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Experimental investigation of dust deposition effects on photo-voltaic output performance

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ABSTRACT

Nowadays, solar energy and photovoltaic panels are taken under serious consideration. Many studies have been conducted on pv modules deficiency. In addition to the characteristics of the panels, the climate and natural condition also have a great impact on the performance of these systems. In order to recognize the impact of dust accumulation on PV performance in Tehran, Iran, a 70-day experiment, started on May 9th, 2017, was developed. Equipment at the Renewable Laboratory of Shahid Beheshty University was utilized to obtain the experimental data. Power reduction as well as delivered energy, and its reduction during the test period were measured. For more accurate and general conclusions, the curves were also plotted versus dust surface density. The results indicate that after 70 days without raining, 6.0986 (g/m^2) dust was accumulated on the surface, which caused 21.47 (%) reduction in the power output. The total reduction in delivered energy was also 289 kWh for each 4.845 kW power capacity. The reduction of this amount of clean energy is equivalent to 3 hectares of forest absorbing carbon (32.7 tons) per MW capacity.

1. Introduction

Photo-Voltaic (PV) technologies due to their advantages in technical, environmental and economical aspect, have received lots of attentions from governments, investors and researchers. So over the last decades numerous studies have done in related areas (Fabrizio et al., 2010; Petersen and Svendsen, 2012; Ramadhan and Naseeb, 2011; Lacchini and Dos Santos, 2013; Nottrott et al., 2013; Shrimali and Jenner, 2013; Zandi et al., 2017). In reading the literature, it can be understood that PV performance can be significantly influenced by climatic conditions (Tanesab et al., 2015; Paudyal and Shakya, 2016; Ferrada et al., 2015; Abderrezek and Fathi, 2017).

Because of great solar potential as well as land availability in deserted regions, these areas are favorable for locating large-scale solar installations (He et al., 2011; Saidan et al., 2016). Different types of PV modules have been investigated in various seasons. Moreover the effect of cooling systems on the PV output performance is studied in Pakistan (Bashir et al., 2014, 2013; Ali et al., 2016, 2015; Bashir et al. 2016). However, dust deposition is the main challenge in successful deployment of PV systems in these regions (Ali et al., 2015; Javed et al., 2017), for instance, the power output of PV modules can be dropped up to 20% by a single dust storm (Adinoyi and Said, 2013). Therefore, the studies show that the investigation of dust accumulation and its effects on PV output performance play an important role in the sustainable development of PV systems (Menoufi, 2017).

Accumulation of dust on a glass cover of a PV system causes gradual reduction of a transmission coefficient (Hegazy, 2001), which then leads to the reduction of energy conversion efficiency. In an early work, El-Shobokshy and Hussein (El-Shobokshy and Hussein, 1993), studied the effect of the dust with different physical properties on the performance of photovoltaic cells. They measured the output of PV systems, on the surface of which various kinds of dust were accumulated. Their study indicated that coarser dust particles, in comparison to fine ones, have less impact on the performance of PV panels. In addition to the size of particles, dust thickness and its chemical compositions have been studied for better understanding of physicochemical characteristics of accumulated dust (Kim et al., 2016; Kazmerski et al., 2016; Mazumder et al., June 2015; Pulipaka et al., 2016; Mehmood et al., 2017). The average decrease in a crystalline photovoltaic module efficiency, corresponding to each micrometer of accumulated dust thickness, is equal to 25.5%/μm for naturally deposited dust (Klugmann-Radziemska, 2015).

In order to investigate the effect of dust accumulationon the performance of PV systems, some studies have been carried out to find the factors affecting dust deposition. The results indicate that factors such as installation tilt, azimuth angle, dominant wind direction, gravity, site pressure, surface stickiness and the time in which panels are placed within the environment, are related to dust accumulation density on the

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surface (Gholami et al., 2017; Sayigh et al., 1985; Michalsky et al., 1988; Salim et al., 1988; Asl-Soleimani et al., 2001; El-Nashar, 2009; Adinoyi and Said, 2013; Rahman et al., 2012; Beattie et al., 2012; Mani and Pillai, 2010). It also could be concluded that dust accumulating rate, which greatly affects the mitigation of efficiency of PV system, is predominantly depended on the weather conditions of the site. For example, in Colorado, a dust deposition rate of 1–50 $mg{\cdot}m^{-2}{\cdot}day^{-1}$ was recorded by Boyle et al. (2015). In a similar work Hegazy (2001), reported a 150–300 $mg{\cdot}m^{-2}{\cdot}day^{-1}$ in Egypt. The noticeable difference between Boyle's results and Hegazy's is primly due to the varied weather conditions.

Recently, morecomprehensiveandaccurateexperimentalresearcheshavebeen reported on dust accumulation (Jiang and Lu, 2016; Darwish et al., 2016; Al Shehri et al., 2017; Jiang et al., 2011); for example, Jiang and Lu (2016), investigated the effect of temperature differences in the particle deposition process on solar PV Modules. Mainly these experiments were under taken in controlled lab conditions and they've done a thorough and sufficient job. Since weather conditions have a great impact on dust accumulation, it is difficult to consider and simulate all the variables. So in order to obtain a better simulation of the natural conditions of dust accumulation in Tehran, the authors decided to do the research under the outside conditions.

Iran same as other countries in the middle east has a great solar potential while struggles with the dust deposition problem. Recently supporting laws were passed in Iran for developing of renewable energy, which led to investment tendency, and techno-economical studies (Zandi et al., 2017). Locally Gholami et al Gholami et al. (2017), studied the factors affecting dust accumulation and their effects on the transmission coefficient of glass for solar applications. They also introduced a correlation form between dust surface density and transmission coefficient lost, Eq. (1). The correlation reflects the behavior of the reduction of transmission due to dust accumulation, where $\Delta\tau$ (%), is the reduction of the transmission coefficient, and ρd (g/m^2), is the surface density of the dust accumulated on the samples:

$$\Delta\tau\ (\%) = -0.001335\rho_d^6 + 0.04398\rho_d^5 - 0.5427\rho_d^4 + 3.05\rho_d^3 - 7.703\rho_d^2 + 11.19\rho_d - 2.25 \quad (1)$$

In another work done by Gholami et al. (2017), experimental investigated self-cleaning property of Titanium Dioxide and nanospray coatings in solar applications. Their results indicated that for samples with surface modification, the transmission coefficient drops were noticeably reduced from 22% to 0.5% and dust accumulation problem was almost completely solved.

By studying the related literature, lack of comprehensive attention, especially locally, towards dust accumulation effects under outdoor conditions is seen. Furthermore, the limited publications, as mentioned above, usually present the dust effects' dependency in terms of time which because of varied weather conditions, the results may not be utilizable in other regions. So to overcome these deficiencies in the current study an experiment under the outdoor conditions is designed, to investigate the effect of dust accumulationon PV output performance. In the following parts, after reporting the climate conditions of test region, basic specifications of the experiment and the results will be explained.

2. Climatology of the test region

Test apparatuses were located on the roof of renewable energy laboratory in Shahid Beheshti University at 35°44′23″ north latitude and 51°34′31″ east longitude in Tehran. Tehran features a cold semi-arid climate with continental climate characteristics and a Mediterranean climate precipitation pattern. Average high temperatures are between 32 and 37 °C. The hottest month is July, with a mean minimum temperature of 26 °C and a mean maximum temperature of 34 °C, and the coldest is January, with a mean minimum temperature of −5 °C and a mean maximum temperature of 1 °C. The record high temperature is 43 °C and the record low is −17 °C (National Weather Service, 2015).

Wind is one of the prominent factors affecting the deposition of dust on the surface, which is formed due to pressure difference and usually blows in horizontal dimension. Normally, winds are introduced in degrees and by the direction from which they blow. According to long-term data, wind's dominant directions in the test site are west and southwest, although during the measurement, its dominant direction was southwest (wind was normally blown-out from southwest toward northeast). As was recorded during the experiment, the average speed of wind was 4.6 ($m{\cdot}s^{-1}$), the average ambient temperature was 34 (°C), and the average relative humidity was 28.2 (%).

These conditions as well as other factors, such as installation tilt, azimuth angle, rain and the time in which panels and collectors are exposed to outdoor conditions without cleaning, affect dust accumulation density on surface (Gholami et al., 2017, 2017).

For instance, Wind could have two effects on the accumulation of dust on surfaces. For the surfaces facing wind, wind will sweep away some of the dust from the surface and caused a reduction in the surface density of accumulated dust. On the other hand, for the surfaces facing away from wind, due to the creation of vertexes of wind, dust accumulation was more than dust removal and as a result, an increase in the dust surface density will be appeared (Gholami et al., 2017).

According to the research done by Oguntoke et al. (2013), atmospheric humidity had negative correlations with dust fall. Mean relative humidity below 50% and mean wind speed above 4 m/s were predicted as critical levels for dust episodes incidence at sites that recorded "heavy" and "very heavy" dust fall. It means that the experiment's site is considered to have heavy dust fall.

It should be noted that, lots of the factors affecting the accumulation of dust, cannot be controlled completely. For example, In order to receive the optimum sunlight during a year, installation tilt is usually set the same as the location latitude. Furthermore, in the northern hemisphere, solar collectors and PV panels are typically faced toward south. Wind and rain conditions are also depending upon the climate and cannot be controlled.

To solve this problem, each measurement for both clean or dusty modules and samples, was taken under the same conditions. It means that, the only variable for the clean and dusty modules was the amount of dust accumulated on the surface of them. In this way the effect of other climate conditions such as, temperature and relative humidity will be minimized and the difference in the output of the panels is only due to the accumulation of dust.

3. Experimental basic specifications

Equipment at the Renewable Laboratory of Shahid Beheshty University was utilized to obtain the experimental data. Details of the installed system configuration are presented in the following sections. The experiment was done outdoors and for a better simulation, samples were exposed to environmental conditions. During the tests, great care was taken to avoid any dust removal except by natural causes, such as wind or rain.

3.1. Photovoltaic panels and inverter

In the current paper, 57 monocrystalline PV panels were used to measure the delivered energy for the experiment. Each 19 panels were wired in a series, and each series was connected to a 5 kW Conergy inverter. In order to measure the power losses two reference cells were also used. Table 1 shows the PV panels' characteristics.

3.2. Test details

As mentioned in the previous part, three series of panels were used in the experiment. These series were used without cleaning throughout

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