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Dust effect and its economic analysis on PV modules deployed in a temperate climate zone

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Abstract

The aim of this study is to investigate the effect of dust on the degradation of PV modules deployed in a temperate climate region, Perth, Western Australia. Results revealed that PV performance, quantified by normalised maximum power output, varied with season. For a one-year period of study, over which the only cleaning activities were due to wind and rain, the performance of PV modules deployed in Perth, decreased at the end of summer and spring, tended to increase at the end of autumn and reached their peaks at the end of the winter season. Assuming the effect of dust on P_{max} output is similar among the PV modules and is linear among the consecutive seasons, economic analysis indicated that the total cost of production losses of 13 polycristalline silicone PV modules caused by dust (A$ 5.47) is lower than total cleaning cost (A$ 78). Therefore, no cleaning procedure is recommended for the grid-connected PV system simulated in the case study.

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Keywords: seasonal dust; effect of dust; contribution of dust; PV performance

1. Introduction

In addition to inclination angle and material and surface texture of PV module's cover, there are several elements of weather that also affect dust deposition on PV modules' surface including rain and wind. Rain is known to have a dual role in terms of dust deposition that affects PV module performance [1]. It can be a good cleaning agent when it occurs frequently and heavily as it has the ability to wash away dust particles from a PV module's surface. Conversely, light rain tends to drop the suspended particles from atmosphere and forms thin layers that make PV performance worse. Similar to the rain, at a higher velocity, wind also can be a means to sweep off dust from a PV surface. At a lower velocity, in other hand, wind accumulates small dust particles on a PV module's surface.

The weather elements mentioned previously vary depending on the season that obviously affects dust deposition on PV modules. As a result PV performance degradation caused by dust is different seasonally. In a study to evaluate the seasonal effect of dust on a solar desalination plant in Abu Dhabi, El-Nashar [2] found that the drop of

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transmittance of glass covers was higher during summer season. It was caused by the greater accumulation of dust as a result of sand storms and lack of precipitation during the months.

The presence of dust on a PV module's surface decreases its power output that leads to the economic losses. This has provoked many efforts by stake holders to mitigate the adverse impact including cleaning. Stridth [3] in a research carried out in three different places found that cleaning procedure was effective to be performed only for PV plant in Murcia, Spain and Munich, Germany as the action could improve the efficiency of the modules proved by a satisfied break-even analysis. Further, Faifer et al. [4] suggested that a cleaning procedure should be performed when the cost of production losses caused by dust is greater than the maintenance cost which taking into account saving and incentive values of a PV plant.

This study was conducted to investigate the seasonal effect of dust on the degradation of PV modules deployed in Perth, Western Australia. As a temperate climate area, Perth, which is situated between 31.95^{o} South latitude and 115.85^{o} East longitude, has four seasons in which December to February is summer; March to May is autumn; June to August is winter; and September to November is spring. Based on the result of dust effect every season, its economic impact was analyzed and applied as an indicator to decide whether a cleaning action was needed or not.

2. Experimental methodology

Three PV modules featuring amorphous silicon (a-Si), polycrystalline silicon (pc-Si) and mono-crystalline silicon (mc-Si) which represent technologies deployed in Perth were chosen randomly as samples for this research. The PV modules have been deployed for almost 20 years at the Renewable Energy Outdoor Testing Area (ROTA), Murdoch University, and were faced to North with an inclination angle of 32^{o}.

To investigate the influence of dust on the PV modules' performance, experiments were carried out several times in accordance with the sampling site's season. A portable solar module analyser was performed to measure I-V curve under real operating conditions (ROC) with varying solar irradiation and temperature. To transpose the results to the standard test conditions (STC), procedure 1 of the IEC 60891 method [5] was applied. The key equations employed in this method are as follows:

$$I_2 = I_1 + I_{sc1}.\left(\frac{G_2}{G_1} - 1\right) + \alpha.(T_2 - T_1) \qquad (1)$$

$$V_2 = V_1 - R_s.(I_2 - I_1) - \kappa.I_2.(T_2 - T_1) + \beta.(T_2 - T_1) \qquad (2)$$

Based on the I-V curve produced by equation (1) and (2), P_{max} was obtained.

where, subscript 1 and 2: ROC and STC values respectively; I and V: current (A) and voltage (V), respectively of I-V characteristic data pairs; G: in-plane irradiance (W/m^2); T: module back side temperature (^{o}C); α: current temperature coefficient (A/^{o}C); β: voltage temperature coefficient (V/^{o}C); R_S: the internal series resistance of the test specimen (Ω); κ: curve correction factor (Ω/^{o}C); P_{max}: maximum power (W); I_{sc}: short circuit current (A); V_{oc}: open circuit voltage (V).

3. Economic analysis of dust on PV application

This analysis is to investigate the losses caused by dust on a PV system. Based on the analysis result, a maintenance action such as a cleaning procedure can be scheduled and performed effectively. Faifer et al [4] suggested that cost of production losses *(C_{PL})* depends on energy losses, saving value *(R_S)* and incentive value *(R_{INC})*.

C_{PL} = energy losses (R_S + R_{INC}) (3)

Energy losses = (P_{max} output in clean condition – P_{max} output in dusty condition) x peak sun hours over a certain time period (4)

Further, in the same reference [4], it is also recommended that maintenance activity cost *(C_{MA})* is the summation of the cost of materials *(C_m)* applied for cleaning and the cost of workforce *(C_{wf})*. The cleaning process should be performed when the losses caused by dust *(C_{PL})* are greater than the maintenance cost *(C_{MA})*.

4. Result and discussion

4.1. The effect of seasonal dust on PV performance degradation

Figure 1 shows transposed result of each PV module normalized using its P_{max} output value in clean condition as a reference measured at the initial stage of this study. Starting in clean condition at the beginning of December 2014, P_{max} output of the modules was maximal. It then decreased after the modules were exposed to the elements for 3 months measured at the end of summer (February 2015). The performance of PV modules increased back during autumn (May 2015) and reached a peak at the end of winter (August 2015). The PV modules' performance dropped again at the end of spring.

PV performance degradation indicates the accumulation of dust which blocked light that would be converted into electricity energy. The intensity of dust caused by human and natural activities was expected to increase as less rainfall occurred during summer and spring seasons. The rains tended to drop the suspended dust particles in the atmosphere and formed thin layers on modules' surface. Similar to the rain, wind, which is a natural cleaning agent, was not able to swipe off dust accumulation on PVs' surface. Meanwhile, great rainfalls are suspected to be the major factor contributed to the PV performance improvements during autumn and winter seasons as it could wash away dust from the PVs' surfaces.

At the end of the study period, a manual cleaning procedure was applied. Consequently, the performance of PV modules was restored but it was under the initial performance recorded at the beginning of December 2014. It is attributed to the permanent degradation caused by non-dust related factors.

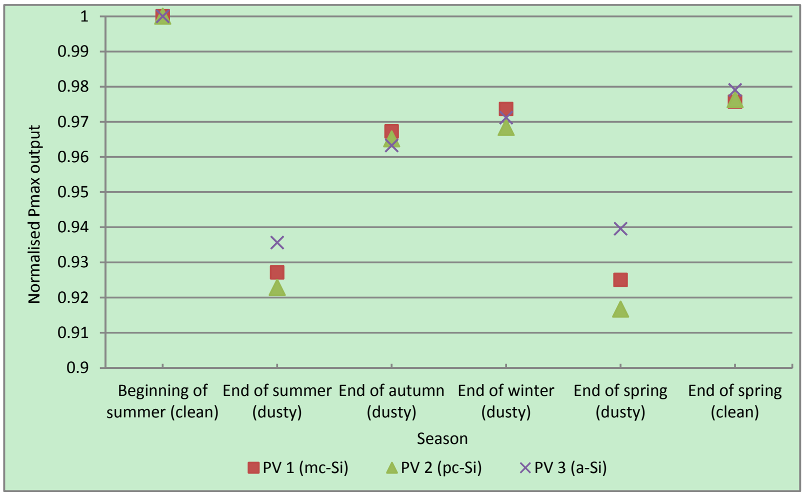

Figure 1. PV modules' performance every season at ROTA

4.2. Economic analysis of dust on PV application

In this study, the degradation trend of PV 2 (pc-Si), most affected PV module, was chosen for analysis. It is noted that P_{max} outputs of PV 2 (pc-Si) recorded at every stage as showed in Figure 1 are 80.50; 74.3; 77.7; 77.96; 73.8 and 78.6 Watt.

In a hypothetical scenario, it is assumed that the PV technology was deployed in a grid-connected PV system to supply a constant 2.5 kWh per day of electricity needs of some appliances of a household in Perth. By ignoring all de-rating factors, and referring to the lowest peak sun hours of Perth by 2.66 in June (Table 2), 13 pc-Si PV modules with P_{max} of 80.5 W are needed to cover the load without interruption during the period of study. By assuming that the effect of dust on P_{max} output is similar among the PV modules and is linear among the consecutive seasons, energy losses were determined as depicted in Figure 2. By considering feed in tarrifs, and the electricity price of exported energy to the grid, which in Perth is 7.135 cent/kWh [6], the cost of production losses caused by dust for the period of study is A$ 5.47. The value, which was based on one day time resolution, is lower than the cleaning cost, approximately A$ 78 for 13 modules (A$ 6 per module [7]). It is an environmentally friendly cleaning process using deionized water to achieve a better performance of PV modules. From these results, regular cleaning is not recommended for similar systems as the overall gain by cleaning the system would be well and truly offset by the cost of cleaning.

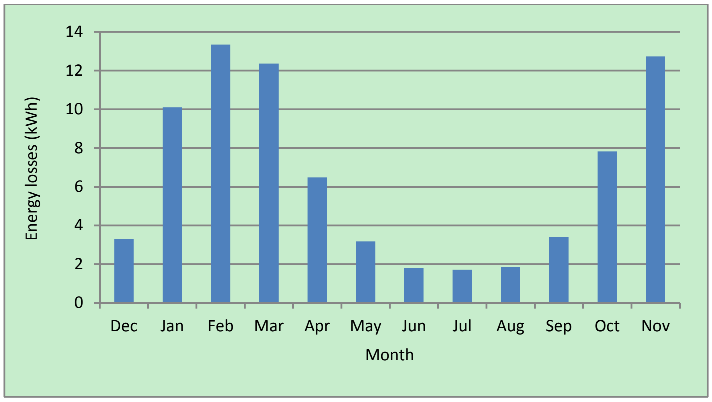

Figure 2. Energy losses of PV modules caused by dust

5. Conclusion

Analysis results indicate that PVs' performance represented by normalized P_{max} output varied with season. For a one year period of study started at the beginning of summer, performance of PV modules in Perth decreased at the end of summer and spring and tended to increase at the end of autumn and winter seasons without any cleaning procedures. Rainfall was the main natural cleaning agent to decrease dust accumulation on PVs' surface deployed in the site. Assuming the effect of dust on P_{max} output is similar among the PV modules and is linear among the consecutive seasons, economic analysis revealed that total cost of production losses of 13 pc-Si PV modules caused by dust (A$ 5.47) is lower than total cleaning cost (A$ 78). Therefore, no cleaning procedure is recommended for the grid-connected PV system simulated in the case study.

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