was recorded when 10 grams of plaster is layered, Abass et al. [16]. Furthermore, the sequence of talcum, dust, sand, and moss deposition was studied on solar PV panel. It's acquired that; the output power was reduced by up to 85% when moss is used, Sulaiman et al. [17].

Experimental indoor analysis on Mono-crystalline, Multi-crystalline and Amorphous silicon PV solar panel was preceded to study the effect of three types of dust pollutants (red soil, ash and sand) on their performances. It's found that, amorphous silicon PV solar panel present better than the other two types in dirty environment. In addition, ash recorded the most considerable impact on the PV voltage, Kazem et al. [18]

In Al-Hussein Bin Talal University, Jordan, an indoor experiment was conducted by Al-Shabaan et al. [19] to investigate the impact of dust grain size and mass deposition density (g/m^2) on the performance of Mono-crystalline solar PV panel. It's concluded that the relation between the mass deposition density (g/m2) and the performance of PV solar panel is inverse relationship. Besides, the same relation goes for the dust grain size.

Considering these facts in view, an experimental study at NERC, Soba, Khartoum state, Sudan has been carried out to investigate the effect and impact of dust on PV solar panel performance. This research, along with similar outdoor experiments, was designed to investigate and characterize the effect of dust on solar PV performance at NERC. The main objective was to develop an empirical correlation of the effect of the dust, at NERC, on the performance of solar PV panels. This correlation will be used later in designing optimum cleaning methods and/or cleaning intervals. Because Sudan is a large country with various climatic conditions and soil characteristics, the experiments can be repeated at other sites in the country, to assess the validity of the correlations.

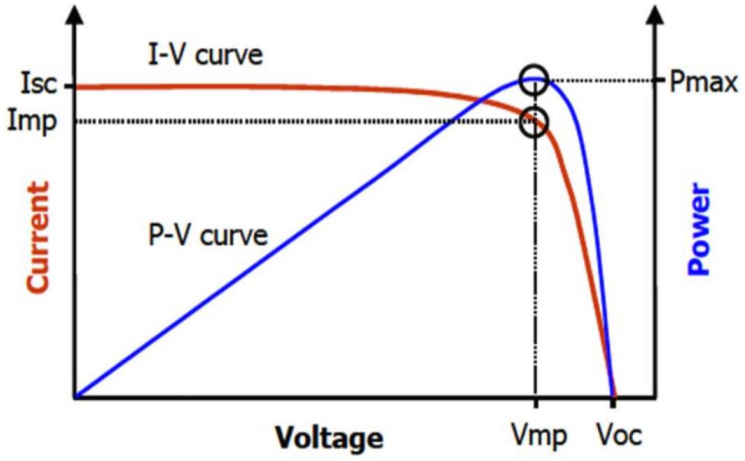

Figure 1. The I-V and P-V curves of a photovoltaic device

3. Experimental Methodology

The system comprised of a solar photovoltaic panel manufactured at NERC, Soba, Khartoum, Sudan, with electrical specification as follow: open circuit voltage (V_{OC}) =17.95 V, short circuit current (I_{SC}) = 1.066 A, peak power (P_{MAX}) =10.41 W, voltage (V_{MP}) = 13.10 V, current (I_{MP}) = 0.795 A, at standard test condition (STC): Irradiance = 1000W/m^2, temperature = 25°C. The solar panel consists of 18 mono-crystalline silicon cells with dimensions of 14 cm * 40 cm and a surface area of 560 cm^2 as shown in figure 2.

The PV solar panel was held at 0^o tilt angle with the horizontal under suspended spotlight positioned about 10 cm vertically above the panel surface, see figure 3. The spotlight delivered constant radiation energy to the PV solar panel rated at 400 W.

In this experiment the tested amount of dust was collected from the surrounding environment at Soba in which the chart obtained will be useful for any sample of dust similar to the nature of Soba's dust particles.

Experiments were performed in an indoor lab using a prepared sample of dust containing three different particle sizes of (45µm, 64µm, 123µm) in diameter, with specific mass ratio of (1:3:2) similar to the actual dust accumulation size spectrum in Sudan, Sharif [20], in order to quantify the effects of deposited dust on the performance of the PV panel. Figure 4 shows the device used to provide the required sizes of dust diameters.

For the measurements of the irradiation, voltage and current; a Silicon Pyranometer SOZ-03 and multi-meter were used in the arrangement. The system's load was simulated by using variable resistance (116Ω) in order to draw the characteristic, I-V and P-V curves of a solar photovoltaic panel, see figure 5.

Figure 2. The Indoor PV panel

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Figure 3. Indoor Experiment Setup

Figure 4. Vibrating Sieve to Sorting Dust Particles Size

Effectiveness of Dust on PV Solar Panel

In order to quantify the current-voltage and power-voltage curves for the PV solar cell the experimental procedure was carried out indoors and 15 measurements were recorded, Farah et al. [22]. The first measurement was taken by covering the surface of the PV solar panel with a layer of 1 gram of dust particles, estimated by the Electronic Balance Device shown in figure 5, distributed evenly using a strainer. The remaining measurements were taken repeatedly, by adding 1 gram of dust layer and take the corresponding readings, until reaching an accumulative layer of 15 grams of dust particles. As a result, the values of open circuit voltage (V_{OC}) and short circuit current (I_{SC}) were obtained. In addition, the output power (P_{OUT}), efficiency (η) and dust thickness were calculated 15 times repeatedly, using these equations below:

- Output power (P_{OUT})

$$P_{\mathrm{OUT}} = V_{\mathrm{OC}} * I_{SC} \quad (1)$$

Where:

V_{OC} is the open circuit voltage (V).

I_{SC} is the short circuit current (A).

- Efficiency of the cell (η):

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$$\eta = \frac{V_p * I_p}{P_s * A} * 100\% \quad (2)$$

Where:

I_p is the electrical current produced by the solar PV panel (A).
V_p is the voltage of the electricity produced (V).
P_s is the power of the incident solar radiation (W/m²).
A is the exposed area of the solar panel (m^2)

The panel area in this experiment is equal to 0.056m^2.

- Thickness of dust

$$t = \frac{m}{\rho * A} \quad (3)$$

Where:

t is the dust thickness (m)
m is the mass of the dust (g).
ρ is the density of dust particles (g/cm^3)

The dust density is equal to 2.44 g/cm^3), Sharif et al. [21].

Figure 5. Electronic Balance Device

4. Results and Discussions

Figure 6 shows the current-voltage (I-V) and power-voltage (P-V) curves of cleaned panel (0gram of dust). The figure depicts relationships similar to those shown in figure 1. At this operation conditions the maximum power is 3.4W which is been generated at a current, I_{SC}, of 0.25A and a voltage, V_{OC}, equals to 13.5V.

Figure 7 shows the I-V and P-V curves when one gram (1g) of dust is been evenly distributed over the solar PV panel. As shown in the figure slight drops occur in the current (I) and the power (P) values as compared to the results of the clean panel, see figure 6. Figures 7 displays a maximum power of 3.1W which is been generated at a current, I_{SC}, of 0.24A and a voltage, V_{OC}, equals to 13.1V.

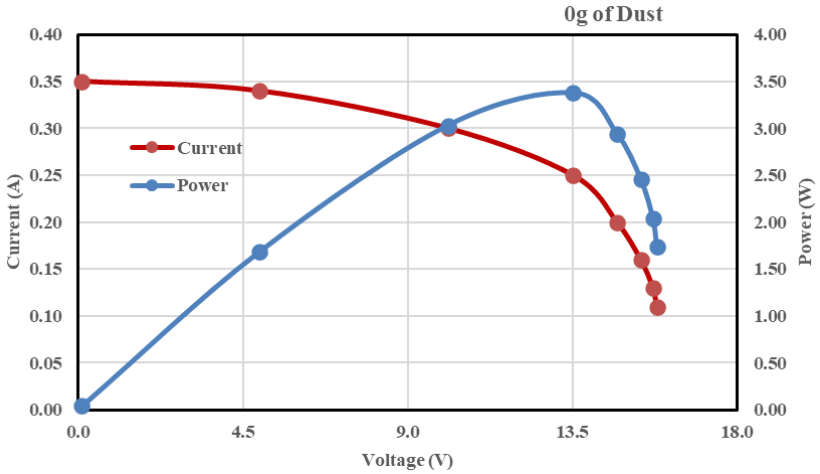

Figure 6. The I-V and P-V curves of a clean PV panel

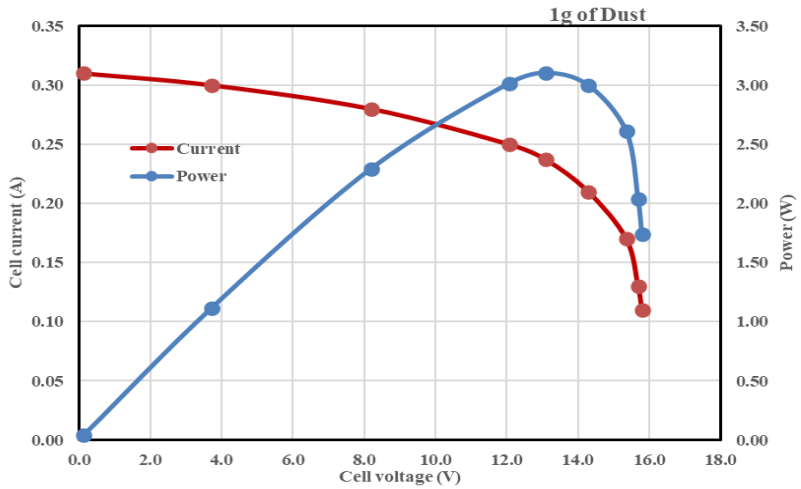

Figure 7. The I-V and P-V curves of 1g dusted PV Panel

Figure 8 shows the current-voltage (I-V) curves for 0, 1, 3, 4, 5, and 10g of dust mass, while figure 9 depicts the power-voltage (P-V) at the same dusting conditions. As expected, and been seen in figure 8, the panel produced current decreases as the dust accumulation increases. Likewise, the PV panel generated power drops with the increase in the dust accumulation, figure 9.

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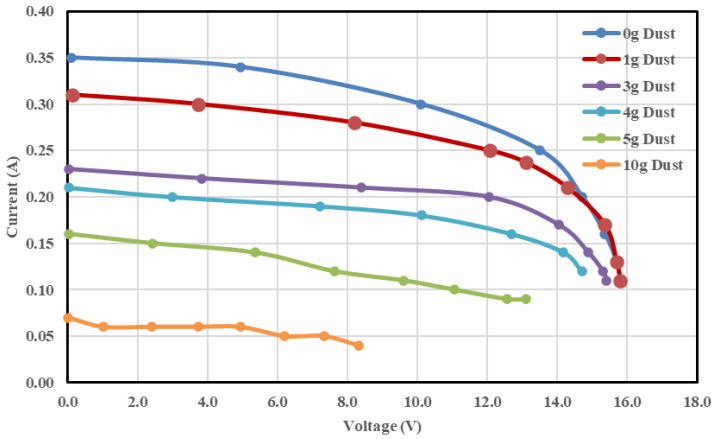

Figure 8. The I-V Curves of clean and dusted PV Panel

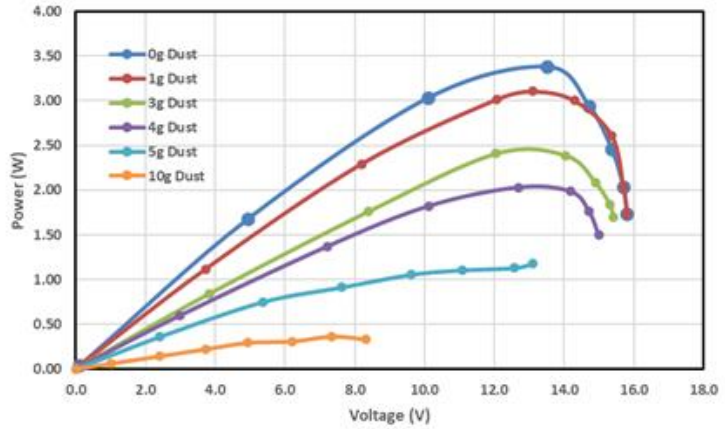

Figure 9. The P-V Curves of the PV Panel

The solar PV panel's generated current (A) and power (W) decrease exponentially figures 10 and 11. The PV generated power decreases until it reaches nearly zero when the amount of dust is 15g (109.8µm thick), as revealed in figure 11.

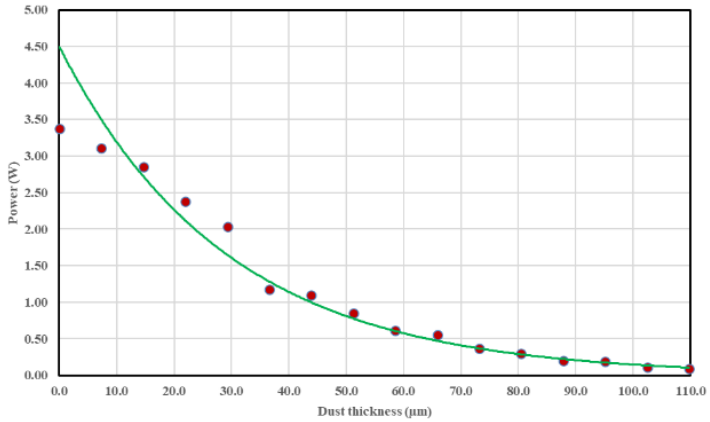

Figure 10. The PV Panel Power and Dust Thickness

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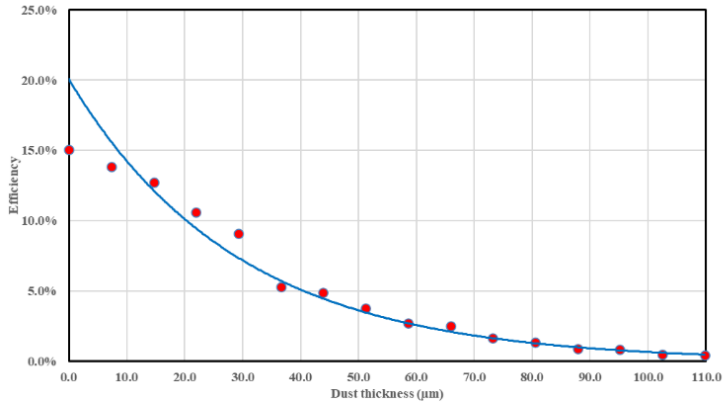

Figure 11. The PV Panel Efficiency and Dust Thickness

It is very interesting to observe the strong dependence of the PV generated power on the associated panel efficiency. The two figures have similar almost identical patterns. Furthermore, these figures (Figure 10 and Figure 11) represent clearly the negative effect of dust deposition on the PV panel performance. However, it worth noting that the effect of dust on the PV panel performance may depend on the geographic location. Most likely this effect is correlated to the local air pollution and the nature of dust in the place where the PV system is installed. It is worth to mention that the power-dust thickness relationship, equations (4) and (5) in very good agreement with experiment data when t > 7 μm, as shown in figures 10 and 11.

The best curve that fits the power-dust thickness relationship in figure 10 can be represented by;

$$P = 4.496e^{-0.034t} \tag{4}$$

With $R^2 = 0.988$

Likewise, the panel efficiency, in figure 11, can be expressed as;

$$\eta = 0.201e^{-0.034t} \tag{5}$$

With $R^2 = 0.988$

The percentage reduction in the output power is shown in figure 12. The reduction in a range from 11.15% to 97.20%. This figure depicts the fact that the PV power will be completely blocked when the dust thickness is approximately 110 μm. At this point no radiation reaches the PV cells and thus no electric power output.

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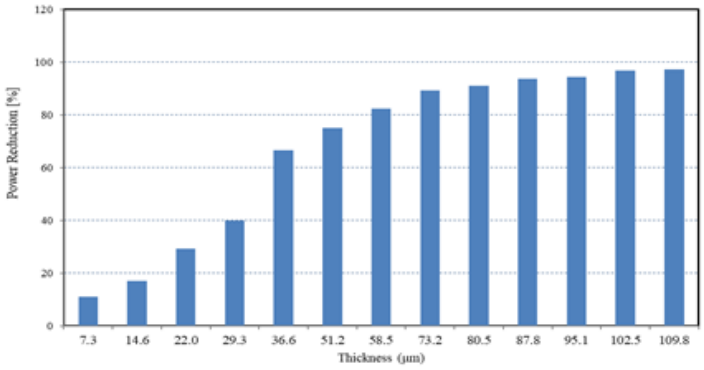

Figure 12. Percentage Power Reduction (Efficiency Drop) with Dust Thickness

5. Conclusions

The effect of dust particles' presence was studied on a mono-crystalline silicon solar PV panel; by obtaining I-V and P-V curves using natural dust with different dust masses (1g up to 15g) in an indoor laboratory at constant radiation source. The followings are concluded points from this study:

- The accumulation of dust has dramatically decreased the generated current and output voltage of the PV system.
- The drop in the current, power and efficiency has followed a continuous decay that is exponentially correlated these parameters with the thickness of the accumulated dust.
- The deposition of 17.86 g/m2 of dust mass leads to a reduction in efficiency by 11.15% and this reduction increased exponentially to 97.20 % at 267.86 g/m^2.
- The developed exponential relation of the solar PV performance (P,η) with the dust layer thickness fits accurately the experimental data.

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