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Characterization of dust accumulated on photovoltaic panels in Doha, Qatar

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ABSTRACT

In this study, samples of dust naturally accumulated for various exposure times on photovoltaic (PV) panels were collected and characterized over a period of ten months in a solar test facility located in Doha, Qatar. The dust accumulation rate (DAR) over the exposure time was determined gravimetrically. The dust samples were characterized using particle size analysis, X-ray fluorescence (XRF), X-ray diffraction (XRD), and scanning electron microscopy (SEM). The cleanness index change rate (CICR), a measure of how fast the PV power output degrades due to soiling, was found to have strong negative correlation with DAR, but the CICR/DAR ratio was found to differ between winter and summer. The DAR and the mean particle size of the accumulated dust both decreased with increasing exposure time, reaching relatively steady values for longer exposure times. Calcium was found to be the most abundant element in the accumulated dust, followed by silicon, iron, magnesium and aluminum. Calcite, dolomite, and quartz were the dominant minerals in the accumulated dust, with gypsum being a minor component. Dust collected after dust-storm events had higher proportions of halite and quartz contents than non-dust-storm days, depending on the direction of the wind. Also, dust particles accumulated on PV panels appeared to agglomerate as the exposure time increased. The data provided in this paper will be useful for quantitatively determine the degree of soiling and its effect on PV performance in Qatar and regions with similar environmental conditions. The data will also be useful for the selection of soiling mitigation technologies.

1. Introduction

Environmental concerns and growing energy demand have increased interest in photovoltaic (PV) solar power worldwide in recent years, as a promising renewable energy source. Qatar, as well as other countries in the Middle East and North Africa (MENA) region, has a tremendous potential for development and deployment of solar power generation, due to the high solar irradiation levels and the availability of land. However, the extreme climatic conditions and desert environment in the region pose significant challenges to the successful deployment of solar power generation (Sarver et al., 2013).

Numerous studies have shown that dust accumulation on solar surfaces can cause significant degradation of their solar conversion efficiency (Darwish et al., 2015; Said and Walwil, 2014; Sayyah et al., 2014; Tanesab et al., 2015). The effect of soiling is a function of dust loading on the PV module. Dust accumulation rate on module surfaces mostly depends on airborne particle concentration, distribution of aerodynamic particle size, and weather conditions, which are all site specific factors (Said and Walwil, 2014). The dust accumulation rate may also vary with the outdoor exposure time (Mastekbayeva and Kumar, 2000). For example, in the Greek capital, Athens, dust deposition masses of 0.1–1 g m^{-2} were recorded for the outdoor exposure periods of 2–8 weeks (Kaldellis and Kokala, 2010). A dust loading of 6.184 g m^{-2} was reported for an exposure period of ten months (February to December) in Dhahran, Saudi Arabia (Adinoyi and Said, 2013). In another work, a dust accumulation rate of 132 mg m^{-2} day^{-1} was found in Mesa, Arizona (Boppana, 2015). Similarly, mass accumulation rates of 1–50 mg m^{-2} day^{-1} in Colorado (Boyle et al., 2015) and 150–300 mg m^{-2} day^{-1} in the Minia region, Egypt (Hegazy, 2001), were observed depending on the tilt angle and location. More recently, dust accumulation rates of 10–80 and 5–20 mg m^{-2} day^{-1} on 40°

Abbreviations: DAR, dust accumulation rate; CICR, cleanness index change rate; PM_{10}, particulate matter concentration with aerodynamic particle size ⩽10 μm; WS, wind speed; WD, wind direction; RH, relative humidity.

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inclined glass plates have been reported at Commerce City and the Erie site, respectively, in Colorado, US (Boyle et al., 2016).

The characteristics of deposited dust have a significant impact on soiling-related PV performance degradation. Various laboratory studies have shown that the impact of dust soiling on PV energy yield is dependent on the dust physicochemical properties (Appels et al., 2013; Jiang et al., 2011; John et al., 2016; Kaldellis and Fragos, 2011; Kaldellis et al., 2011; Kaldellis and Kapsali, 2011; Khatib et al., 2013; Sulaiman et al., 2011). These laboratory studies have identified 15 types of dust pollutants, of which six pollutant types (i.e. ash, limestone, red soil, calcium carbonate, silica, and sand) are believed to have a greater effect than others on PV performance degradation at a given surface loading (Darwish et al., 2015). However, most of these studies have used artificial dust, and there has been little research regarding the physicochemical characteristics of naturally deposited dust in real-world operating conditions. Soiling studies with adequate natural dust chemical composition information would be useful for understanding the relation between soiling-induced effect and chemical composition.

Understanding physicochemical characteristics of accumulated dust is also essential for the development of soiling mitigation technologies. Chemical composition, along with particle size distribution, determines how dust particles interact with the PV surface, and hence affects the applicability and effectiveness of PV soiling mitigation technologies (Horenstein et al., 2013; Johnson et al., 2005; Kazmerski et al., 2016; Mazumder et al., 2015). Various theories suggest that, by rendering the PV module surface hydrophilic or hydrophobic, it is possible to mitigate soiling. However, it has been shown that the affinity of particles to PV surfaces is not only dependent on the PV surface properties, but also the particle properties. These aspects highlight the importance of understanding the characteristics of deposited dust (Kim et al., 2016). There are also active methods of PV soiling mitigation, through the mechanical or electrostatic removal of dust particles from the surface. Information on the particle properties will be useful for assessing the adhesion force of the particles, or for determining their motion in an electric field (Mazumder et al., 2015; Quesnel et al., 2015).

Soiling-related PV performance degradation is also dependent on particle size distribution of dust deposited on the surface (El-Shobokshy and Hussein, 1993; Pulipaka et al., 2016; Said and Walwil, 2014). Particle size plays a significant role in reflectance, scattering, and absorption of light incident on solar cells and in turn, leads to PV performance degradation. The greater tendency of resuspension for larger particles, even at moderate wind speed, promotes accumulation of smaller-size dust particles (Weber et al., 2014). Finer particles may cause more significant performance degradation of PV modules than larger particles for the same mass of dust. Smaller particles, having the greater specific surface area, may be distributed more uniformly as compared to the coarser dust particles, thus reducing the voids between the particles through which light can pass (Tanesab et al., 2015). Weber et al. (2014) reported that particle sizes deposited on the PV surface mostly lie within a range of 1–50 μm. However, overall there has been limited research on particle size distribution of dust accumulated on PV panels in desert environments.

Characterization of accumulated natural dust and its impact on PV system efficiency are limited, given the fact that dust accumulation is a complex phenomenon and varies with site-specific environmental and weather conditions (Kazmerski et al., 2016; Mani and Pillai, 2010). However, through systematically study dust accumulation in various locations of interest to PV power generation, it is hoped that the PV soiling problem may be better understood and addressed. This study was carried out in Doha, Qatar. It was intended to characterize dust accumulation on PV surfaces through a systematic approach. Specifically, this study aimed to (1) quantify the rate of dust accumulation on PV panels for various exposure periods, and (2) determine the physical and chemical properties of accumulated dust, and their correlation with environmental variables, time of exposure and soiling-induced PV performance loss.

2. Methodology

2.1. Sampling of accumulated dust

Sampling of dust accumulated on PV panels was carried out at the Solar Test Facility (STF) (at latitude 25°19′32.61″N and longitude 51°25′59.83″E) located at Qatar Foundation, Doha, Qatar. Samples of accumulated dust were collected from the surface of twelve panels of a PV array (CdTe thin film frameless, P*max* 90 W, tilted at 22° and facing due South). Each panel is 1.2 m in width, 0.6 m in height and 6.8 mm in thickness. A photo of the test PV array is shown in Fig. 1. Of the twelve panels, four panels were used to collect daily samples, i.e., accumulated dust was collected every 24 h from these four panels. The 24-h dust samples were collected from 11 January 2015 to 20 February 2015 (winter period), and from 1 June 2015 to 15 July 2015 (summer period). The other eight panels were used to collect two-week, one-month, two-month and six-month accumulated dust samples; two panels for each sampling frequency.

The matrix of dust sampling from the PV panels is shown in Fig. 2. The environmental variables, shown in Fig. 2, have no strong trend that might be constructed to have a role in causing the dependence on exposure time. Dust accumulated on the surface of the PV panels was scraped off with a rubber spatula and carefully collected in a polystyrene Petri dish. The spatula used for scraping dust was made from a polyvinyl chloride acetate (PVCA) card that measures 90 mm by 45 mm by 1 mm. A long side of the spatula was gently pressed against the PV panel surface and moved down to scrape the dust down the lower edge of the panel. The falling dust was collected in the Petri dish. Multiple scrapes were used for each area of the PV panel until the area was clean; i.e. there was no visible dust present. This procedure was carried out for the entire PV panel so as the ensure all dust on the panel was collected

2.2. Analyses of the dust samples

All collected dust samples were subjected to the analyses described below. Daily collected dust samples during a month were subjected to gravimetric analysis individually and then

Fig. 1. Photo of a test PV array used in this study. The 12 panels on the outside (perimeter) were used for dust sample collection.