Soiling Rates of PV Modules vs. Thermopile Pyranometers

Martin Waters[1], Tejas Tirumalai[1], Michael Gostein[2], Bill Stueve[2]

[1]Recurrent Energy, San Francisco, CA, 94104. [2]Atonometrics, Austin, TX, 78757.

***Abstract* — Performance monitoring of solar facilities depends on quantifying both irradiance and soiling losses, among other factors. Frequently thermopile pyranometers are used for irradiance measurement in conjunction with PV module-based soiling monitoring stations. However, thermopile pyranometers are also subject to soiling and must be cleaned regularly to maintain accuracy. In this paper we compare the rate of soiling of a thermopile pyranometer to a PV module at a site in the western US. The results for this site indicate that the thermopile pyranometer soils at less than half the rate of the PV module. The data can be used to establish cleaning guidelines for thermopile pyranometers. In addition, the results show that soiling of thermopile pyranometers should not be used as a proxy for the soiling of a PV array.**

I. Introduction

Accurate performance monitoring of solar facilities is highly dependent on accurately quantifying both the irradiance at the facility and any losses due to the accumulation of soiling. In order to quantify both of these at large scale solar installations it is common practice to install both pyranometers and soiling monitoring stations. However, as the number of pyranometers installed increases, maintenance on these devices becomes a non-trivial operational cost. While it is common to quantify the soiling rate of modules at a PV facility, it has not been common to quantify the rate of soiling on the pyranometers.

II. Methodology

A. Monitoring station description

For the purpose of monitoring both module soiling as well as pyranometer soiling, a system consisting of the following equipment was deployed in January of 2016 at a site in the western US: an Atonometrics RDE300 soiling station with one soiled PV module and one self-cleaning reference cell, a tipping bucket rain gauge, and three pyranometers. The pyranometers consist of two Second Class Hukseflux LP02 pyranometers and a Hukseflux SR20 pyranometer serving as a reference measurement for the station. The LP02 pyranometers were field-calibrated to a reference device of the same model. For the purposes of this paper the two LP02 pyranometers are designated LP02-1 and LP02-2, with LP02-2 being the device that was allowed to soil. Figure 1 shows a close-up photograph of the instruments in the monitoring station.

The station received weekly maintenance consisting of leveling of all of the pyranometers, cleaning of LP02-1 and SR20, maintenance of the soiling station and reporting of site conditions. In addition to the routine maintenance, there were three events over the test period where the station was recalibrated to a clean condition. These occurred due to an initial calibration error, bird droppings on the reference module, and a module cleaning of the entire site; each was accounted for in the analysis.



Fig. 1. Monitoring Station with SR20 (Left), LP02-1 (center), LP02-2 (right), self-cleaning reference cell (foreground), and reference module (back right)

B. Soiling ratio of module

As previously described [1][2][3], the RDE300 series soiling measurement station measures PV module soiling by performing an I-V sweep on the soiled PV reference module, determining the module power from the sweep, and comparing the measured power to the expected power for clean conditions. In the present work the measurement is performed once per minute, from which the system calculates the module soiling ratio

$$SR = \frac{P}{P_0 \cdot \left(1 + \gamma \cdot (T - T_0)\right) \cdot (G/G_0)} \qquad (1)$$

where P is the measured maximum power of the soiled module, P_0 is the module maximum power at STC, γ is the temperature

To appear in proceedings of the 2017 IEEE PVSC, Washington, DC

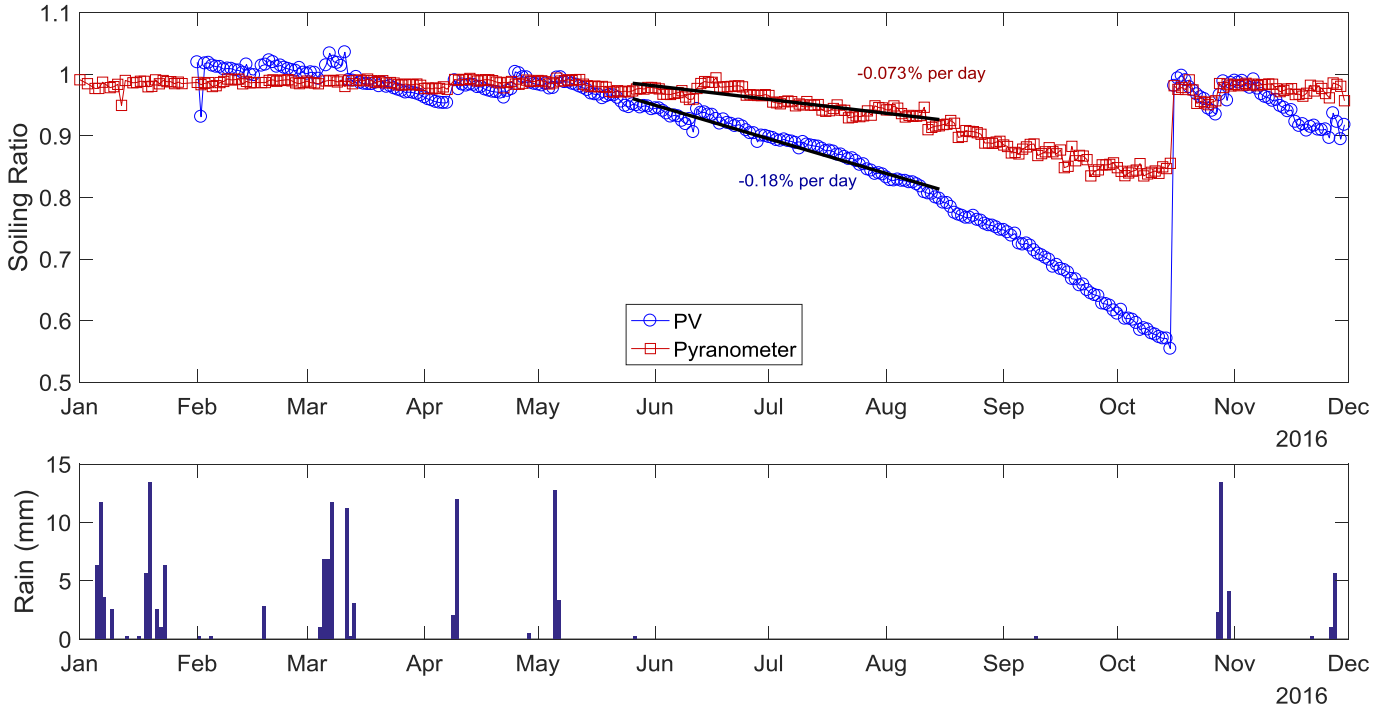


Fig. 2. Measured daily average values of the soiling ratios for the POA PV module and thermopile pyranometer and daily rainfall.

coefficient of maximum power, T_0 is 25° C, G is the measured plane-of-array irradiance determined from the automatically cleaned PV reference cell, and G_0 is 1000 W/m^2. The numerator and denominator in (1) are the measured and expected power, respectively; under clean conditions the ratio should be 1.

In order to quantify a daily value for the soiling ratio, we first filter the once-per-minute reported *SR* values, excluding periods of irradiance <500 W/m^2, periods of shading due to tracker misalignment, and early morning and late afternoon data that are subject to angle-of-incidence artifacts [4]. We then perform an irradiance-weighted average of the remaining points for each day, to yield the daily average values of the soiling ratio.

C. Soiling ratio of pyranometer

We determine the pyranometer soiling ratio by dividing the reading of LP02-2 by the reading of LP02-1. We filter the once-per-minute values of this soiling ratio using the same filter employed for the PV module analysis, and then perform an irradiance-weighted average of the remaining points for each day, yielding the daily average values of the pyranometer soiling ratio.

Due to the manual nature of the cleaning regime for the pyranometers, the data often appears to have a leveling off of the soiling ratio for the periods of time in between cleanings. This is likely due to the accumulation of dust on LP02-1 following the cleanings at a rate similar to that of the accumulation on LP02-2. Deriving the soiling rate over a number of cleaning intervals helps to account for this effect.

III. Results

A. Module vs. pyranometer soiling

Figure 2 shows the measured daily average values of the soiling ratios for the PV module and thermopile pyranometer as well as the daily rainfall. The summer and early fall were dry leading to an extended period of soiling where the soiling ratios steadily decrease until a module cleaning took place on Oct. 14th.

We performed a linear fit to each soiling ratio curve to extract an initial soiling rate for each device, with fit slopes shown in the plot. It is notable that the PV module soiling ratio and to a lesser extent the pyranometer soiling ratio appear to decrease nonlinearly, with the apparent soiling rate increasing in late August and September. This could be due either to higher airborne particulate concentrations or higher particulate sticking probabilities during this period.

It was found that the pyranometer in this test soiled at approximately 35% the rate of the reference PV module. The greater soiling of the PV modules relative to the LP02-2 pyranometer is also apparent in Figure 3.

The lower soiling rate of the thermopile pyranometer in comparison to the PV module is in agreement with

manufacturer claims that thermopile pyranometers resist soiling due to their hemispherical domes. [5]



Fig. 3. Soiled pyranometer (bottom) compared to soiled modules (background).

B. O&M indications

It can be assumed that the pyranometer will lose accuracy at a rate concurrent with the rate of soiling accumulation inducing a downward bias in the readings. Based on this assumption, it is a simple calculation to determine the frequency of maintenance based on the desired accuracy. Assuming a well calibrated secondary standard pyranometer with a calibration uncertainty of 1.2% [6], it can be seen that the downward bias caused by uniform soiling will be within the uncertainty of the device for approximately 18 days at this site. Thus at this site it may be possible to reduce the required maintenance frequency from weekly to once every two weeks, thereby reducing maintenance expense.

In addition, the results demonstrate that thermopile pyranometers should not be used as a proxy for determining soiling losses of PV arrays. In this study, the soiling rate of the thermopile pyranometer remained less than half that of the PV modules over an extended period.

REFERENCES

[1] M. Gostein, et al, "Soiling Station to Evaluate Anti-Soiling Properties of PV Module Coatings," in *43rd IEEE Photovoltaic Specialists Conference*, Portland, OR, 2016.

[2] M. Gostein, T. Düster, and C. Thuman, "Accurately Measuring PV Soiling Losses with Soiling Station Employing Module Power Measurements," in *42nd IEEE Photovoltaic Specialists Conference*, New Orleans, LA, 2015.

[3] M. Gostein, B. Littmann, J. R. Caron, L. Dunn, "Comparing PV Power Plant Soiling Measurements Extracted from PV Module Irradiance and Power Measurements," in *39th IEEE Photovoltaic Specialists Conference*, Tampa, FL, 2013.

[4] M. Gostein, J. R. Caron, B. Littmann, "Measuring soiling losses at utility-scale PV power plants," in *40th IEEE Photovoltaic Specialists Conference*, Denver, CO, 2014.

[5] Web: https://eko-eu.com/faqs/solar-radiation-and-photonic-sensors/sun-trackers/soiling-effect-versus-measured-irradiance

[6] Web: http://www.hukseflux.com/product/sr20-pyranometer?referrer=/product_group/pyranometer