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Characterization of power losses of a soiled PV panel in Shekhawati region of India

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Abstract

This paper introduces a model that quantifies the relationship between power output, incident irradiance and soil particle size composition of soiled photovoltaic panels. Soil samples used in artificial soiling experiments were collected from Shekhawati region in India and their relative percentage of standard particle sizes is determined from sieve analysis. A non-linear relationship between irradiance and power is obtained using regression analysis showing the effect of particle size composition present on the panel. Further, the tilt angle for maximum power extraction is determined for each soiled panel and the deviation from the optimum tilt angle of a clean panel is observed. It is concluded that, when the soil present on the panel is rich in the particles with diameter (75 μm and below), the deviation from the tilt angle of a clean panel is 4°, however if the soil contains higher composition of both 150 μm and 300 μm particle sizes the deviation is 8°.

Keywords: Irradiance; Particle size composition; Regression; Soiling; Tilt angle

1. Introduction

Tilt angle and orientation of a photovoltaic (PV) panel are instrumental in deciding the irradiance received by it and the maximum power output under changing environmental conditions. Trackers that follow the direction of sun for maximum irradiance are used to obtain maximum power from a panel as reported by Chang (2009) and Ma et al. (2011). However, these trackers are not economically feasible and are a trade of between efficiency and economical operation of panels. It is therefore necessary to mount a solar panel at an optimum tilt angle for maximum power production throughout the year. As reported and widely accepted in literature, the panels in northern hemisphere are to be oriented facing south direction, while the ones in southern hemisphere are oriented to face north. Initial research works suggest that a solar panel must be kept at a tilt angle equal to the latitude (ϕ) of the area of operation. In further investigations into this optimum tilt angle calculation, Lunde (1980) and Garg (1982) conveyed that the performance of panel is enhanced at a tilt angle (β) equal to $\phi \pm 15$, for winter and summer respectively. Duffie and Beckman (1982) provided insights about the optimum tilt angle calculation for their respective locations, but not a generalized expression for robust use.

In recent years, researchers across the globe explored the effect of varying tilt angles on the panel and proposed models to calculate optimum tilt angle. Siraki and Pillay (2012) proposed a modified sky model to calculate the optimum

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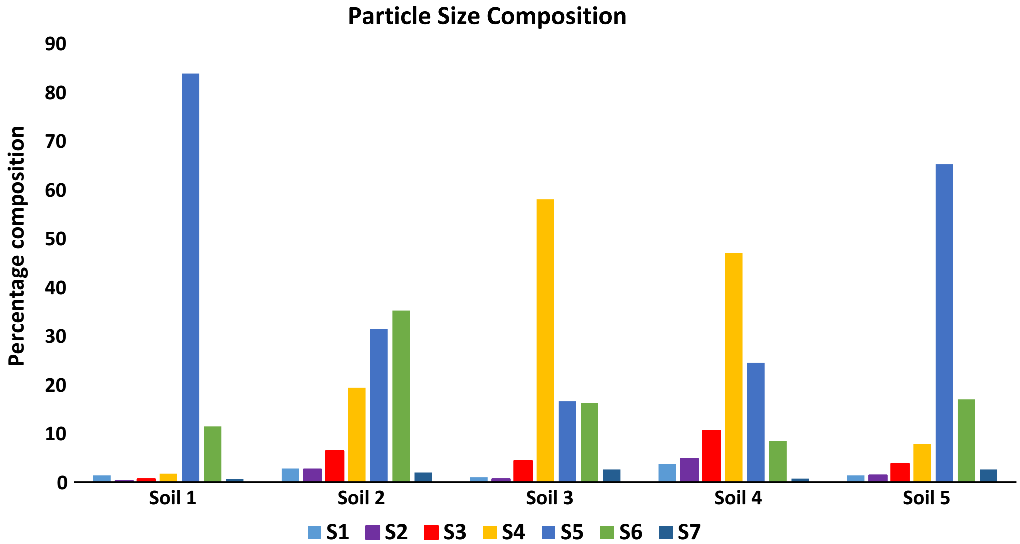

Fig. 1. Particle size composition of soil samples.

tilt angle, while (Benghanem, 2011) used the solar irradiance data available along with the geographical location parameters. A regression model was proposed by Asowata et al. (2012) for maximizing output power from a PV panel with varying tilt angle. Gulin et al. (2013) discussed predictive control algorithm for PV panel orientation taking local weather prediction into consideration. There were discussions negating the concept of optimum tilt angle of the panel (Beringer et al., 2011), while the influence of optimum tilt angle from electrical system perspective was discussed by Hartner et al. (2015).

Soiling on a panel reduces its power output due to spectral and reflective losses. It also changes the dependency of the angle of incidence on the solar radiation received by the solar panel. Zorrilla-Casanova et al. (2013) reported daily irradiance losses as high as 20% due to soiling after a long period without rain. A 3–4% power loss due to soiling was reported by Appels et al. (2013) at 35° tilt angle at Belgium while, the influence of particle size composition of the soil on a panel was observed by Pulipaka et al. (2016). Garcí et al. (2011) reported irradiance incidence angle losses due to dust particle on a solar-tracking Photovoltaic plant in Navarra, Spain. PV panels with smaller tilt angles (<5°) had comparatively larger soiling losses was reported by Mejia and Kleissl (2013) from a study carried out in California. Klugmann-radziemska (2015) observed the maximum daily losses close to 0.8% for a PV panel tilted at 37° in northern Poland. A mathematical formulation for soiling losses with respect to angle of incidence was expressed and analyzed by John et al. (2015).

The aforementioned works talked about tilt angle and soiling in individual context and proposed models for quantifying soiling losses as well as calculating optimum tilt angle. However, the correlation between tilt angle and the soiling on the panel is not explored yet. Hence, a regression based model is developed to understand the effect of particles with different diameter on the power output of a soiled PV panel. This empirical formulation of power output at each tilt angle for a PV panel signifies the varying effect of soil present on the panel and also conveys a non-linear relationship between power and irradiance incident on a panel.

2. Data acquisition

2.1. Sieve analysis

Soil samples are collected from five different locations (Raghunathgarh (Soil 1), Neem Ka Thana (Soil 2), Khetri

Table 1
Sample data set.

Soil: Pilani Tilt angle (°)	Temperature: 23.9 °C Irradiance (W/m^2)	Wind Speed: 8 mph humidity: 34% Current I_{sc} (A)	Date: 2/8/15 time: 10:40 am 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	20.7
69	988	3.27	20.67
70	988	3.25	20.65
75	984	3.16	20.61
90	978	3.02	20.56