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Experimental Study to Investigate the Effect of Dust, Wind Speed and Temperature on the PV Module Performance

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Abstract

This paper investigates the environmental effects (temperature, wind speed and dust) on photovoltaic module (mono-crystalline) performance. The degradation of the PV performance owing to an increase of temperature and dust density is investigated. A series of experiments were conducted in order to study the effect of these parameters on the PV performance. First, a test of the PV module at standard test conditions (STC) was analyzed. Then, the effects of temperature, wind speed and several type of dust accumulation on the PV performance were examined. The depositions of red soil, sand and white soil dust were used in the study. I-V characteristics were determined for various intensities of dust. The evolutions of the short circuit current, the open circuit voltage, and the maximum power for the several cases were examined. The experimental results show that the PV voltage and power is affected significantly by pollutant type and deposition level. However, a larger reduction in the PV performance was observed in the case of white soil dust, owing to its smaller particles, than sand or red soil.

Keywords: *The PV performance, Dust, Red soil, White dust.*

1. Introduction

Solar energy is one of the most important renewable energy sources on account of its easy availability, cleanness and cheapness. Nowadays a number of solar energy approaches are being pursued and photovoltaic cells are being given more attention by electrical power engineers, owing to rapid development in the world and society. More recent attention has focused on the use of PV power systems on the distribution networks as well as the degradation effects of PV on the distribution system stability, power losses and reliability. Al-Maghalseh [1-5] investigated the differential impact of renewable energy distribution generation on the system performance and stability. PV system performance can be affected by several conditions such as temperature, weather conditions, dust, wind speed. However, There is a large volume of published studies have investigated the effect of dust and climate conditions on the PV performance. Mani and Pillai [6] reviewed the literature from the period to evaluate the impact of dust on PV performance. The research has been conducted into two phases for two time periods. Drawing on an extensive range of sources, the authors identifies the challenges of future research and the appropriate cleaning/maintenance cycle of the PV systems. Batra et al [7], investigate the effects of Badarpur, fly ash, and rice husk on the PV performance. He found that the rice husk has the highest effects on the PV performance.

El-Shobokshy and Hussein[3, 4]carried out both experimental and numerical study in order to investigate the effect of dust on PV performance. The study has shown that the short circuit current was reduced significantly with dust deposition. Further, the finer particles have a greater effect on the PV performance compared to that of courser particle. Kymakis et al.[5] examined the effect of dust deposition on the power losses of a grid connected PV park. The system has a peak power of 171.36 kWp and it indicated that the annual loss is about 5.86% due to the dust deposition. Kaldellis et al.[6]conducted an outdoor experiment to study the impact of temperature and wind speed on the PV performance. It was found that the PV efficiency has reduced by 0.3%-0.45% per the increase of temperature (C). Schwingshackl et al.[7] numerically investigated the effect of wind on the PV Module temperature. Several techniques are investigated, and it was found that the wind cooling effects plays an important role for the power estimation.

The performance of a photovoltaic cell depends on manufacturing technology and the operating conditions under Standard Test Conditions (STC)[8]. The photovoltaic cell of terrestrial solar power modules is tested in order to measure and explain its I-V curve characteristic and to compare the performance of different solar power modules under uniform operating conditions. These performance conditions are at incident sunlight of 1000 W/m², a cell temperature of 25°C (77°F) and an AM (air mass) of 1.5. The air mass determines the radiation

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impact and the spectral combination of the light arriving on the earth's surface [8]. With the increasing use of the PV systems, it is vital to know the effects that active meteorological parameters such as humidity, dust, temperature, wind speed have on their efficiency. This paper investigates the effect of temperature and dust on the PV system performance and parameters such as light intensity or irradiation, tracking angle, temperature, air velocity and dust. Through the photovoltaic parameters like open circuit voltage, short circuit current, maximum output power, fill factor and efficiency are generally affected by the above environmental parameters.

A temperature experiment of the PV by Chander et al. [9] studied the effect of cell temperature on the photovoltaic parameters of a monocrystalline silicon solar cell. The experiment was carried out employing a solar cell simulator with varying temperatures in the range of 25–60°C at constant light intensities of 215–515 W/m^2. The results show that cell temperature has a significant effect on the photo voltaic parameters and controls the quality and performance of the solar cells. The open circuit voltage of the solar cell is highly sensitive to cell temperature. The open circuit voltage, fill factor and maximum output power decrease with an increase in temperature, while short circuit current increases with an increase in temperature. Therefore, the temperature coefficient of the open circuit voltage, fill factor and maximum output is negative, yet positive for the short circuit current. A relative change study of photovoltaic parameters with temperature was also undertaken.

Sulaiman et al. [10] made a study of the effect of dust accumulation on the PV panels. The study used a solar panel (50W) under constant light radiation provided by two spotlights, each giving 500W. An artificial dust of two kinds (dried mud, talcum powder) was used instead of real dust. The dust was spread on a plastic sheet. To measure the dust accumulation on the plastic sheet, a Scanning Electron Microscope (SEM) was used. The power of the solar panel was measured under four conditions: with no plastic sheet, with a clear plastic sheet, with dried mud on the plastic sheet, and with talcum on the plastic sheet. The result showed that the highest peak power occurred when the panel was not covered by a layer of dust or a plastic sheet. If the dust had accumulated on the plastic sheet, the reduction of power generated could be up to 18%. Thus the clean plastic and solar the PV panel without plastic gave the highest efficiency owing to the absence of dust on its surface. Conversely if the dust appeared on the surface of the photovoltaic solar panel it could reduce the system's efficiency by up to 50%.

In this paper, the influence of different values of temperature and the accumulation of dust types on the efficiency of solar the PV panels is assessed by using artificial materials. A constant radiation condition is used by a sun simulator to overcome the variation of the sunlight.

2. Experiment set-up

Basically, the system comprised a multi-crystalline photovoltaic module. This module is a 10W, 21.08V, 0.59A, 1.5 kg and 415×268×22m^3 the PV module. The PV module is connected to the sun simulator to control the radiation by autotransformer. The performances of the PV module are monitored by digital multimeters, temperature sensors and dust sensors. In this research, indoor experiments are conducted to investigate the effect of uniform dust, wind speed and temperature on the PV performance, so the experiments are divided into four sections: (i) The PV module at STC, (ii) the impact of temperature on the PV performance, (iii) the impact of uniform dust on the PV performance, and (iv) the impact of wind speed on the PV module. Fig. 1 shows the experimental block diagram and procedure.

Firstly, in order to determine the impact of the different selected dust (red soil, sand, white soil) on the PV module performance, an experimental procedure was carried out in order to compare the voltage output of the PV module under different dust deposition conditions at constant radiation (1000W/m^2) and a temperature of 30°C. The experimental procedure was carried out indoors and at least 30 measurements were recorded within the time period 110s. The experimental analysis was conducted in the Renewable Energy Laboratory located at the Palestine Polytechnic University in Hebron, Palestine. The dust deposition density was measured in mg/m^3 by using dust sensor GP2Y1010AU0F. Then different types of dust were monitored by an Arduino controller to record the values on an Excel sheet and draw the curves. The dust was uniformly distributed on the PV surface using a fan. Secondly, to determine the effect of temperature on the PV module, the experimental procedure was carried out indoors at a constant radiation (1000W/m^2), varying the value of temperature from 25°C to 55°C, and then taking the mean value of 50 measurements for each value of temperature. In this section, the Arduino microcontroller was connected with the temperature sensor to observe and record its values. In the wind speed effects on the PV experiments, an anemometer was used to measure the value of wind speeds. Also, we used a multispeed fan in order to obtain several wind speed values.

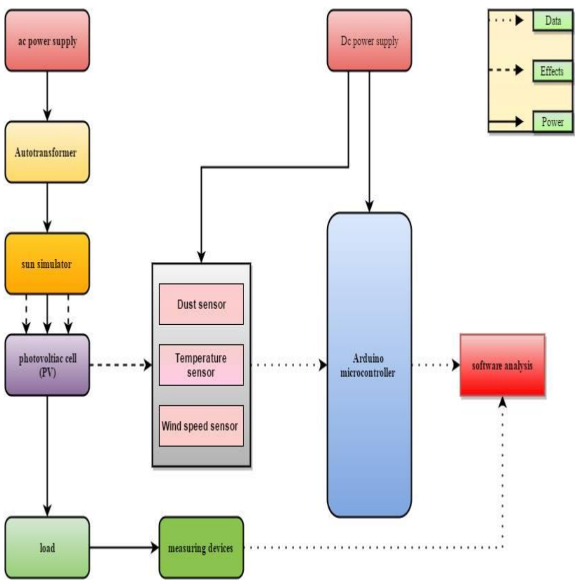

Figure 1: Experiment Block diagram and procedure

3. Results and discussions

3.1. Photovoltaic module at standard test conditions.

Fig. 2 illustratesthe I-V and P-V curves for the PV cell under STC conditions (1000W/m^2, 25°C, A.M 1.5). In this case, the short circuit current (Isc) was 0.6A and open circuit voltage 20.7V. Under STC the maximum power that could be obtained from the PV module was 9.352W and the efficiency was 9.396 %.

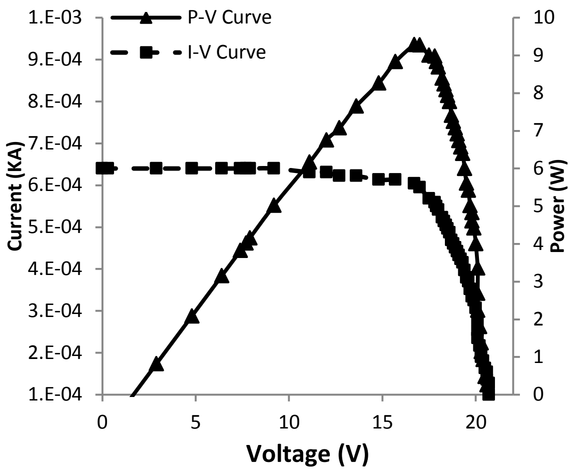

Figure 2: I-V and P-V curvesof the PV module at STC.

3.2. The effect of temperature change on thePV module.

In this section, the performance of the PV module at different temperature levels was investigated. The analysis considers the effect of temperature on the open circuit voltage (V_{oc}), the short circuit current (I_{sc}), maximum power and efficiency of the PV module. Figures 3 and 4 illustrate the I-V and P-V curves at different temperatures of the PV. It can be seen that when the temperature of the PV increased to 30, 35, 40, 45, 50 and 55°C, the open circuit voltage (V_{oc}) decreased to 20, 18.9, 18, 17.4, 16.4 and 16.1V respectively. While the short circuit current (I_{sc}) increased slightly to 0.61, 0.62, 0.64, 0.65, 0.66 and 0.67A respectively. In other words,V_{oc} was decreased by 3.89% per 5 °C above 25°C and I_{sc} was increased by 2% per 5°C above 25°C.

The P-V curves of the PV showed that maximum power (P_{Max}) that could be generated from thePV decreased to 9.263, 8.584, 8.208, 7.611, 7.02 and 6.786W, when the temperature of thePV was raised to 30,35, 40, 45,50 and 55°C. Also, the efficiency of thePV decreased to 9.263%, 8.584%, 8.208%, 7.611%, 7.02% and 6.786% respectively. From these results it can be concluded that P_{Max} and η were decreased by 5% per 5°C above 25 °C (STC). In case of the temperature of the PV below 25°C, V_{oc} increased to 21 V and Isc was decreased to 0.56 A. The maximum output power (P_{Max}) and the efficiency (η) generated from the PV was decreased to 8.823W and 8.86%, respectively. The results agreed well the previous work of [11-14].

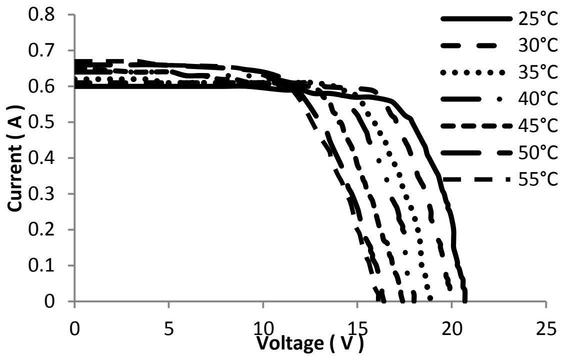

Figure 3: I-V curves of the PV module at different temperature.

The effect of temperature change on maximum output power of the PV module is demonstrated in Fig. 5. From the figure below we can obtain a mathematical expression that describes the relation between P_{Max} and temperature of the PV (T). The P_{Max} of the PV is a function of temperature is drawn below:

$$P_{Max}(T) = -0.09398T + 11.88, \quad T \geq 25°C \qquad (1)$$

$$P_{Max}(T) = 0.092T + 7.029, \quad T \leq 25°C \qquad (2)$$

where:P_{Max} is the maximum output power that can generated from the PV module (W), and T is the temperature of the PV module (°C).

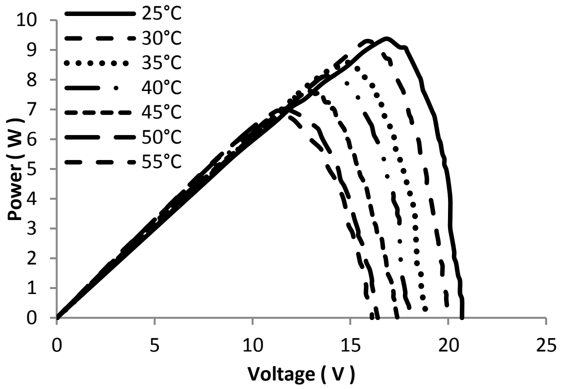

Figure 4: P-V curves of the PV module at different temperature.

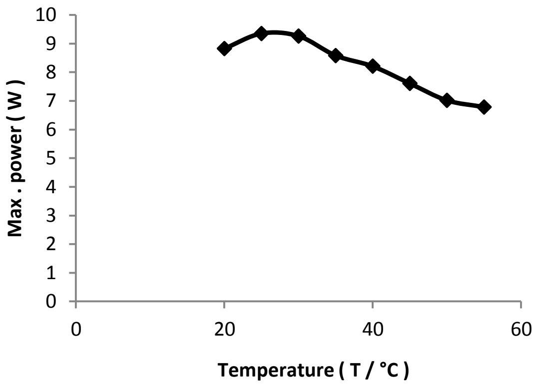

Figure 5: The maximum output power of the PV module at different temperature.

3.3. The effects of dust density on the PV module

In this section, the effect of several types of dust on the PV performance was investigated. Three types of dust were used in the experiment. These were red soil, sand and white soil. It was found that the short circuit current (I_{sc}) was strongly decreased as the dust density increased. Also maximum output power and efficiency decreased significantly as the dust density increased. However, different dust types with different densities did not vary greatly in their effect on the open circuit voltage (V_{oc}).

3.3.1. Effect of red soil dust on thePV module

Figures 6-8 show the effect of red dust on the I-V curve, power, and efficiency of the PV module. The results show that the short circuit current (I_{sc}) was decreased from 0.61 to 0.56, 0.64 and 0.48 A for red dust densities of 25, 30 and 35mg/m^3, respectively, while the open circuit voltage (V_{oc}) was slightly increased to 20.1 and 20.3V for red dust densities of 30 and 35mg/m^3. In other words, I_{sc} was decreased by 2.4% and V_{oc}increased by 0.15% per 5 mg/m^3 of red dust density. Furthermore, the $P_{Max}$of the PV module was decreased as the red dust densities increased. It can be seen that without any dust on the PV module, the maximum power was 9.263W, but where red dust densities were 25, 30 and 35mg/m^3, the maximum power varied between 8.036, 7.56 and 7.26W respectively. It can be concluded that the maximum power of the PV is decreased by 13.24%, 18.38%, and 21.62% for the cases of 25, 30, 35mg/m^3 respectively. In other words, the maximum power of the PV was decreased by 3% per 5mg/m^3 of red dust. Similar observation was made for the effect of red soil density on the PV efficiency (Figure 8). The results agreed well with the results of [2, 15-17].

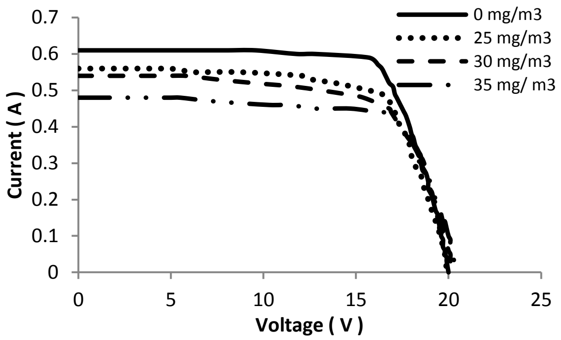

Figure 6: I-V curves at 30°C and different red soil dust densities.

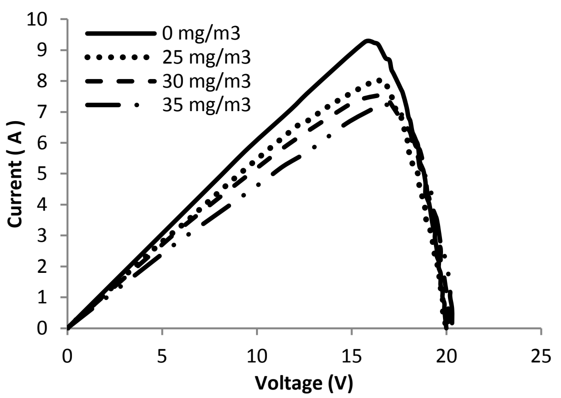

Figure 7: P-V curves at 30°C and different red soil dust density.

3.3.2. Effect of sand dust on the PV module

Figures 9–11 show the effect of sand dust on the I-V curve, power, and efficiency of the PV module. The experimental results show that without any dust on the PV, the short circuit current (I_{sc}) and open circuit voltage (V_{oc}) were 0.61A and 20V respectively. But when the PV was subjected to sand dust with densities of 25, 30 and 35 (mg/m^3) the short circuit current (I_{sc}) was decreased to 0.59, 0.58 and 0.55A respectively. But the V_{oc} increased to 20, 20.5 and 20.8V for sand densities of 25, 30 and 35 mg/m^3 respectively. Which mean that I_{sc} decreased by 3.27%, 4.91% and 9.83% for the cases of 25, 30 and 35 mg/m^3. And for 30 and 35 mg/m^3, V_{oc} increased by 2.5%, 4% and sequentially. In general, V_{oc} increased by 0.5% (5mg/m^3) but I_{sc} decreased by 1.02% (5mg/m^3).

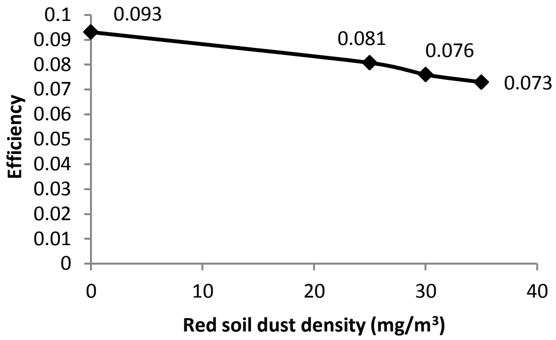

Figure 8: The efficiency of the PV module at different red soil dust densities.

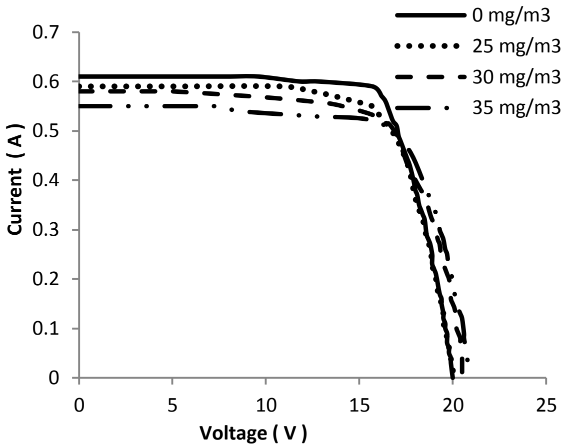

Figure 9: I-V curves of the PV module at different sand dust densities.

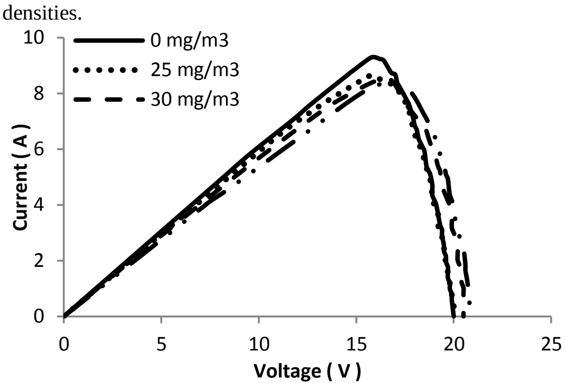

Figure 10: P-V curves of the PV module at different sand dust densities.

The maximum output power obtained from the PV module at different sand densities was measured. It was found that the maximum power when the PV was clean was 9.263W. But with sand dust on the PV at densities of 25, 30 and 35mg/m^3, the maximum power was decreased to 8.635, 8.528 and 8.225W, ie by 6.77%, 7.93% and 11.2% sequentially. Beside this, for 5mg/m^3 of sand dust, the maximum power of the PV module decreased by 1.5 %. Also the efficiency of the PV at different dust densities decreased by the same percentage as maximum power decreased. These results agreed well with the results of [17-20].

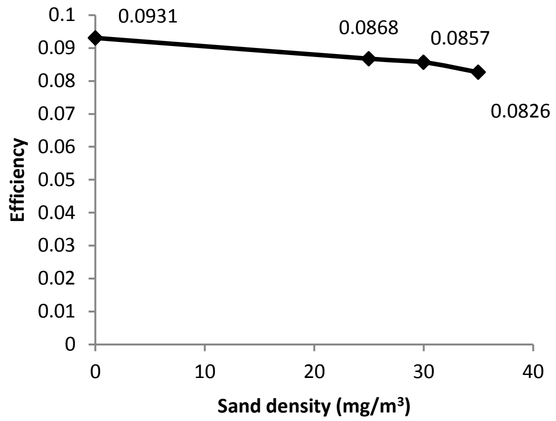

Figure 11: The efficiency of the PV at different sand density.

3.3.3. *Effect of white soil dust on the PV module*

Figures 12–14 show the effect of white dust density on the PV module. It can be seen that the white dust has a significant effect on the short circuit current (I_{sc}). However, in case of clean the PV module (without any dust), the short circuit current was 0.61A and open circuit voltage (V_{oc}) was 20 V. When the PV was covered with white dustthe short circuit current (I_{sc}) was decreased to 0.53, 0.51 and 0.43A for the white dust densities of 20, 30 and 40 mg/m^3 respectively. Conversely, the open circuit voltage (V_{oc}) was increased to 20.7, 20.8 and 20.9 for 20, 30 and 40 mg/m^3 densities. For 20, 30 and 40 mg/m^3 of dust density, it was found that the short circuit current (I_{sc}) is decreased by 13.11%, 16.39% and 29.5% respectively, but open circuit voltage (V_{oc}) was increased by 3.5%, 4% and 4.5% respectively. However, it was found that V_{oc} increased by 0.54% per 5 mg/m^3 and I_{sc} decreased by 3.4% per 5 mg/m^3 of white soil dust. Further, the maximum power when the PV was without any dust was 9.263W, and decreased to 7.701, 7.425, and 6.498W for the cases of 20, 30, and 40 mg/m^3 of dust density respectively. Thus the maximum power and efficiency of the PV were decreased by 16.86%, 19.84%, and 29.84% for the cases of 20, 30, 40 mg/m^3 respectively. However, it was found that the maximum power was decreased by 3.6% per 5mg/m^3 of white dust (3.6 %/ 5mg/m^3). Similar results were found for the effect of white dust on the PV efficiency (Figure 14). These results agreed well with the results of [1, 21, 22].

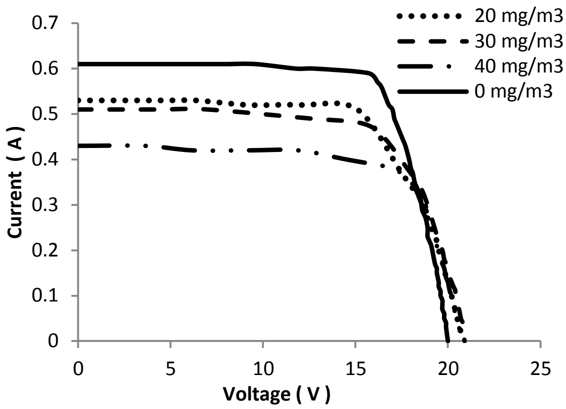

Figure 12: I-V curves of the PV module at different white dust densities.

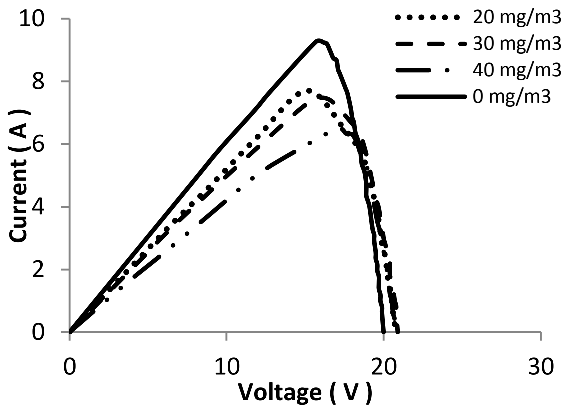

Figure 13: P-V curves of the PV panel at different white dust densities.

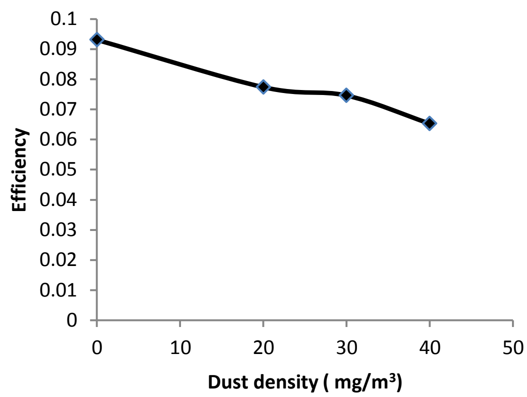

Figure 14: The efficiency of the PV module at different white dust densities.

3.3.4. *Effect of wind speed on the PV module*

In this section, the effect of wind speed on the PV performance by was studied. We take the PV data at 1m/s as a reference. Figures 15 and 16show the effects of wind speed on the I-V and P-V curves, respectively. At 1m/s of wind speed the short circuit current (I_{sc}) and open circuit voltage were 0.6A and 17V, respectively. When the wind speed is in increased to 2, 3, 4 and 5m/s, the short circuit current changed to 0.6, 0.59, 0.59 and 0.56A respectively. Conversely, the open circuit voltage (V_{oc}) was increased to 17.3, 17.8, 18.5 and 20.2V respectively. From this data, it can be concluded that I_{sc} slightly decreased by 1.48 % (1m/s) while V_{oc} was increased by 2.02 % (1m/s).

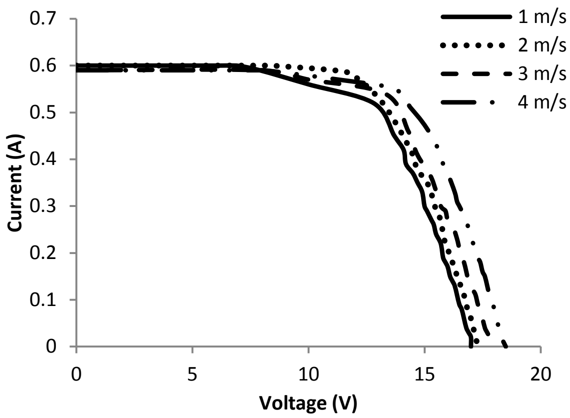

Figure 15: I-V curves of the PV panel at different wind speed.

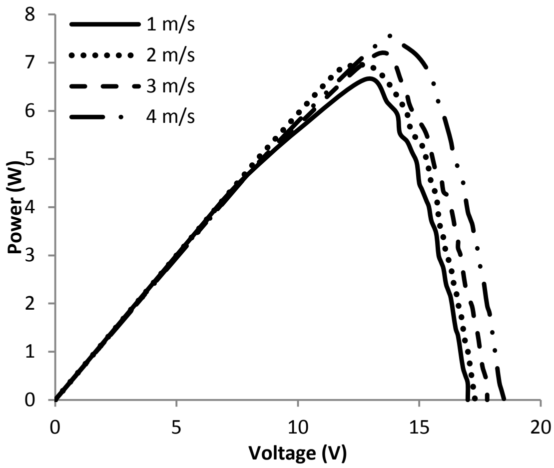

Figure 16: P-V curves of the PV panel at different wind speed.

On the other hand, at 1m/s of wind speed, the maximum power of the PV was 6.656W. In case of increasing wind speed to 2, 3, 4 and 5m/s , the maximum power increased to 6.902, 7.182, 7.535 and 8.064W, respectively. In other words, the maximum power and efficiency was increased by 3.6%, 7.9%, 13.2% and 21.1% for cases of 2, 3, 4 and 5m/s sequentially. In other word, the maximum power and efficiency of the PV was increased by 5% per 1m/s increase of wind speed (Figure 17). These results agreed well with the results of [6, 23, 24].

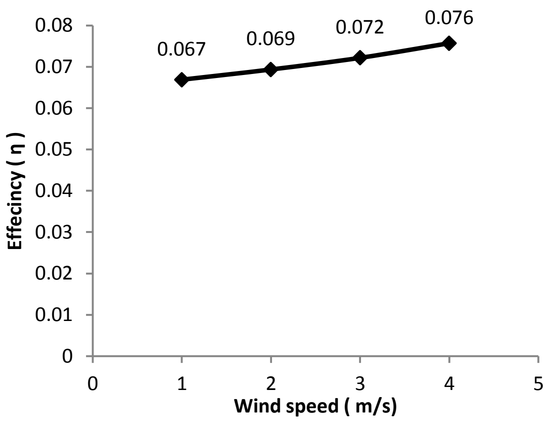

Figure 17: The efficiency of the PV module at different wind speed.

4. Conclusion

The effects of dust, wind speed and temperature on the mono-crystalline PV module were investigated at constant radiation (G=1000W/m^2). A series of experiments were conducted in order to investigate the effect of several types of dust. These were red soil, sand and white soil. The results showed that a significant effect was observed on both module current and short circuit current. However, they were dramatically decreased as the dust density increased. On the other hand, the dust density did not have a significant effect on the module maximum output voltage and the open circuit voltage. Moreover, a larger reduction in the PV performance was observed in the case of white soil dust, owing to its smaller particles, than sand or red soil. The effect of temperature on the PV module was also investigated. It was observed that the open circuit voltage (V_{oc}) was decreased by 4%/5^{o}C, while the short circuit current (I_{sc}) was slightly increased by 2%/5°C. Consequently the maximum power (P_{Max}) and efficiency dramatically were decreased. In addition, when the effect of wind speed on the PV module was investigated it was found that the performance of the PV increased as the wind speed increased since the temperature of the PV was reduced.

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