Solar Energy 160 (2018) 94–102

Contents lists available at ScienceDirect

Solar Energy

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

Saharan dust transport to Europe and its impact on photovoltaic performance: A case study of soiling in Portugal

Ricardo Conceição[a,*], Hugo G. Silva[a], José Mirão[b], Michael Gostein[c], Luis Fialho[a], Luis Narvarte[d], Manuel Collares-Pereira[a]

[a] Renewable Energies Chair, University of Évora, Portugal
[b] Hercules Laboratory, University of Évora, Portugal
[c] Atonometrics Inc., TX, United States
[d] Universidad Politécnica de Madrid, Spain

ARTICLE INFO

Keywords:
Solar energy
Saharan desert dust transport
Soiling
Photovoltaic performance

ABSTRACT

The impact of long range Saharan dust transport, arising from one event in February and other in March 2017, on the performance of photovoltaic flat panels is reported as a case study of soiling. Through satellite images, dust coming from north Africa was detected, while using the Hybrid Single-Particle Lagrangian Integrated Trajectory, specific origin locations of the dust were found. Dust accumulated on glass coupons deployed in Southern Portugal, Évora and Alter do Chão, was analysed by Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy. Mass accumulation on those coupons was weekly measured with a microbalance and related with environmental parameters, aerosol optical depth and rain, through a proposed empirical model. Performance measurement took place at Évora using mc-Si PV flat panels and an I-V curve tracer to get two parameters: maximum output power and short-circuit current. It was found that the first dust event led to decreases in the maximum output power of $\approx 8\%$ and in the short-circuit current of $\approx 3\%$, while the second event led to a decrease of $\approx 3\%$ in both parameters. A relation between PV performance and mass accumulation was successfully explored.

1. Introduction

Soiling, defined as particle deposition on surfaces, reduces a PV cell's incoming radiation by reflecting it back to the atmosphere or absorbing it. The amount of soiling and how it is spread along the surface of the PV panel is geography and time dependent, which means soiling will vary from site to site. This fact is easy understandable, since different locations may have different climates, which implicates different meteorological conditions, like temperature, relative humidity, rain, wind speed and direction (Sayyah et al., 2014), that affect the way particles adhere to surfaces (Kazmerski et al., 2016). Moreover, different locations may have different types of particles suspended in the atmosphere, which also might have a different effect on how and to what extend the radiation entering the panels will be reduced (El-Shobokshy and Hussein, 1993; Appels et al., 2013). Even neighbor locations may have different types and amounts of soiling, depending if they are close to a specific source of particles, e.g. factories, airports and roads, among others (Mejia and Kleissl, 2013). Though most of those studies were done in or near desert areas, where soiling is a major problem (Mallineni et al., 2014) and where there are high values of solar energy availability. However, there are other locations with huge potential for solar energy usage that also need attention regarding soiling and where it can also be problematic, as will be shown, Portugal being one of these cases. This country is one of the best to deploy solar energy harvesting technologies in Europe (Šúri et al., 2007); its southern region has annual availabilities of global horizontal irradiation that can go up to approximately 1800 kW h/m^2, (Lopes et al., in preparation). With such availability, it is therefore expected that solar technologies, such as PV, will be very common in Portugal in the future, which makes soiling an interesting and very important factor to be taken into account. Besides that, it is also an objective to understand and explain phenomena like the ones documented here and draw conclusions that may in fact be used in future studies. Also taking into account the latest NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) (Thrasher et al., 2012; Sheffield et al., 2006), in 2100 this region will have higher air temperatures than at the present time and it will rain less frequently but with more intensity, which are negative projections regarding soiling, since if they become a reality,

* Corresponding author.
E-mail address: rfc@uevora.pt (R. Conceição).

https://doi.org/10.1016/j.solener.2017.11.059
Received 22 September 2017; Received in revised form 13 November 2017; Accepted 22 November 2017

there will be more time for particles to build up on the surfaces, leading to an increased soiling over time. Moreover, if climate change follows this trend, Southern Portugal and Spain will become semi-arid regions, which can also lead to an increase of particles suspended in the atmosphere that are able to deposit, because vegetation acts as a particle retainer and obstacle (Smith, 1977).

In this context, Saharan desert dust storms are a significant source of dust, that frequently reach Portugal (around 4–5 major events per year) (Flentje et al., 2015), bringing quantities of dust that significantly influence the performance of PV systems, as will be shown. In fact, during this study a major Saharan desert dust storm took place on 20th–24th February 2017, in which a large amount of dust was swept up into a low pressure system over North Africa, leading to the transportation of a dust cloud over Portugal. Significant soiling was detected and it was derived mainly not from local particles, but from the ones with very far away origin. Though with less intensity, another dust event occurred on March 2017 from 14th–16th and it is also documented here. This work points towards the fact that not only local environment affects soiling, but it shows instead that long-range dust transport (from a process developed thousands of kilometres away) can also influence soiling and the PV performance on a far away region. This work uses the mentioned Saharan desert events as a case study to highlight the importance of these phenomena in the energy production of the region and also the need to develop mitigation tools, e.g., proper dust storm forecasts or the use of active and passive cleaning mechanisms.

2. Experimental setup

Soiling measurements took place at two rural locations in Southern Portugal (Alentejo): Évora at Plataforma de Ensaios de Coletores Solares (PECS) facilities from the Renewable Energies Chair (CER) (Horta et al., 2015) and Alter do Chão in a 200 ha olive tree property of Elaia group (ELAIA) with the following coordinates: Évora - 38°34′0.01″ N; 7°54′0.00″ W and Alter do Chão - 39°12′3.39″ N; 7°39′37.09″ W. The glass sample at this location is part of a larger soiling experiment of the European project MArket uptake of an innovative irrigation Solution based on LOW WATer-ENergy consumption (MASLOWATEN funded by Horizon 2020, contract number 640771). The MASLOWATEN project, in which CER participates, is led by Universidad Politécnica de Madrid and its objective is to use high power PV pumping systems for productive agriculture irrigation consuming zero conventional electricity and achieving less water consumption.

2.1. Mass accumulation

SINA high transmittance solar glass coupons, from Interfloat Corporation, were left outdoors in two experimental setups. In PECS, the experimental setup consists of 25 coupons, with 11 cm length 9 cm width and 3.2 mm thickness at approximately 1.5 m height from the ground, with 6 samples per geographical direction (North, East, South and West) in 15° inclination steps and one completely horizontal on the top, following the idea in Elminir et al. (2006), as shown in Fig. 1a. For clarity, N6 and E6 are the designations used for the glass coupons oriented towards North and East with 15° inclination regarding the horizontal position, respectively. In ELAIA a single glass coupon was deployed on a single-axis tracking PV system, approximately 1.5 m above the ground, in a structure that replicates the usual PV module assembly glass-metal frame, see Fig. 1b. Weekly mass measurements were done to all 25 samples at PECS and monthly Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) measurements were done to selected coupons from PECS and ELAIA. Mass was obtained using a Bosch SAE 80/200 microbalance model and the testing campaign started in the end of January 2017. The mass measurement uncertainty, 0.17 mg, was determined from several measurements of a clean glass. The objective is to study the mass accumulation on the glass coupons and relate it with the environmental conditions as well as to characterize the soiling accumulated. Mass accumulation on week t,$m_a(t)$, is determined by subtracting from the measured mass at that week, mass (t), the initial mass of the clean glass, mass(0):

$$m_a(t) = \text{mass }(t) - \text{mass }(0). \tag{1}$$

No cleaning is done to the glass during the experiment and only environmental action (e.g., rain) can act towards reducing the mass accumulated on the coupons.

2.2. PV performance

The testing campaign, related to the evaluation of the PV performance, being conducted since 31st October 2016 in PECS, is depicted in Fig. 1c. It shows two mc-Si PV flat panels of the same model FTS-220P, manufactured by Fluitecnik. The current-voltage (I-V) characteristic curves were obtained with a Eurotest PV Lite MI 3109 manufactured by Metrel. On these PV modules, one was manually cleaned before each I-V curve tracing and the other was kept unclean since the begining of the experiment. Three I-V curves were obtained for each module. The measurements were only performed in clear sky, near solar noon, and the tracker was always set perpendicular to the sun when performing the measurements. When not performing measurements, the panels are set facing south and tilted 30° from the horizontal. This is done to represent what would be the approximate position of a real fixed system, optimized for this location. This experiment is based fundamentally on Gostein et al. (2015), with one main difference: measurements are not taken continuously, so the number of points which contribute to the calculations is much smaller. The Soiling Ratio index (SR) is calculated by comparison of the short-circuit current (I_{SC}), which is denoted ($SR_{I_{SC}}$) and the maximum power output, ($P_{\max}$), denoted ($SR_{P_{\max}}$) of the two photovoltaic panels. The main difference noted in Gostein et al. (2015) is the fact that when soiling is homogeneous both metrics give similar results, but when the soiling is not homogeneous, calculating the soiling ratio based on the short circuit current can give either an underestimated or overestimated result, comparing it what was actually lost in power output. The reason for this is the fact that non-uniform soiling distorts the I-V curve in such a way that in some cases it changes considerably the I-V maximum power point. In mathematical terms, ($SR_{I_{SC}}$) and ($SR_{P_{\max}}$) are calculated through Eqs. (2)–(4):

$$SR_{I_{SC}} = \frac{I_{SC}^{soil}}{I_{SC}^{soil,0}[1 + \alpha(T_{soil} - T_0)](G/G_0)}, \tag{2}$$

where I_{SC}^{soil} is the short-circuit current of the soiled PV panel, $I_{SC}^{soil,0}$ is the short-circuit current of the soiled PV at clean condition in Standard Test Conditions (STC), α is the short-circuit temperature correction coefficient, T_{soil} is the cell temperature of the soiled panel, T_0 is the temperature at reference condition (25 °C), G is the irradiance in the PV plane and G_0 the irradiance at STC conditions (1000 W/m^2).

$$SR_{P_{\max}} = \frac{P_{\max}^{soil}}{P_{\max}^{soil,0}[1 + \gamma(T_{soil} - T_0)](G/G_0)}, \tag{3}$$

where $P_{\max}^{soil}$ is the maximum power of the dirty PV panel, $P_{\max}^{soil,0}$ is the maximum power at clean condition and γ is the maximum power temperature correction coefficient. For the calculation of the irradiance in the PV plane, the clean module is used:

$$G = G_0\frac{I_{SC}^{clean}[1 - \alpha(T_{clean} - T_0)]}{I_{SC}^{clean,0}}, \tag{4}$$

where I_{SC}^{clean} is the short-circuit current of the clean PV panel, $I_{SC}^{clean,0}$ is the short-circuit current at clean condition in Standard Test Conditions (STC), α is the short-circuit temperature correction coefficient and T_{clean} is the cell temperature of the cleaned panel.