Solar Energy 139 (2016) 68–80

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Experimental analysis of the effect of dust's physical properties on photovoltaic modules in Northern Oman

Hussein A. Kazem [a,*], Miqdam T. Chaichan [b]

[a] Sohar University, PO Box 44, Sohar PCI 311, Oman
[b] Mechanical Eng. Dept., University of Technology, Baghdad, Iraq

ARTICLE INFO

Article history:
Received 3 February 2016
Received in revised form 19 July 2016
Accepted 19 September 2016

Keywords:
Dust effect
Pollutant type
Physical properties
Photovoltaic

ABSTRACT

Dust depositions on photovoltaic (PV) modules reduce the transmittance of PV glazing, resulting in the degradation of efficiency. The primary source of dust is wind-blown sand and soil particles from the ground. The coarse dust particles have a diameter larger than 2 μm. Photochemical reactions of gaseous pollutants in the atmosphere and dried droplets of seawater forming salt particles form most of the fine particles smaller than 2 μm in diameter. The physical properties of dust, such as specific gravity, particle shape, surface properties, moisture content, plastic and liquid limits, and particular grain size, vary from location to another all over the world. These differences are due to the topographic, geological, and environmental conditions of each region. The weight and shape of dust particles have a significant effect on their deposition behaviour and PV performance. In this paper, an investigation of energy losses caused by dust deposition on PV modules in Oman is presented.

Six dust samples collected over three months from six locations in Northern Oman were investigated to evaluate their physical properties. Most of the dust particles (64%) diameters size ranged from 2 to 63 μm. The dust deposition on PV modules was found to vary from one location to another. The results indicated that there is no significant energy-yield loss caused by the low surface mass concentration of dust (<1 g/m^2) on the PV module. The maximum daily efficiency loss was measured and compared with that from the literature, revealing that the efficiency loss was 0.05%, which is small compared to those of neighbouring countries. However, the results show a decline in the productivity of the PV module up to 35–40% after exposure to the weather conditions for more than three months, indicating that the advisable cleaning period, is every three months. Therefore, establishing PV systems at these sites is a reasonable option.

1. Introduction

Renewable energy technologies, in particular photovoltaics (PVs), are affected by several parameters (e.g., location, orientation, technology, environment.). The environmental parameters have a large impact on both the power productivity and the efficiency of PVs. Some of the environmental parameters are temperature, wind speed and direction, humidity, solar radiation and the presence and amount of dust. Dust has been investigated in the last decades using several approaches (Sarver et al., 2013; Mani and Pillai, 2010). Some studies classified and discussed the dust problem based on its physical (e.g., size, shape, morphology, and composition), chemical (e.g., dust type and material), and biological properties. In addition, the relationship between dust accumulation and the tilt angle and orientation of PV modules has been investigated. Other studies have focused on the effect of dust in terms of the relationship with other environmental parameters (i.e., temperature, wind, humidity).

Defining the physical properties of dust particles (e.g., size, geometry, weight, and pollutant type) gives an indication of its impact on the performance of a PV module. It is important to understand the relationship between dust size and type and its impact on solar light scattering and transmission. Dust classification is a significant issue that is needed to develop effective prevention techniques. The physical nature of dust and its deposition characteristics are dominated by the region in which it is studied. Many researchers have studied the interrelationships between dust properties and its deposition on PV modules.

2. Literature review

Studies determining the effects of the physical properties of dust on PV performance are found in the literature (Sayigh et al.,

* Corresponding author.
E-mail address: h.kazem@soharuni.edu.om (H.A. Kazem).

http://dx.doi.org/10.1016/j.solener.2016.09.019
0038-092X/

1985; El-Shobokshy and Hussein, 1993a,b; Hegazy, 2001; Sulaiman et al., 2011; Kazem et al., 2013, 2014; Darwish et al., 2013, 2015; Al-Hasan, 1998; Chaichan et al., 2015; Klugmann-Radziemska, 2015; Sayyah et al., 2014; Biryukov, 1996, 1998; Jiang et al., 2011; Niknia et al., 2012; Kaldellis et al., 2010, 2011; Cabanillas and Munguía, 2011; Landis, 1994; Mastekbayeva and Kumar, 2000; Rahman et al., 2012; Kaldellis and Kapsali, 2011; Appels et al., 2012; Pang et al., 2006; Massi Pavan et al., 2011; Sanusi, 2012; Asl-Soleimani et al., 2001; Kumar et al., 2013; Al-Ammri et al., 2013; Keller and Lamprecht, 1995; Adinoyi and Said, 2013; Qasem et al., 2013; Sueto et al., 2013; Said and Walwil, 2014; Tanesab et al., 2015; Rifai et al., 2016). Sarver et al. (2013) presented an overview of the area of study over the last seven decades. The aim of this study was to review, evaluate and understand the impact of dust on PV performance. A portion of the study focused on the physical and chemical properties of dust itself. The authors claimed that dust and soiling remain important problems, especially in desert-sand regions where solar radiation conditions are optimal.

Mani and Pillai (2010) comprehensively reviewed the impact of dust on PV performance. They classified the research in the literature into two phases, 1945–1990 and 1990 onward. Several aspects were covered. The authors claimed that the physical properties of dust are part of the research challenges and need to be characterised.

Sayigh et al. (1985) and El-Shobokshy and Hussein (1993a,b) are considered the pioneers in the study of dust's effect on solar cell performance in the Middle East. Sayigh investigated natural dust in Kuwait and its impact on solar cell power efficiency. Moreover, the effect of the PV tilt angle on dust accumulation was presented (Sayigh et al., 1985). El-Shobokshy simulated artificial dust using cement, carbon particulates and limestone. The diameters of the particles were 5, 10 and 50–80 μm for carbon, cement, and limestone, respectively.

Hegazy (2001) experimentally investigated dust accumulation on PV surfaces in terms of the tilt angle and cleaning methods for a period of one year in Egypt. The author proposed a correlation between the dust factor and tilt angle. Based on the results, the author advised weekly cleaning of PV modules.

Sulaiman et al. (2011) investigated the impact of artificial dust, which was composed of mud and talcum, on PV module performance. Kazem et al. (2013) investigated the effect of artificial dust of five pollutants: sand, ash, red soil, silica and calcium carbonate. The decrease in voltage resulting from pollution and its change over time was measured, and the results were related to a change in temperature. The degradation in open-circuit voltage ranged from 4% to 24%, and the greatest decrease was observed for ash.

Darwish et al. (2015) revised and investigated the effect of pollutant types on PV performance. The authors studied the impact of natural and artificial dust on PV performance. They developed a critical review and posed challenging questions for researchers working in the field. The authors claimed that there is a need to investigate the effect of the pollutant type on PV performance, and they found that there were almost 15 pollutant types investigated in the literature in terms of their effect on PV modules.

Al-Hasan (1998) conducted an experimental and analytical study of the impact of dust layers on light transmittance at the PV module glass surface. The study indicated that dust accumulation has a relationship with light transmittance. The author proposed a mathematical model to relate normal and diffused incident angles to beam transmittance based on the assumption that dust particles are equal in size and geometry. This relationship was necessary to determine the proper design of PV systems. The study results showed that transmittance decreased as the dust concentration increased, and this result was not wavelength dependent.

Chaichan et al. (2015) carried out a practical investigation to evaluate the effect of air pollution and dust on PV module performance. The results indicated that a combination of dust-air pollutants deteriorated the PV module performance. The exposure of the module to outdoor conditions without cleaning, even for a short period of two months, reduced the generated power to approximately 12%. Meanwhile, a naturally cleaned module lost approximately 8% of its power compared to the clean module.

Darwish et al. (2013) investigated the direct impact of dust compared with other parameters on PV performance. The study revealed the significant influence of dust on the performance of a PV system. The dust particle variations in phase, type, and chemical, and physical properties resulted from variable environmental conditions and caused different effects. Environmental parameters, such as air temperature, humidity, and wind speed, play a significant role in the dust distribution and its accumulation on a PV module.

Kazem et al. (2014) conducted a review of the human activities that caused an increase in desert areas in Iraq, consequently causing an increase in dust storms. The study focused on dust causes, types and specifications. Moreover, the authors analysed the physical and chemical effects of dust on PV systems. The study found that PV efficiency is greatly affected by dust storms.

Klugmann-Radziemska (2015) studied the degradation in electrical performance of PVs in Poland. The current-voltage characteristics were investigated with respect to the dust layer thickness. Moreover, the chemical composition and size of dust particles were evaluated. The author claimed that the average reduction in efficiency and power was 25.5% and 3% per year, respectively.

Sayyah et al. (2014) reviewed and investigated the impact of dust on the solar PV module energy yield. The degradation in performance based on the type of solar collector used, the local climate, geographical location, and exposure period of the collectors in the absence of any manual cleaning was discussed. The study analysed the advantages of cleaning processes, including manual, natural, passive and automatic methods.

Biryukov (1996) investigated and analysed the effect of the dust particle size. Different microscopic techniques were used in this study. The authors proposed that there are relationships between the tilt angles, deposition rates, and dust particle size and PV performance.

Jiang et al. (2011) performed an experimental study to investigate the efficiency degradation due to dust accumulation on various types of PV arrays using a test chamber and a sun simulator. The study results confirmed other researchers' findings that dust accumulation affects the PV array output voltage and current. Additionally, the results showed that the decline in the PV module efficiency was amplified when the intensity of solar radiation was very high or very low. No particular effect resulted from changing the cell types. However, the polycrystalline silicon PV module coated with epoxy may have faster dust deposition and accumulation than other types of PV modules.

The general conclusions from the literature are summarized in Table 1, which shows an overview of some of the studies relating to dust composites and their impact on PV performance. The table is based on a database from the experimental investigation of dust pollutants in different countries. Some of the research used natural and artificial dust as well as indoor and outdoor experiments. Dust properties were investigated in different locations and by various techniques. Moreover, the investigators proposed different models. The physical properties of dust are a popular topic, and many researchers in various countries have investigated dust regarding its relationship with PV productivity, efficiency and cleaning methods. This justifies investigations of the impact of dust on PV performance in other regions and areas. Moreover, further study of the impact of dust on PV efficiency is important.