Characterization of PV Soiling Losses in Urban Mediterranean Environment

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Abstract

Soiling losses may have an impact in PV performance as a result as a complex balance between sources associated to environmental conditions and removal mechanisms like precipitation and wind. In the PVCastSOIL project a small experimental facility is set up in a park zone in Madrid to characterize the soiling in a near forest urban zone. The soiling ratio has been estimated from two different methodologies by comparing the performance of a soiled module with a reference module (which is cleaned every week). The methodologies are based on estimating the performance ratio from the maximum power and from the short-circuit current (since I-V curves are being monitored for every PV modules). The preliminary results show an average soiling ratio below 1% for modules with tilt angle of 8º and 0.5% for 35 tilt angles.

Keywords: PV performance, soiling losses, PV and soiling monitoring

1. Introduction

The penetration of PV technologies nowadays is noticeable worldwide. Moreover it is foreseen a continuous increase for the next few years (IEA-PVPS, 2018). The performance and efficiency of any PV system is closely linked to the in-site meteorological conditions. However, sites with high irradiation levels increasing the performance are typically accompanied by low precipitation rates and high aerosol loads. Under that conditions, the benefit of the high irradiation can be partially reduced by the performance losses due to deposition of dust and other particles and contaminants on the modules surfaces, denoted as soiling effect (Beattie et al., 2012; Ilse et al., 2018; Massi Pavan et al., 2011; Menoufi et al., 2017; Micheli and Muller, 2017). The impact of several meteorological parameters on the soiling losses have been reported by several works (Micheli and Muller, 2017).

The losses due to soiling are the result of a balance between natural sources and sinks of soiling: particle deposition versus particle removal or resuspension. The process is complex because of the many influencing factors including meteorological conditions, PV module surface properties and characteristics of the PV array regarding tilt angle and orientation.

The project PVCastSOIL is intended to improve the forecasting capabilities for PV production. The project is being developed and will run until the end of 2020. One of the key specific objectives in this project is to characterize the soiling losses in different sites in Spain and to develop explicit functions or models that correlate the soiling ratio with the main affecting environmental parameters (rain intensity, wind speed, airborne particle density, etc.). Thus the project is being mainly developed by three institutions: Ciemat (Madrid), UAL (Almería) and UHU (Huelva). A small scale roof-top experimental facility is built at CIEMAT (Madrid) for monitoring single individual PV modules performance and the soiling losses. In Almería, south-east Spain there is a small scale PV plant of 15 kW

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that will be used for developing a model that incorporates the soiling losses. Finally in Huelva, south-west Spain, a small facility is setting up for studying the spectral transmittance losses of individual PV modules due to soiling.

This paper presents the main characteristics and objectives of PVCastSOIL projects and the preliminary results regarding the individual PV modules performance and soiling monitoring so far. The soiling ratio measured during the first semester of 2019 was very low. The environment of the Madrid site will likely result in seasonal periods of different soiling loads: First two months could be characterized by some cupressaceous pollen loads and in summer dust soiling is expected due to long periods of dry conditions with no rain.

2. Experimental facility

The experimental facility consists of four groups of three PV modules each one covering two technologies and two different tilt angles. Both multi crystalline silicon and CdTe are placed with south orientation and tilt angles of about 35° and 8°. Calibrated cells are used at each tilt angle to measure irradiance at the plane of the array (POA). The Dust IQ instrument from Kipp & Zonen is also installed in the 8° tilt structure to measure the soiling ratio. This device measures the soiling ratio based on measuring the transmission losses of light in two small windows. Every group contains three PV modules. The denoted as reference module is carefully cleaned once a week. The other two are exposed to the environment without manually cleaning and are called soiled and coated, since one of them was treated with an anti-soiling coating at the glazing. Figure 1 shows a picture of the experimental facility. In addition, a few spaces for small glass pieces can be observed on the right of the picture. They are intended for measuring the spectral transmittance of soiled glasses.

Fig. 1: Picture of the experimental facility

All the modules are off-grid connected and thus I-V curve is being monitored individually for each module using a PVPM2540C tracer and a specific electronic device for linking the tracer to each module. Temperature of the modules is also monitored by a thermocouple attached to the rear part of every module. Recommendations found in PVPS Task 13 have been followed in monitoring single I-V curves (Friesen et al., 2018). Therefore there is electric information of every module every 5 minutes, POA irradiance at two tilt angles and additional meteorological variables (ambient temperature, relative humidity, wind velocity and direction and precipitation, mainly) from a Vaisala meteo station. All the modules where carefully cleaned on 27th February 2019 and therefore that day can be considered as the starting point for the soiling study.

3. Preliminary results

Individual I-V curves for each module and additional meteorological variables have been monitored every 5 minutes since 27th February. Figure 2 shows the soiling ratio measured with the Dust IQ and the average rain intensity in daily basis. According to Dust IQ measurements the soiling ratio is very low in the whole semester. It reaches the 1% at the end of February, middle May and end of June. The first one could be associated to the high load of cupressaceae pollen that took place during January and February. In addition correlation with the precipitation can be also observed in the figure.

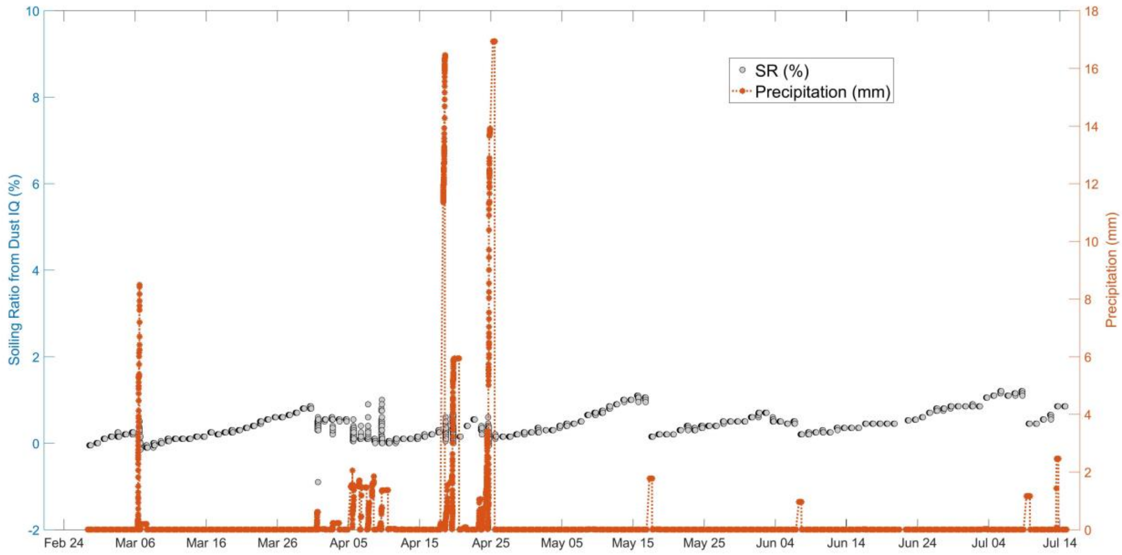

Fig. 2: Soiling ratio from the Dust IQ (left axis) and precipitation (right axis)

In order to minimize the uncertainties coming from shadowing, clouds transients and cloud enhancement, angular losses and so on a filtering of the single electrical data monitored was made using the incident irradiance. The first filter consisted in select those instants with conditions closer to clear sky, which are denoted as near clear sky instants. The algorithm proposed by Zhao was used to select near clear sky time instants (Zhao et al., 2018). It must be remarked here that there is no perfect algorithm to select clear sky instants without any failure. A thorough revision of methods for identification of clear sky conditions was presented by Gueymard et al. where Zhao method is included along with many others and where it concludes that there is still effort to be made on clear sky detection algorithms (Gueymard et al., 2019). Figure 3 shows the global tilt irradiance measured at 8.2° tilt angle along with the global tilt irradiance computed for clear sky, using the Ineichen clear sky model and the isotropic model for transposing to the tilt angle, and the selected instants considered as near clear sky (Ineichen and Perez, 2002). Cloud enhancement conditions (i.e reflection by clouds near the sun producing eventually very high irradiance peaks) have been also removed in the filtering. According to the figure 3 the Zhao algorithm combined with the removing of cloud enhancement conditions is a good approximation to select the best conditions to estimate single module performance.

On the selected instants corresponding to near clear sky conditions a second selection of data was performed to remove the single module shadowing taking place in the morning and late afternoon due to surrounding trees placed around the roof-top. Therefore, a time window was selected around 12:00 and 16:00 solar times where no shadowing at all occurred in the analyzed period.

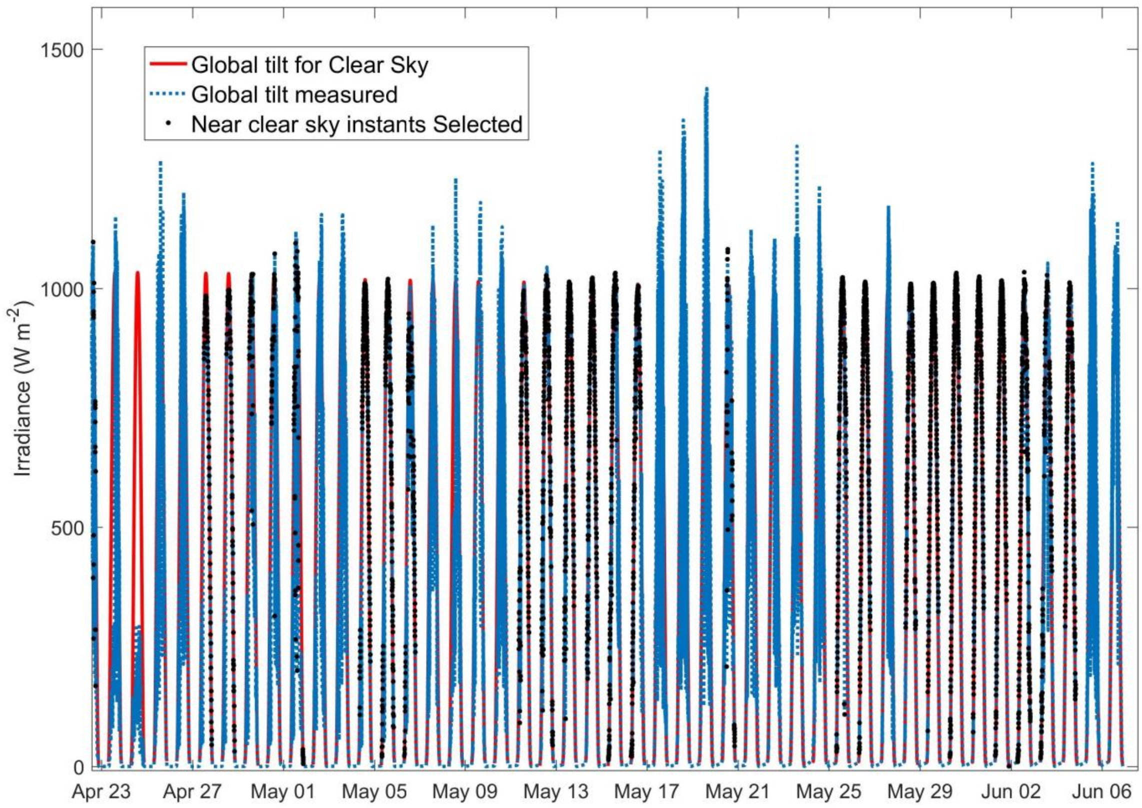

Fig. 3: Selection of near clear sky conditions in the experimental data

Performance ratio aggregated to daily basis can be calculated, for every single module, from the maximum power measurements and the POA irradiance by,

$$PR_{Pmax} = \frac{\sum \frac{Pmax}{Pstc}}{\sum \frac{G_{POA}}{1000}} \qquad \text{(eq. 1)}$$

where Pmax and Pstc are the maximum power of the module and the power at standard conditions (1000 Wm^{-2} and 25 °C), respectively, and G_{POA} the incident irradiance at the plane of the array. However, in cases where the I-V curve is being monitored it could be more convenient to express the performance ratio as a function of the short-circuit current (Friesen et al., 2018),

$$PR_{Isc} = \frac{\sum \frac{Isc}{Isc,stc}}{\sum \frac{G_{POA}}{1000}} \qquad \text{(eq. 2)}$$

being Isc and Isc,stc the short-circuit current measured in the module at outdoor and standard conditions, respectively. The performance ratio estimated with equation 2 should be less sensitive to the temperature effect and it is expected to be more stable along the year and more sensitive to soiling even under low soiling conditions.

Therefore, daily performance ratio is computed for those days accomplishing the near clear sky conditions and for the time window selected for avoiding shading effects. Since for each technology and tilt angle there is a clean module and a soiled module, the soiling ratio for every case can be computed from the performance ratio for each tilt angle (associated to maximum power or to short-circuit current) by,

$$SR = 100\,(1 - \frac{PR_{soiled}}{PR_{clean}}) \qquad \text{(eq. 3)}$$

Figures 4 and 5 show the performance ratio of clean and soiled modules at 8 degrees of tilt angle (upper curve) for multicrystalline silicon and the corresponding soiling ratio (bottom curve) computed using the maximum power and the short circuit current, respectively. The PR plot is accompanied by the precipitation. The soiling ratio during the monitoring period (close to 6 months) is rather low, reaching daily average losses around 0.8% in the short-circuit current and a 1.3% in the maximum power. Clear correlation with the precipitation can be observed in both curves. The measurements of the Dust IQ resulted in a daily average loss of 0.5% for the six-month period.

It must be noted that the performance ratio computed using the maximum power measurements from the I-V curves was corrected by the temperature using the temperature coefficient of power and the module temperature being monitored with a thermocouple in the rear part of the module. However the uncertainty in the module temperature might have an effect in the PR determination. Therefore, the soiling ratio determined from short-circuit current measurements could be a more reliable method than the use of the maximum power. In any case the results are preliminary since the soiling losses are still rather low. As the monitoring is progressing and when the exposure time is longer and thus the soiling deposition larger the differences among the different methods for determining the soiling ratio will decrease.

Figure 6 shows the soiling ratio computed with short-circuit current and power compared to the measurement of the Dust IQ. The three methods show the same trend but there are larger differences as the soiling ratio increase.

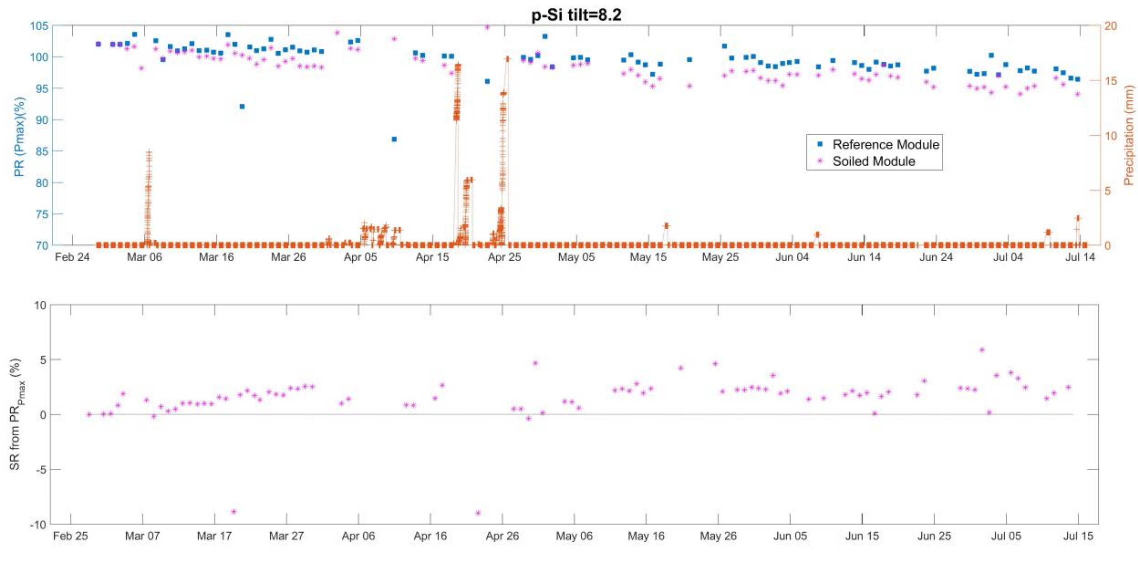

Fig. 4: Soiling ratio estimated from short-circuit current in 8º PV modules

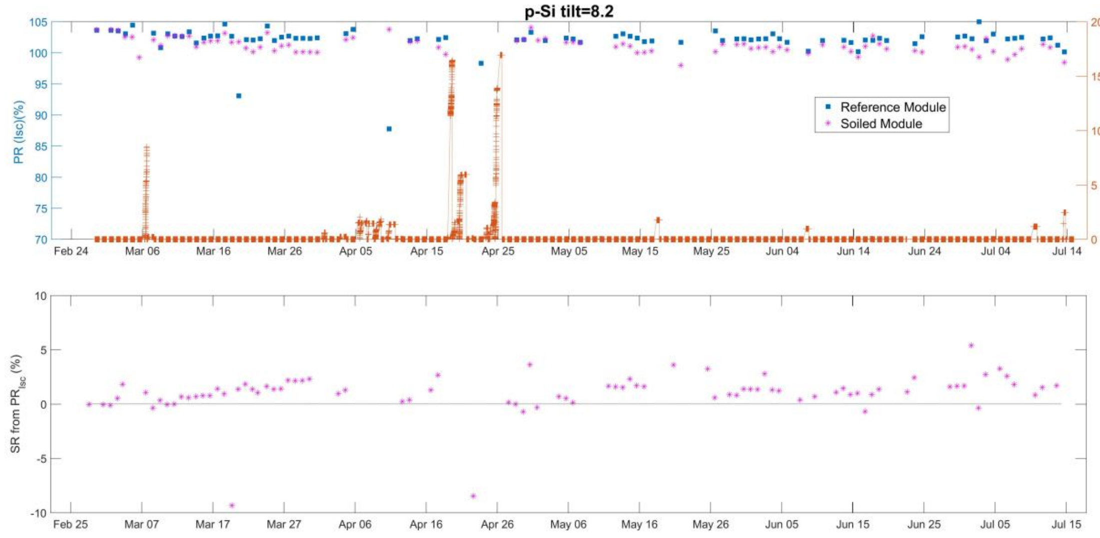

Fig. 5: Soiling ratio estimated from maximum power in 8º PV modules

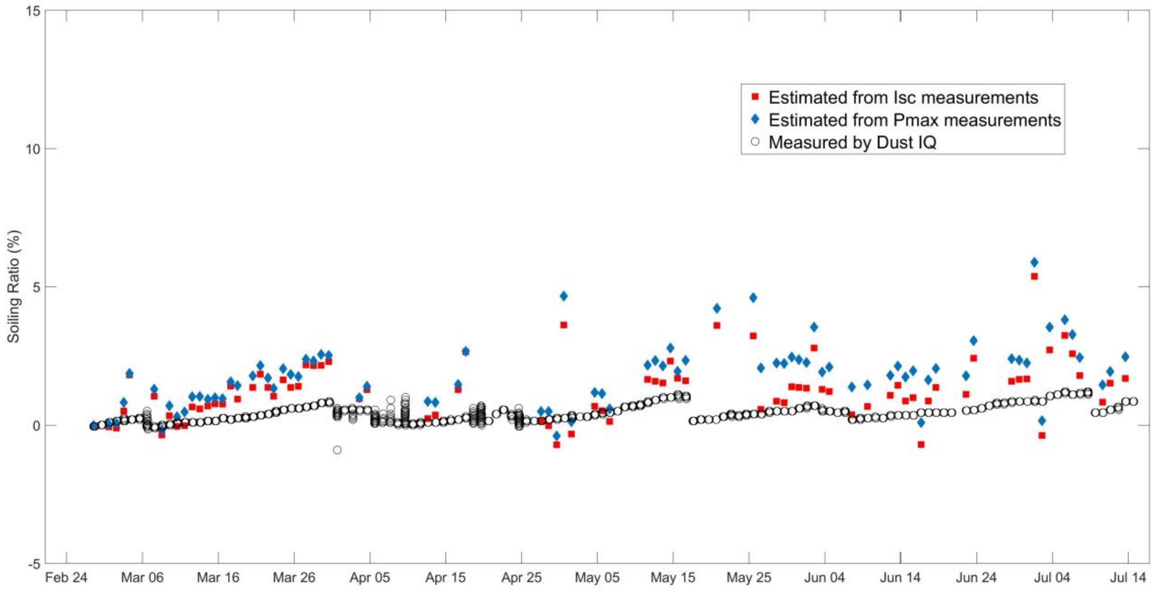

Fig. 6: Comparison of different ways to estimate the soiling ratio

Figure 7 shows the determination of the soiling ratio for 35 degrees of tilt angle from the different performance ratio definitions used here. As expected the soiling effect is much lower in this case than in the case of 8º of tilt angle. The environmental conditions during this near six month period were rather clean and more significant results are expected for longer testing period.

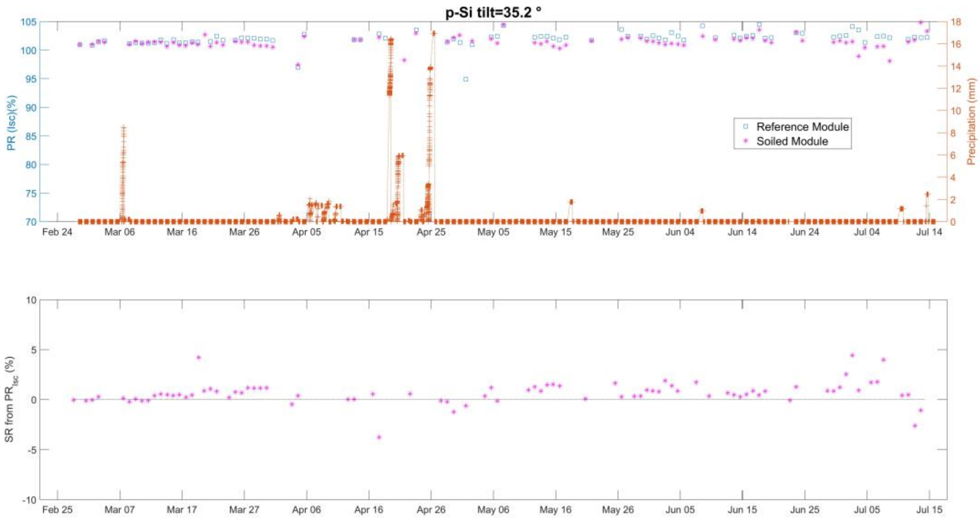

Fig. 7: Soiling ratio estimated from maximum power in 35º PV modules

4. Conclusions

The project PVCastSOIL is aimed at incorporating the soiling losses in a forecasting scheme of PV generation that will include the forecasting of incident solar irradiance and other parameters to predict the soiling losses. Within the project activities a small experimental facility was set up to characterize the soiling losses and find correlations with the environmental parameters. The experimental facility is analyzing two different PV technologies (p-Si and CdTe) and two different tilt angles (around 35º and 8º). For every case a group of three modules is arranged: the called reference module is being cleaned every week, the soiled and the coated modules are being exposed to the environment, the latter has an anti-soiling coating. The facility is placed in a large park in Madrid.

The preliminary results from about six months of monitoring the I-V curves of every module have shown a small soiling ratio, around 0.5-1.5 %. Good correlation with the precipitation was found as expected. Under low soiling exposure different methods for determining the soiling ratio have been explored. The advantage of monitoring the I-V curves allows to determine the soiling losses from the short-circuit current instead of from the maximum power which would be the usual parameter to compute the performance ratio. In conditions of very low soiling ratio the selection of near clear sky conditions is fundamental for analyzing the results. In this sense, this paper presents a novel method for selecting clear sky instants in POA irradiance measurements using the POA estimation for clear sky conditions. Under low soiling ration conditions it should be also remarked that uncertainties play arole in establishing differences in the soiling ratio measure by Dust IQ (with a small measuring window) and soiling ratio obtained from electric measurements in modules (with a larger surface for exposure). More significant results are expected in the future for longer testing time (after finishing the summer season and other subsequent seasons with pollen load).

5. Acknowledgments

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