Mitigating the Impact of Soiling on Performance and Capacity Testing Using Optimized Soiling Measurement Strategies

Michael Gostein[1], Beth Copanas[2], Audrey Marquis[1]

[1]Atonometrics, Austin, TX, USA; [2]RES Group, Denver, CO, USA

***Abstract* — Soiling losses can affect PV power plant performance and capacity testing, causing delays in achieving project completion milestones that can have negative financial impacts. While soiling losses can be measured with soiling sensors, soiling sensor deployments are not always planned around the needs of capacity testing. We propose deploying soiling sensors alongside PV modules during construction to ensure accurate soiling loss measurement during later commissioning of the PV plant. Ideal sensor characteristics for this purpose include no calibration requirement, high sensitivity to small soiling levels, ease of deployment, and low cost. The Mars™ optical soiling sensor is presented as meeting these requirements, and field data from an example power plant project demonstrates its effectiveness in capturing soiling variations that can inform testing campaigns.**

***Index Terms* — photovoltaic (PV) systems, performance testing, capacity testing, soiling**

INTRODUCTION

PV system performance testing is required for various project completion milestones during the construction of a PV plant.

For example, capacity testing is commonly required in the US at substantial project completion to validate the system performance, typically following the ASTM E2848 method. The IEC 61724-1 capacity test method is also under update to be used for such testing.

Delays or problems in performance testing can have significant financial consequences for all the parties involved in the project development.

A frequent problem in system capacity or other performance testing is soiling losses that result in underperformance versus expectations. Soiling, the accumulation of dust, dirt, and other contaminants, can cause substantial energy loss in PV systems, depending on seasonal effects, weather patterns, and system cleaning schedules [1]. Often performance guarantees on capacity tests require system performance within a narrow window of expectations, with typical loss tolerances of ~3%. Therefore, unexplained soiling losses of even 1-2%, when added to normal uncertainties and performance variations, could mean the difference between successful and unsuccessful testing, with significant financial consequences.

Ideally, treatment of soiling losses would be included comprehensively in contracts and test plans prior to construction, but this is not always the case. Contracts deal with soiling losses in different ways, and often result in difficult negotiations between the various parties to the project, including developers, engineering, procurement, and construction (EPC) companies, and third-party engineers.

In some cases, developers and EPC providers may determine that a site under development is to be cleaned before performance testing. But this still leaves the issue of who is responsible for the cleaning and who bears the risk of cleaning and potential associated damage.

Alternatively, the parties may determine that soiling losses should be measured during performance testing and the performance results compensated for soiling losses. However, while soiling sensors are installed on most utility scale sites, often they are not installed in a way that is optimal for use during initial capacity testing. This is because often PV modules are installed significantly before soiling sensors are installed and commissioned. In such cases the soiling level accumulated on the modules may be different than that on the soiling sensors, rendering the soiling sensor data unusable for compensating capacity test results.

Sometimes the EPC or operations and maintenance providers will attempt to quantify the level of soiling losses during performance testing using photographs of modules. But this is typically only a qualitative measure as there is no known way to accurately quantify soiling losses from module photos.

Another approach that is sometimes used to determine soiling losses on a site where there are questions about performance testing results is to perform string I-V measurements before and after cleaning selected strings. However, obtaining this service from qualified personnel can be costly and/or result in delays to project completion. The cost of this activity would be better spent on planning optimal soiling measurement strategies from the beginning of the project.

During the planning of a PV plant, soiling sensors are typically considered as part of the meteorological station and to support the long-term operational performance analysis of the plant. Therefore, commissioning of these sensors is often one of the last steps before completion. Commissioning these sensors earlier could be very beneficial.

Here we propose strategies for how to deploy and use soiling sensors for greatest benefit during the capacity and performance testing required for project completion milestones.

RECOMMENDATIONS

We propose that the selection and deployment of soiling sensors should be done in a manner that directly supports goals of capacity and performance testing and allows for mitigation of adverse and unexpected cleanliness conditions at the time of testing.

Unless washing the plant prior to substantial completion is planned, soiling sensors should be deployed concurrently with the modules, to ensure that they will be in the same cleanliness state as the modules.

Multiple soiling sensors should be deployed and distributed throughout the plant to sample different conditions throughout the plant and allow best compensation of losses from different areas.

Note that for these recommendations it is not necessary to begin logging the soiling sensors in a SCADA system concurrently with module deployment, which in many cases would be difficult as SCADA systems may not yet be installed. However, if the sensors are installed and commissioned together with the modules, they will accumulate soiling during the time that modules are exposed prior to performance testing. The sensors can be left alone, even unpowered, so that their cleanliness state (accumulation of dust and cleaning by rain) matches the modules.

Prior to performance testing, if soiling sensors indicate significant soiling losses, the parties may decide to clean the modules. A soiling loss threshold should be set in contracts prior to construction and the responsibility for cleaning should be determined during the contract negotiation.

Alternatively, if losses measured prior to performance testing are small enough, they can be reliably compensated using soiling sensor readings provided that the sensors were deployed with the modules, as recommended above.

These recommendations can help to prevent costly delays or negotiations between the parties during performance testing.

Ideal Soiling Sensor Requirements

Soiling measurement sensors are used for various purposes, including pre-construction resource assessment, identifying losses during commissioning and capacity tests, assessing performance against guarantees, and, of course, optimizing washing schedules for O&M [2].

Many types of soiling sensors have been developed, each with different characteristics and tradeoffs. The optimal choice of sensor for a particular project depends on specific application goals, maintenance requirements, and other factors.

To implement the above recommendations on optimal soiling measurement strategies to support performance and capacity testing, soiling sensors would ideally have the following characteristics:

- Compact and easy to deploy. The sensors should be easily deployable by the construction team.
- No need for field calibration: This is an essential point. Many types of soiling sensors require some initial field calibration or normalization, which often cannot be performed immediately upon deployment. If sensors require an unknown waiting period before calibration, this makes installation during the module deployment almost impossible.
- Sensitivity to small soiling levels in the range of 0-3% and resolution <0.5%: Losses of only 1-2% can be significant during performance testing. Therefore, for optimal benefit during the performance testing, soiling sensors should be very sensitive to even small losses in the 1% range, with resolution to changes <0.5%. This is challenging for various soiling sensor technologies.
- Low cost, to support distribution throughout a site: Soiling losses can vary significantly throughout a site. Therefore, sampling more points in the site can be very beneficial to accurately assess losses. Low sensor cost helps enable this.

Mars Soiling Sensor

The Mars™ optical soiling sensor meets the above requirements well. It is completely water and maintenance free and can be very easily deployed at any time because it does not require any site-specific calibration [3], [4] or special installation process.

The Mars soiling sensor uses a unique technology that eliminates the need for field calibration and is very sensitive to even small amounts of soiling particles. The sensor includes a window, as shown in Fig. 1, on which soiling particles collect and an internal camera which captures an image of the window as viewed from the inside. Soiling particles cast shadows on the image of the window, so transmission losses through the glass can be calculated by analyzing the camera image, which is done automatically by a processor within the sensor. Since the sensor is measuring the losses in light transmission – exactly the phenomenon affecting power loss on PV modules – it does not depend on soiling particle color [4] and does not require field calibration for local dusts. Field testing has demonstrated the applicability of the technology and correlation of the results to soiling ratio measured on washed/unwashed PV reference cell pairs [5] and modules [6].



Fig. 1: Mars™ optical soiling sensor, version 2. The sensor measures dust and soiling particles that collect on its window, using an internal camera which captures a microscopic image of the soiling.

Field Data Example

RES Group has deployed Mars™ soiling sensors at multiple sites throughout the United States.

Here, as a case study, we review example data from a ~100 MW PV power plant constructed by RES Group in the US. Mars™ soiling sensors were deployed at four meteorological stations and used to measure soiling at the site during the time periods that capacity testing was performed.

Time series data from the four sensors are displayed in Fig. 2 along with precipitation data. Precipitation data were not available during weeks 5 and 6.

Note that at the beginning of the time series the sensors are mostly clean, with low soiling losses. This is followed by significant accumulation of soiling in weeks 3-4, up to 6% loss, due to nearby farming activity. Reviewing the time series data demonstrates that the Mars soiling sensors have significant sensitivity, with resolution to capture small changes less than 0.5%.

The variations in the readings between the four soiling sensors suggest potential location-based soiling differences within the site at different times. Stations 1 and 4 were located along a north/south road at one end of the plant and were closest to an area of farmland that was being actively farmed during the first two months of the data series, likely explaining the higher soiling readings of the soiling sensors at these two stations in week 4. These spatial variations in soiling throughout a large PV plant are similar to those observed in [7], which found a connection between soiling rates, land use, and wind direction. The variations illustrate the need for including multiple soiling sensors distributed throughout a plant to sample average conditions.

The data highlight the value of the Mars soiling sensor data in identifying potential performance loss causes during the performance testing. Losses observed by the soiling sensors during the performance testing were used to inform the performance testing process.

Capacity testing of the PV plant was performed four times over the period shown in Fig. 2, approximately in weeks 3, 4, 11, and 19, denoted A, B, C, and D. Fig. 3 displays the normalized capacity test ratio for each of these measurement campaigns versus the average soiling ratio measured by the soiling sensors. The capacity test ratio is the ratio of measured system power to the expected power, based on the system model, at a particular reference condition, excluding limitations from inverter clipping or curtailment. The soiling ratio is the ratio of measured power to power expected if the system were clean and is equal to one minus the average of the soiling loss data shown in Fig. 2. From A to B the improvement in the capacity test results is primarily due to the reduction in soiling levels, since in the one week between A and B no changes were made to the PV system. Between B, C, and D, the DC performance of the PV system was improved by addressing remaining outstanding issues from construction, and the improvement in the capacity test ratio over these measurements was due to a combination of DC improvements and soiling reduction. These results illustrate the potential importance of soiling data during the performance testing process and the correlation of performance test results with measured soiling data.

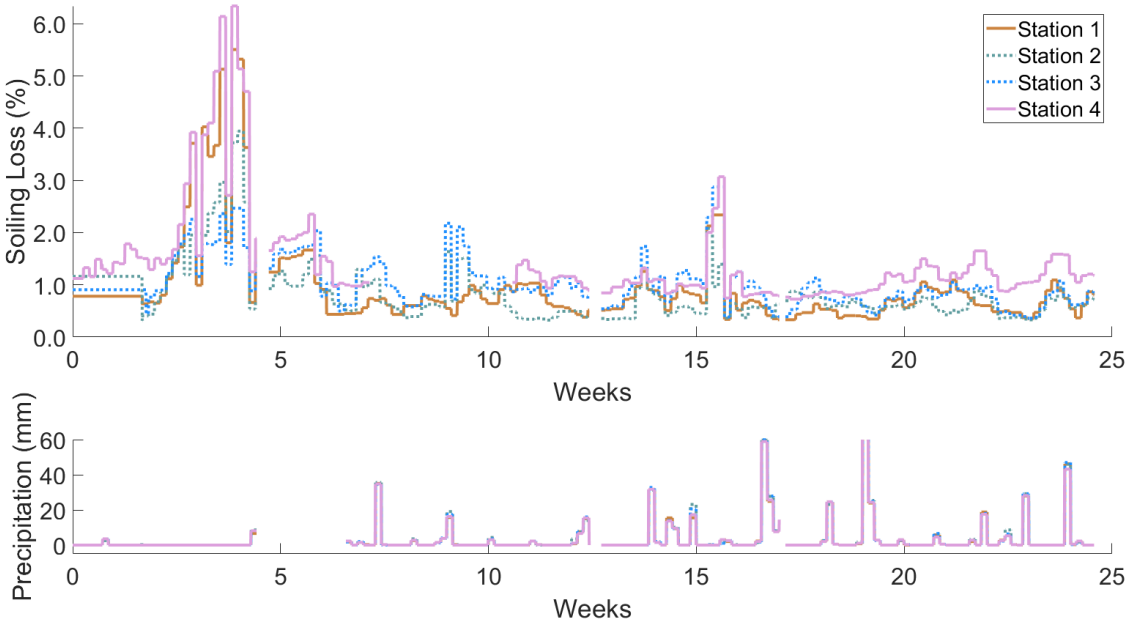


Fig. 2: Soiling losses measured by Mars™ optical soiling sensors deployed at the example site.

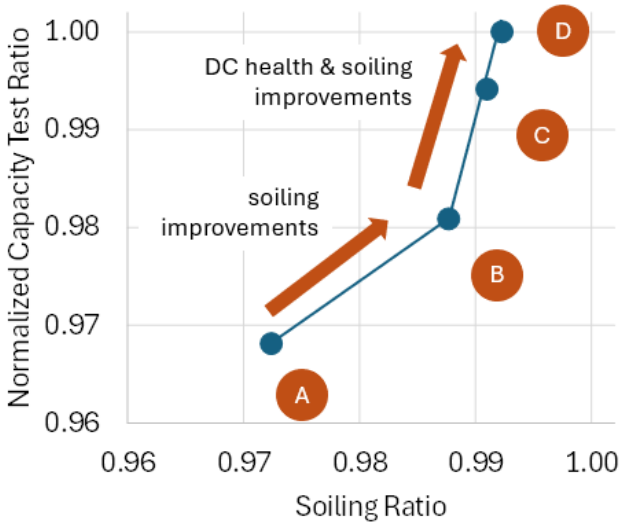


Fig. 3: Relation between capacity test results and soiling ratio during four different capacity test measurement periods A, B, C, and D. Soiling was reduced between A and B by rain, while the DC system performance was improved between B, C, and D by completing the construction of the plant.

Power Losses

While the Mars™ soiling sensor captures light transmission losses due to soiling particle deposition on glass, like all small-area soiling sensors it does not determine power losses on PV modules which may be affected by non-uniform shading losses due to redistribution of soiling following precipitation events. Such non-uniform soiling distributions may cause disproportionate power losses [8], [9]. In fact the effects of such non-uniform soiling were observed at the site studied here, using infrared imaging. The resulting power losses could also be measured directly on the PV modules by using in-situ I-V measurement devices, as discussed in [10], potentially in combination with the Mars™ sensor.

Summary

We highlight the potential negative effects that soiling can have on performance test results, and propose that soiling sensors should be deployed early in the project construction, concurrently with PV module deployment. This is to ensure that soiling sensors reach the same cleanliness state as PV modules during critical milestones such as capacity testing, allowing the data to be used to inform or compensate the test results. These points are illustrated with a case study from a ~100 MW site constructed by RES Group.

In ongoing work, we intend to study soiling and performance data from additional sites under construction by RES Group, with a focus on how soiling measurements can best be used to improve capacity and performance testing.

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