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Analysis of irradiance losses on a soiled photovoltaic panel using contours

Subrahmanyam Pulipaka *, Rajneesh Kumar

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

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ABSTRACT

This paper introduces an irradiance loss factor that quantifies the relationship between irradiance, tilt angle and power output of a soiled panel with the soil particle size composition. Artificial soiling experiments were performed using four soil samples at irradiance levels between 200 and 1200 W/m^2 at 18 tilt angles. Biharmonic interpolation was used to develop power contours in terms of irradiance and tilt angle from experimentally obtained data. These contours were compared with ideal ones of a clean panel to observe deviation in the nature of contours for a soiled panel. A correction factor in terms of particle size composition (as a coefficient to tilt angle) was proposed to calculate power output of a tilted soiled panel. The angular loss on a panel with soil sample containing 150 μm particle size in abundance was observed to be 22% and for sample containing 75 μm particles in majority, the loss is 24%. Presence of 300 μm particle size in abundance causes a 23.7% loss, while 52% angular loss was observed for soil with highest composition of less than 75 μm particle size.

1. Introduction

Power obtained from a solar panel depends on the solar radiation received by it at a given tilt angle. The amount of radiation received at a given location is determined using variable parameters like temperature, sunshine duration, rainfall, etc. Al-Mostafa et al. [1] reviewed 52 models at Jouf, Saudi Arabia using sunshine duration for predicting the irradiance and identified the best models suitable for prediction. Park et al. [2] used the topographic factors of Korean Peninsula, in addition to sunshine duration to determine the irradiance received and developed a map presenting monthly mean variation in the incoming solar radiation. Routinely observed meteorological data like maximum and minimum temperatures was used in [3] at Chongqing, China to predict the irradiance and it was concluded that the model using temperature, rainfall and dew point data is accurate in predicting irradiance with a RMSE of 2.91 MJ m^{-2} day^{-1} . Alonso et al. [4] used emerging sky camera technologies to predict irradiance levels in 1 minute intervals. Similarly, Yacef et al. [5] developed a combination of empirical and Bayesian Neural Network based models to predict the irradiance in Algeria. A support vector regression machine based model to estimate irradiance was developed in [6] to calculate irradiance in 365 sites containing no irradiance sensors. Further, to predict monthly irradiance, linear, quadratic and cubic empirical models were developed using meteorological data by Teke et al. [7]. A reliable model to predict irradiance is developed in [8] for Turkey by addressing the problem of multicollinearity. Sky radiance data was used to predict irradiance on an inclined panel in [9] with a good accuracy. Mefti et al. [10] used sunshine data to predict hourly irradiance on inclined surfaces in Algeria. Yoon et al. [11] deployed a photographical method to predict and calculate the irradiance on an incident surface in South Korea. Existing models (3 isotropic and 6 anisotropic) that determine irradiance incident on a tilted panel from horizontal irradiance data were discussed in [12]. Validity of some of these models were evaluated by transposing 10 min diffuse solar irradiation from horizontal to tilted surface in [13]. However, presence of soil on a panel makes these models less accurate due to loss of irradiance caused by soiling.

Arid regions are the most opted choice for solar PV installations due to large sunshine availability throughout the year and lower population density. However, soiling is an inevitable phenomena in these areas leading to power loss due to irradiance reduction caused by soiling. A decrease in power output as high as 30% is reported by Zorrilla-Casanova et al. [14]. Initial studies on quantifying the effect of soiling on a panel surfaced four decades ago when Garg [15] investigated the effect of soiling on glass panels in Roorkee, India and reported a decrease in the transmittance

* Corresponding author.
E-mail addresses: pulipakasubbu@gmail.com (S. Pulipaka), rajneesh1872@gmail.com (R. Kumar).

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Nomenclature

α	elevation angle (°)	β	tilt angle (°)
δ	declination angle (°)	φ	latitude of the location (°)
ε	angular position with respect to sun (°)	Γ	azimuthal angle (°)
DNI	direct normal irradiance (kW h/m^2/day)	B_n	direct horizontal irradiance (W/m^2)
B_β	module irradiance on tilted surface (W/m^2)		

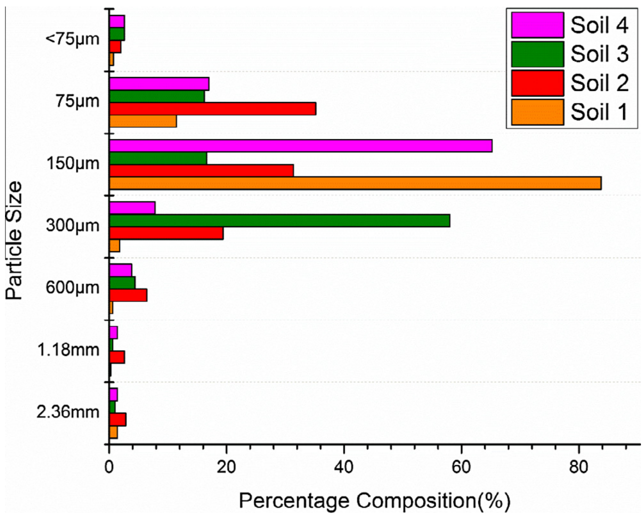

Fig. 1. Particle size composition of the soil samples.

Fig. 2. Natural soiling.

Fig. 3. Artificial soiling.

from 90% to 30% over a period of 3 months. In another study, the effect of dust on a 60 kWp capacity PV system was observed in Burgdorf, Switzerland [16] by examining the power data before and after cleaning the panels. Elminir et al. [17] conducted artificial soiling experiments on a panel at a set of 7 tilt angles and from the results obtained concluded that a decrease in density of soil from 15.84 to 4.48 g/m^2 the transmittance diminishes from 52.54% to 12.38%. Lorenzo and Moreton [18] reported an increase in voltage losses for an inhomogeneous soil on a panel. The effect of sandy soil and compact soil on large scale photovoltaic plants in Italy was studied in [19] and a loss of 6.9% and 1.1% respectively was reported. For a concentrated PV systems (CPV) similar experiments were conducted and maximum losses up to 26% were observed by Vivar et al. [20]. The influence of soiling on *I–V* curves of a panel was analyzed in [21] with a 20% decrease in the power output effi-

Table 1
Sample experimental data set. Irradiance (W/m^2), current, *I* (A), voltage *V* (V), and power *P* (W).

β (°)	Temperature – 17 °C, wind speed – 8 mph, date – 08.02.2015, humidity – 34%, and time – 10:10 am–10:40 am															
	Soil 1				Soil 2				Soil 3				Soil 4			
	Irradiance	*I*	*V*	*P*	Irradiance	*I*	*V*	*P*	Irradiance	*I*	*V*	*P*	Irradiance	*I*	*V*	*P*
0	344	0.87	20.1	17.487	391	0.9	20.06	18.054	300	0.72	20.01	14.4072	340	0.66	19.02	12.5532
15	345	0.97	20.24	19.6328	394	1.02	20.22	20.6244	305	0.8	20.14	16.112	338	0.7	19.1	13.37
30	345	1.18	20.43	24.1074	395	1.23	20.4	25.092	305	0.96	20.34	19.5264	334	0.74	19.2	14.208
45	346	1.29	20.52	26.4708	396	1.36	20.5	27.88	306	1.08	20.46	22.0968	333	0.88	19.38	17.0544
55	347	1.44	20.62	29.6928	398	1.47	20.58	30.2526	307	1.25	20.57	25.7125	327	0.93	19.48	18.1164
60	350	1.51	20.65	31.1815	402	1.58	20.64	32.6112	314	1.33	20.59	27.3847	324	0.98	19.54	19.1492
61	351	1.54	20.65	31.801	402	1.61	20.63	33.2143	315	1.34	20.59	27.5906	323	0.98	19.55	19.159
62	352	1.55	20.66	32.023	403	1.62	20.63	33.4206	315	1.34	20.59	27.5906	321	0.98	19.55	19.159
63	352	1.55	20.66	32.023	404	1.65	20.64	34.056	317	1.35	20.59	27.7965	320	0.97	19.54	18.9538
64	369	1.55	20.65	32.0075	406	1.66	20.62	34.2292	318	1.35	20.58	27.783	316	0.96	19.54	18.7584
65	370	1.55	20.64	31.992	406	1.65	20.6	33.99	319	1.35	20.58	27.783	315	0.96	19.54	18.7584
66	372	1.56	20.63	32.1828	406	1.65	20.6	33.99	321	1.36	20.57	27.9752	313	0.95	19.53	18.5535
67	373	1.55	20.61	31.9455	407	1.67	20.63	34.4521	323	1.36	20.55	27.948	312	0.95	19.54	18.563