Effect of Dust Deposition on the Performance of Multi-Crystalline Photovoltaic Modules Based on Experimental Measurements

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Abstract- This paper investigates the dust effect on the photovoltaic module (multi-crystalline) performance. The degradation of PV performance due to the deposition of different pollutant types and accumulation has been investigated. Experiments concerning the effects of air pollutants including red soil, ash, sand, calcium carbonate, and silica on the power generated are conducted and analyzed. The results show that the reduction in PV voltage and power is strongly depends on pollutant type and deposition level. The results show that the ash pollutant is the most effecting dust particle on the PV module voltage as compared to the other used dust pollutants. The highest reduction in PV voltage (25%) is recorded when the ash pollutant is used. This paper presents technical information about PV systems performance under Omani desert climate.

Keywords- Photovoltaic; dust deposition; red soil; ash; limestone

1. Introduction

Electricity generation around the world is mainly produced by using non-renewable energy sources, especially fossil fuels. However, these resources will be largely depleted at some time in the close future (Sayigh, 2009). Such a situation forces us to look for renewable energy resources. At the current time the best and most logical alternative for Gulf Cooperation Council (GCC) countries is to direct the attention to solar energy (Kazem, 2011). Solar PV technology is well-proven for producing electricity, where the global production has been increasing 370 times that in 1992 (Kazmerski, 2011).

The output of a PV module is usually rated by manufacturers under Standard Test Conditions (STC), where each module is tested under a temperature of 25 ^{o}C; solar radiation of 1000 W/m^2, air mass of 1.5 and wind speed of 2 m/s. However, Tthese conditions are different from the conditions in the practical fields. With the increasing use of PV systems, it is vital to study meteorological parameters that affects the performance of these systems such as humidity, dust, temperature and wind speed. Therefore, in this paper the effect of dust and temperature is studied.

The effect of dust on PV modules performance have been investigated in different ways as can be found in the literature. In (Hottel, 1942) a degradation in collector

performance of 4.7%, were reported due to dust deposition. Meanwhile in (Salim, 1988) the authors indicated that a 32% reduction in performance after eight months is happened under desert conditions in KSA. In (Wakim, 1981) the authors claimed that 17% of PV power is lost due to dust deposition on PV modules in Kuwait city. In (Sayigh, 1985) the effect of dust accumulation on the tilted glass plates revealed a reduction in plate-transmittance ranging from 64% to 17%, for tilt angles ranging from 0° to 60° respectively after 38 days of exposure. A reduction of 30% in useful energy gain was observed by the horizontal collector after three days of dust accumulation. In addition to that in (Goossens, 1999) the reported experiment showed that the deposition of fine dust particles on the cover of PV modules significantly affects the performance of these modules. In (Katz, 2008), it was reported that the dirt on PV modules caused a 2% of power reduction as compared to clean PV modules. However. Sayigh reported a power decrease of about 11.5% in a PV module exposed for only 72 hours in Riyadh, Saudi Arabia (Sayigh, 2009). In addition, The effect of a sand dust layer on beam light transmittance at a PV module glazing surface have been investigated by Al-Hasan experimentally and mathematically (Al-Hasan, 1998). Kaldellis and Kokala evaluated experimentally the actual performance of five identical pairs of roof-top PV panels, operating in the urban environment of Athens (from the atmospheric air pollution point of view) (Kaldellis, 2010). Then they experimentally investigated and modeled the effect of three types of dust (red soil, limestone and ash). The impact of dust accumulation, humidity level and the air velocity has been elaborated separately. The impact of each on the other was clarified by (Mekhilefa, 2012). Moreover, sand and dust particle accumulation on PV modules in dry regions has been numerically modeled and analyzed by (Beattie, 2012). Monto and Rohit have reviewed the current status of research in studying the impact of dust on PV and they identify challenges and recommended further pertinent research (Mani, 2010).

The main objective of this research is to study the effect of four types of dust available in Oman on photovoltaic modules in order to investigate the potential of these systems under the climate of Oman.

2. Experiment Methodology

In this study, a multi-crystalline photovoltaic module is used. This module is a 10 Wp, 21.3 V, ,0.66 A, 1.5 kg and 440×282×28 m^3 PV module. The PV module is connected to a monitoring system. The monitoring system comprised of three sets of units, digital multimeters, 10 A solar charger controller Steca PR1010, to measure electrical quantities, CMP6 pyranometer, AR 922 temperature and 8040 multi-purpose moisture meters and an Environmental Monitoring Station (EMS) for acquiring data of the ambient conditions to measure global irradiance, ambient temperature, relative humidity and wind speed and direction.

In this research, indoor experiments are conducted to investigate the effect of dust on PV performance. The PV module is tested using different dust elements. Since the dust effect is considered geographically site dependent, it is directly related to the local air pollution of the place where the PV system is installed. The investigation was conducted for each element separately. Five elements of air pollution are selected to investigate their effects on PV modules performance based on experimental measurements. First, red soil which is obtained from dry land is investigated is used. Second, carbonaceous fly-ash, mainly is originated from the incomplete combustion of hydrocarbons emitted from vehicular exhausts. Third, a common urban air pollutant, sand, which is a naturally occurring granular material composed of mineral particles and finely divided rock. The composition of sand is extremely variable, depending on the local rock sources and conditions and it is mainly used for civil construction activities (Chitlange, 2010). Fourth, calcium carbonate, which is a common form of sand, mostly been created over the past half billion years, by various forms of life like shellfish and coral. (Kralj, 2000). Finally, silica which represents the most common constituent of sand in inland continental settings and non-tropical coastal settings (Belyakova, 1999) (see Figure 1).

Fig. 1. Different types of pollutants used in the experiment

In order to determine the impact of the different selected air pollutants on PV-panels performance, an experimental procedure is carried out in order to compare the voltage output of the PV module under different dust deposition conditions. The experimental procedure was carried out indoors and at least 10 measurements were recorded within the time period examined (approximately 1 measurement per 60 s). The experimental analysis is conducted in the Renewable Energy Laboratory located at the campus of the Sohar University, Oman.

The dust deposition density "ΔM" is expressed in "g/m^2", via the PV panel area "Ac", as

$$\Delta M = \Delta m/Ac \quad (1)$$

Where "Δm" is the total mass of dust layer on the surface of polluted PV panel.

3. Results and Discussion

Despite the available data from the various parts of the world, quantified data from hot, dusty and humid climate region such as Oman is very difficult to obtain. In this section the effect of dust on PV module performance is investigated for different PV technologies and different pollutants, both indoor and outdoor.

The first experiment aims to investigate the effect of red soil on the performance of the PV module. Different pollutant mass depositions were selected, (the values vary between 5 g/ m^2 and 10 g/ m^2). It is worth to note that each time the panels were polluted uniformly with sprayed pollution. Anyway, when 5 g/ m^2 of red soil is spread on the PV at zero time (PV cool) it is noticed that the voltage steps down a little. Meanwhile, the voltage started trickle-down more, due to an increase of temperature on the PV after 5 minutes. The same procedure is repeated after spreading 10 g/ m^2 red soil on the PV and it is also found that the decrease in voltage after 5 minute is more as compared to zero time test. Moreover, the reduction in voltage in the case of 10 g/ m^2 is more as compared to the 5 g/ m^2 dust deposition case. As a result, the proportion of accumulated dust on the PV leads to low voltage and more reduction occurs with the increase of cell temperature. The quantitative effect of the increase in Δm clearly appears as dramatic decrease in PV module voltage (see Figure 2).

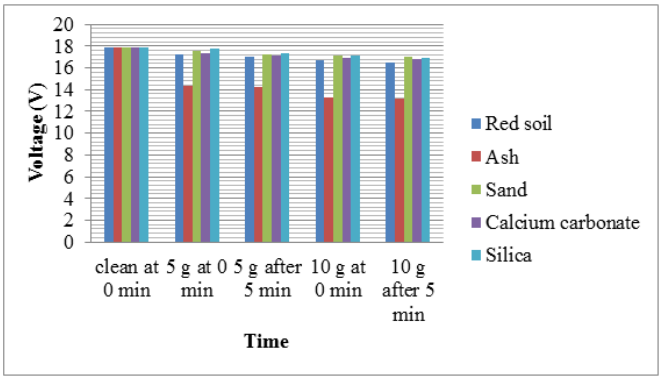

Fig. 2. Effect of five air pollutants on the PV module voltage

On the other hand, Figure 2 illustrates the voltages of the clean and polluted PVs for the highest and smallest recorded ash, sand, calcium carbonate and silica mass deposition, respectively. For instance, the smallest reduction in voltage due to the mass deposition effect is recorded for sand, 0.9 V, and the highest is recorded for ash, 4.7 V. In addition to that, Figure 3 shows the effect of these pollutants on the voltage as a percentage figures. It is clearly noticed that there is a strong indication that in comparison to other pollutants, ash deposition on PV surface leads to a much larger reduction in voltage, while red soil came in the second level, then calcium carbonate, silica and sand, respectively.

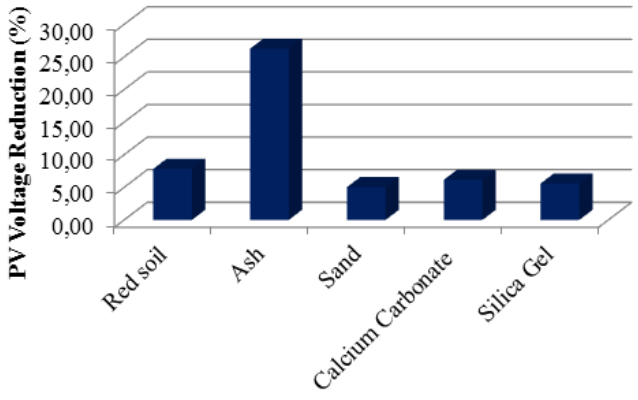

Fig. 3. Reduction in PV voltage due to different pollutants

As for the effect of dust on the power production, three outdoor experiments have been conducted for 30 days to measure current, voltage, power, humidity, ambient and module temperatures for: (1) dry and dirty panel, (2) dry and clean panel, and (3) cooled and cleaned panel (fan used for cooling). Figure 4 shows the result of this experiment. The PV modules generate the highest power when it is clean and cool. While, reduction in the output power occurs when the panel is dry and clean and suffers a larger reduction in output power when it is dry and dirty.

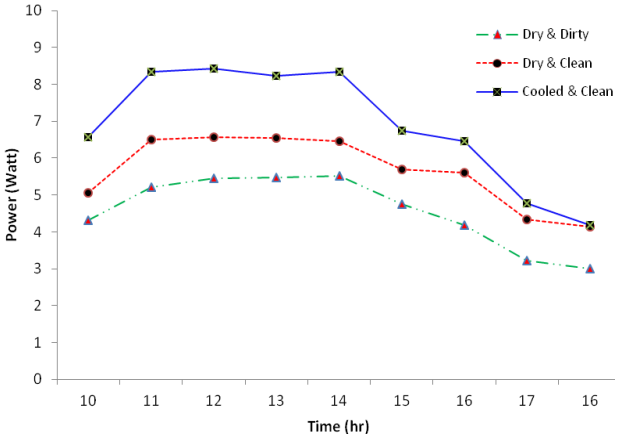

Fig. 4. Effect of dust on power production of a PV module

4. Conclusion

The dust effect on multi-crystalline PV module was investigated for indoor and outdoor conditions. The PV module performance have been tested under the deposition of different pollutants (red soil, ash, sand, calcium carbonate, and silica). The aim of the conducted experiment is to identify the effect of dust on the voltage and output power of PV modules. According to the obtained results, a drop of PV module's voltage and output power is observed when dust particles are deposited on the PV module depending on the mass accumulated, and the type of pollutant. Moreover, larger reduction occurs when the PV module's temperature is increased. In addition to that, keeping the PV modules clean and cool, results efficient system performance.

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