Solar Energy 161 (2018) 90–99

Contents lists available at ScienceDirect

Solar Energy

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

Analysis of soil distortion factor for photovoltaic modules using particle size composition

Subrahmanyam Pulipaka*, Rajneesh Kumar

Department of Electrical and Electronics Engineering, Birla Institute of Technology and Science, Pilani 333031, India

ARTICLE INFO

Keywords:
Irradiance
Smoothing spline
Soiling and tilt angle

ABSTRACT

This paper introduces a soil distortion factor (SDF) to establish a relationship between particle size compositions of soil and irradiance received by a tilted soiled solar panel. Particle size composition of five soil samples was determined using sieve analysis and artificial soiling experiments were performed to measure open circuit voltage (V_{oc}) and short circuit current (I_{sh}) to calculate power output of soiled panel. The power obtained from experimental data was compared with the ideal power output of a clean panel to quantify SDF at three regions of tilt angle. Further, SDF is expressed in terms of particle size composition of soil using regression analysis to calculate irradiance loss. It was observed that the irradiance loss varies with tilt angle and particle composition of soil. Soils rich in particles with 150 μm diameter (Soil 1) and 300 μm diameter (Soil 3) cause irradiance losses up to 6% and 21% while Soil 2 with high composition of 75 μm particle size leads to maximum losses of 10%. Soil 4 with 300 μm particles as its major composition causes losses as high as 22% in the same tilt angle range. Soil 5 having the highest composition of less than 75 μm size particles causes 12% irradiance loss in 0–60° tilt angle region.

1. Introduction

Irradiance incident on a solar photovoltaic (PV) panel is one of the vital elements that determine its power output. Meteorological stations provide information regarding direct and diffused irradiance on a horizontal surface from which the irradiance incident on a tilted panel is calculated. Various numerical models were developed during initial stages of PV plants installations to determine the value of irradiance on a tilted panel and classified into isotropic and anisotropic sky model approximations. Koronakis (1986), Badescu (2002) in their reported work modeled diffused radiation on a tilted panel using isotropic sky model assumptions. Willmott (1982), Hay (1979), Reindl et al. (1990), Gueymard (1987), Perez et al. (1987) developed anisotropic models to calculate diffused irradiance on a tilted panel. Twidell and Weir (2006) stated that direct irradiance over a tilted panel can be obtained from horizontal direct irradiance through trigonometric expressions. However, these models have not taken into consideration the effect of soiling in determining the direct irradiance on a tilted panel which is responsible for decrease in irradiance received by the panel, thereby reducing the power output. Analysis of soiling on a panel dates back to 1942, when (Hottel and Woertz, 1942) reported an average irradiance loss of 1% for a 30° tilted glass plate. Anagnostou (1978) concluded that the effect of soiling is site dependent and remains constant after a period of time while (Cuddihy, 1980) described methods for deploying materials with low affinity to soil retention. Subsequent reported works on power reduction due to soiling were quantified based on experimental observations. Said (1990) reported 7% reduction in power output due to soiling while (Rahman et al., 2015) observed a 7.7 W loss in power output of a panel due to soiling. The effect of soiling on output power efficiency using I-V curves was studied by Schill et al. (2015). Vivar et al. (2010) observed maximum losses up to 26% due to soiling on concentrated PV systems in their experimental work carried out at Madrid and Canberra. Massi Pavan et al. (2011) reported variation in the soiling losses due to sandy and compact soil on a solar panel with 6.9% and 1.1% losses respectively. Zorrilla-Casanova et al. (2013) reported irradiance losses of more than 20% for solar panels installed in arid regions. The effect of soil density on power output of a solar panel was experimentally observed by Rao et al. (2014) and losses of 45–55% were observed with a soil density of 7.155 g/m^2 in an indoor experimental setup and 5–6% for 1.4 g/m^2 deposition in outdoor experimental setup. The influence of spectral properties of soil was observed by Burton et al. (2015b) and Burton et al. (2015a) with a quantification of minimum detectable density of soil, affecting the power output of a panel with artificial soiling experiments. In a recent experiments carried out by Paudyal et al. (2017) found that power output of a dusty solar module decreased by 29.76% as compared to the module cleaned

* Corresponding author at: Department of Electrical and Electronics Engineering, Vidya Vihar, BITS Pilani, Pilani, Rajasthan 333031, India.
E-mail address: pulipakasubbu@gmail.com (S. Pulipaka).

https://doi.org/10.1016/j.solener.2017.11.041
Received 28 January 2016; Received in revised form 15 November 2017; Accepted 16 November 2017

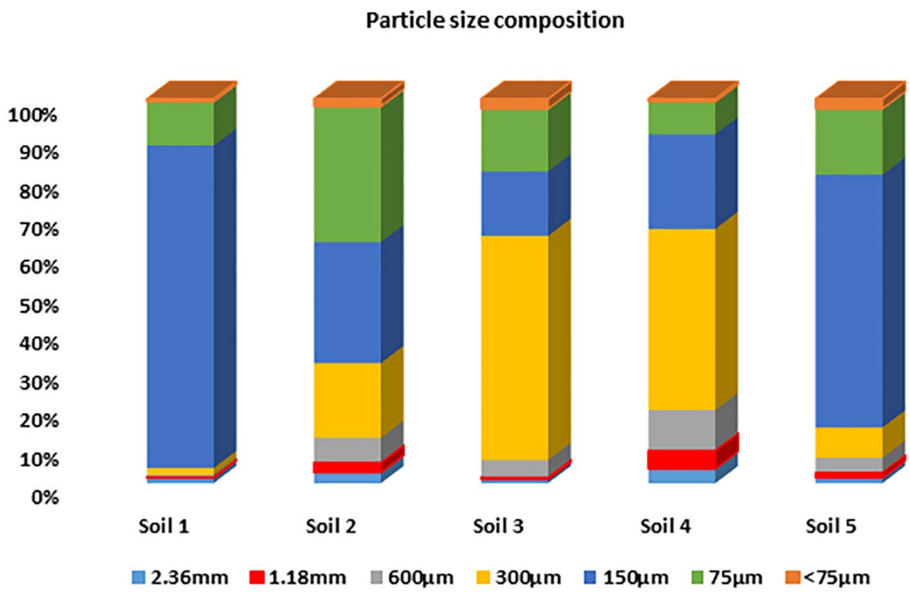

Fig. 1. Particle size composition of the soil samples.

Table 1
Sample data set during experiments.

Soil: Pilani Tilt angle (°)	Temperature: 17 °C Humidity: 34% Irradiance (W/m^2)	Wind speed: 8 mph Time: 10:40 am Short circuit current, I_{sc} (A)	Latitude: 28° Date: 8/2/2015 Open circuit voltage, V_{oc} (V)
0	960	2.14	20.53
15	957	2.38	20.61
30	963	2.72	20.74
45	964	2.96	20.82
55	967	3.17	20.85
60	967	3.22	20.85
61	972	3.25	20.84
62	976	3.27	20.82
63	980	3.29	20.81
64	979	3.28	20.78
65	979	3.28	20.76
66	979	3.28	20.74
67	982	3.27	20.72
68	985	3.28	20.70
69	988	3.27	20.67
70	988	3.25	20.65
75	984	3.16	20.61
90	978	3.02	20.56

on daily basis when the dust deposition density on the PV module accounted to 9.67 g/m^2. Jiang et al. (2017) studied the impact of wind velocity on the re suspension of soil particle sizes ranging from 0.1 to 100 µm on a PV panel. Menoufi et al. (2017) proposed photovoltaic soiling index to quantify the losses due to dust deposition after performing an experiment at East Bank of the Nile. Javed et al. (2017) developed a model to characterize the soiling on a panel as a function of environmental variables and daily change in the Cleanness Index. The reduction in power output of a solar panel was attributed to the density of dust deposition on it in these reported works. However, the effect of particle size composition of soil on power output of a solar panel is not reported in these research publications. Pulipaka et al. (2016) used particle size composition of soil to model the soiling losses on a PV panel using regression and artificial neural networks.

This research work aims to develop a correlation between the particle size composition of soil deposition on the panel to the losses generated by the deposition. Based on extensive artificial soiling experiments, this paper proposes a correction factor termed as soil distortion factor (SDF) to calculate direct irradiance incident on a tilted soiled panel. Mathematical expression of this factor in terms of particle size composition is developed for three tilt angle intervals based on the behavior of irradiance vs tilt angle curve plotted for a wide range of irradiance levels. Proposed work will help in planning the future installation of PV systems in arid region where soiling is a major factor of power loss. For large power plants where tilt angle is fixed at latitude of the place, slight deviation in tilt angle depending on soil particle size composition may lead to better efficiency. Also, in building integrated systems this analysis will help in correct estimation of power output from solar panels with soiling.

2. Experimental methods (Mani et al., 2015)

Five soil samples were collected from five different locations in Shekhawati region of Rajasthan in India. The soils collected belonged to the following regions namely, *Raghunathgarh* (Soil 1), *Neem Ka Thana* (Soil 2), *Khetri* (Soil 3), *Sikar* (Soil 4) and *Pilani* (Soil 5).

2.1. Sieve analysis

Sieve analysis is a technique adopted to assess the particle size distribution of a granular material. In this analysis, a box which contains seven sieves with standard sizes of 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm, 75 µm and a pan (to collect particle sizes less than 75 µm particle sizes) that are placed from top to bottom respectively. A 500 g sample of each soil is taken one at a time and is deposited in the top sieve of 2.36 mm size. Fig. 1, shows the output of the sieve analysis where the percentage of the standard particle sizes in the five soils is interpreted through a column chart representation. Soil 1 has higher composition (83.8%) of 150 µm particle size as well as the highest composition of this particle size among the five soils. Soil 2 has equal composition of 150 µm (32%) and 75 µm (35%) particle sizes and it has the highest composition of 75 µm particle size among these soils. Soil 3 and Soil 4 have 300 µm particle sizes in their composition in abundance (58% and 47% respectively). However soil 3 has highest 300 µm particle size composition among the soils. Soil 5 has 150 µm particle sizes mainly constituting its particle size composition (65.2%).

2.2. Artificial soiling experiment

In the artificial soiling experiment, all the 5 soil samples are spread over a PV panel one at a time and the corresponding short circuit current (I_{SC}) and open circuit voltage (V_{oc}) readings were taken and one of the sample data set is shown in Table 1. These readings were