FIELD EVALUATION OF MARS™ OPTICAL SOILING SENSOR

Michael Gostein[1], Ben Bourne[2], Fabrizio Farina[2], Bill Stueve[1]
[1]Atonometrics, Austin, TX, USA
[2]SunPower Corporation, Richmond, CA, USA

ABSTRACT: We report on a field evaluation of the new Mars™ optical soiling sensor technology. The Mars™ soiling sensor was specifically developed to provide a compact, low-cost, water-free and maintenance-free method to measure soiling at PV power plants, especially for small utility or commercial-scale sites where more complex solutions can be prohibitive. In this study, a Mars™ soiling sensor was deployed at a test site in California. The site also included a reference soiling measurement system employing a washed/unwashed PV reference cell pair. Results to date demonstrate good overall correlation between the Mars™ sensor and the reference measurement.
Keywords: soiling, system performance, monitoring

1 INTRODUCTION

Soiling of PV modules is one of the principal energy loss factors for PV systems. Accordingly, in recent years there has been a growing interest in measuring PV soiling at both pre-production prospecting and operational sites [1]. Motivations include performance prediction, monitoring of plant operations, verifying compliance with performance guarantees, and optimizing wash schedules for best return-on-investment of washing expense.

Traditional soiling sensors compare the output of two PV devices, one of which is allowed to soil naturally and the other of which is routinely washed to serve as a reference [1][2]. Daily or weekly washing is performed either manually by onsite personnel or by an automated [3] washing system. The most complete measurement is achieved by using a full-size PV module, identical to those on the PV array, as the soiled reference device and measuring the module's maximum power output [4][5] relative to expectations from a washed module or washed cell. A simpler approach, often used as an approximation, is to compare the outputs of washed/unwashed PV reference cells.

However, eliminating the requirement for washing a reference device at all could significantly lower the cost of soiling monitoring and would be especially favorable for commercial-scale PV sites that typically have smaller budgets and no onsite personnel.

In this work we evaluate a new proprietary all-optical soiling sensor concept developed by Atonometrics (Mars™ soiling sensor, [6]), conceived as a solution for compact, low-cost, water-free and maintenance-free measurement of soiling loss.

2 MARS™ SENSOR CONCEPT

The Mars™ soiling sensor concept has been previously described [7][8]. Briefly, the sensor includes a dust collection window configured to be in the same plane as the PV modules to be monitored and uses an internal microscopic imaging system to detect dust particles on the window, coupled with proprietary image analysis techniques which accurately quantify the fraction of light blocked by the dust particles. The sensor directly measures losses in transmission of sunlight through the glass – rather than reflectance of the particles themselves. It therefore does not depend on dust color and does not require on-site, dust-specific calibration [7][8].

3 EXPERIMENT

The test site, shown in Fig. 1, is a solar test field near Sacramento in the Central Valley. In addition to the Mars™ sensor, the setup includes a washed/unwashed reference cell pair that is used as a reference for comparison to Mars™. The two reference cells are identical and are mounted side by side as shown in Fig. 1. The washed cell is washed 3 times per week. The irradiance readings of each cell are averaged for each day and the ratio of the daily averages from the unwashed cell to the washed cell is used as a measure of soiling ratio [1][2][3]. The Mars™ sensor and both cells are mounted at a tilt angle of 20°, facing south. Rain data are collected on-site.

The Mars™ unit operates daily at sunset and measures the transmission loss (TL) through its sensor window, from which a soiling ratio is calculated ($SR = 1 - TL$).

4 RESULTS AND DISCUSSION

Fig. 2 shows the results from the test site. The upper panel compares the soiling ratio measured by the Mars™ sensor to that measured with the reference cell pair, while the lower panel shows the daily rain total. In the upper



Figure 1: Mars™ sensor (red arrow) at test field with washed/unwashed reference cells (yellow arrow).

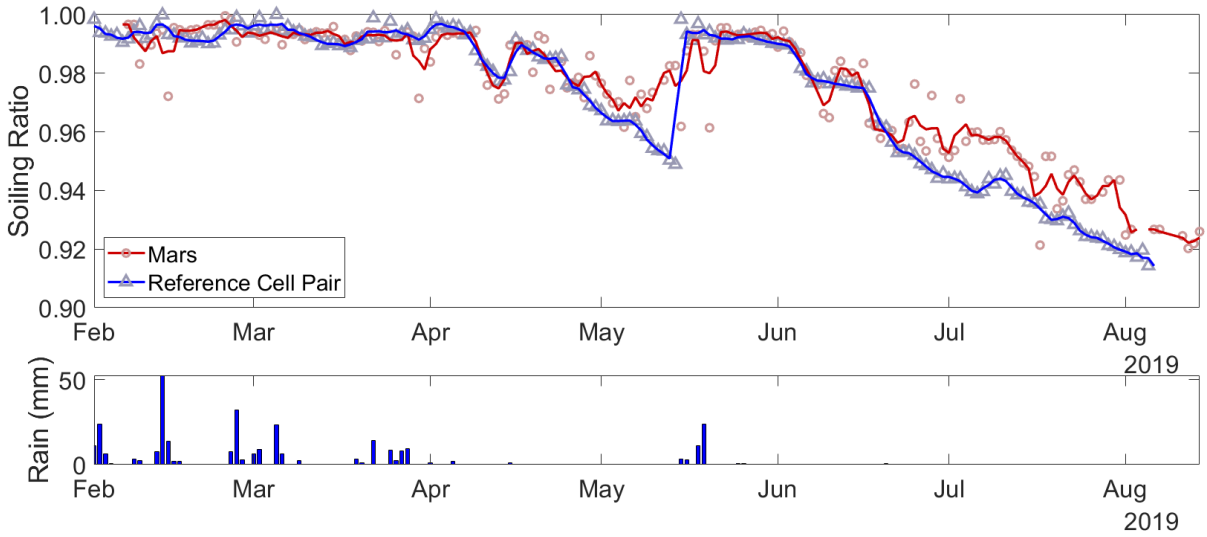


Figure 2: Comparison of Mars™ results to soiling measurements with a washed/unwashed reference cell pair.

panel, symbols represent the daily measured soiling ratios, and the solid lines are a 3-day rolling average of the daily measurements.

The overall level of agreement between the Mars™ sensor and the reference measurement is good. Both show a similar trend, with little to no soiling loss in the winter and early spring months due to frequent rains followed by steady accumulation of soiling loss in the spring and especially the summer months. The overall loss levels are similar.

However, there are some differences between the soiling losses measured by Mars™ vs. the reference cell pair on any particular date. These types of differences could be expected to occur when comparing any two soiling measurement devices on a single site, especially when using compact small-area sensors, since soiling has a spatially random component and because different sensors may show different soiling and cleaning behavior due to their construction.

In addition, some of the variance between the data sets may be due to measurement noise related to each of the techniques. The PV reference device pair data are affected by irradiance fluctuations because spatial and temporal fluctuations in irradiance can degrade the correlation of nearby reference cells on cloudy days. Additional factors, including angular misalignment [1] and temperature effects can also degrade the correlation. The Mars™ data exhibit some daily random error due to variations in sky conditions and limitations of the internal analysis algorithm. In addition, raindrops on the Mars™ sensor can be perceived as a soiling loss, which affects several days in the data sets (e.g. Feb. 13 and May 19).

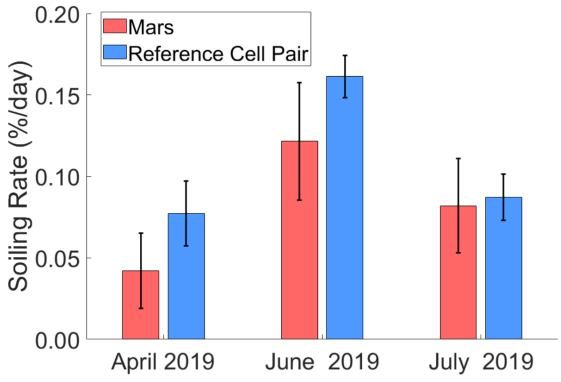


Figure 3: Soiling rates determined from Mars™ and reference cell pairs.

To examine the soiling rates, we fit the data in Fig. 2 during each of the three months which had no days with rain exceeding 5 mm: April, June, and July. Fits were performed using the robust Thiel-Sen estimator together with bootstrapping to determine 95% confidence intervals [9][10]. The resulting rates and confidence intervals are displayed in Fig. 3. The determined soiling rates in the range of 0.05%-0.15% per day are within the typical range for the region [11][12] and agree between the Mars™ sensor and the reference cell pair within the uncertainties.

Despite the differences between the Mars™ and reference cell pair data discussed above, overall the data sets show good correlation when evaluated over the full time period. The standard error of correlation between Mars™ and the reference cell pair for the data in Fig. 2 is 0.8%, indicating the ability of Mars™ to detect soiling level differences on the order of 1% or better.

An additional potential benefit of the Mars™ technology, especially for utility-scale sites, is the ability to deploy more sensors around a site at lower cost in order to measure within-plant non-uniformity of soiling, which can be significant for large sites that border local sources of particulates such as farms or other operations [10].

5 CONCLUSIONS

Field test data of the Mars™ soiling sensor has shown good correlation to traditional soiling measurements using a washed/unwashed reference cell pair, demonstrating the validity of the Mars™ technique. The results are promising for providing a low-cost, compact, maintenance-free soiling sensor that can be more widely deployed than traditional solutions.

6 REFERENCES

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

[2] "Photovoltaic system performance – part 1: monitoring," IEC standard 61724-1, 2017.

[3] M. Gostein, et al, "Soiling measurement station to evaluate anti-soiling properties of PV module coatings," in *43rd IEEE Photovoltaic Specialists Conference,* Portland, 2016.

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

[5] S. Kagan, E. Giosa, R. Flottemesch, R. Andrews, J. Rand, M. Reed, M. Gostein, B. Stueve, "Impact of Non-Uniform Soiling on PV System Performance and Soiling Measurement," in *45th IEEE Photovoltaic Specialists Conference,* Hawaii, 2018.

[6] U.S. Patent 10,171,029.

[7] M. Gostein, S. Faullin, K. Miller, J. Schneider, B. Stueve, "Mars Soiling Sensor™", in *45th IEEE Photovoltaic Specialists Conference,* Hawaii, 2018.

[8] M. Gostein, S. Faullin, K. Miller, J. Schneider, B. Stueve, "Mars Soiling Sensor™", in *35th European Photovoltaic Solar Energy Conference,* Brussels, 2018.

[9] M. G. Deceglie, M. Muller, S. Kurtz, Z. Defreitas, "A scalable method for extracting soiling rates from PV production data," in *43rd IEEE Photovoltaic Specialists Conference*, Portland, 2016.

[10] M. Gostein, K. Passow, M. Deceglie, L. Micheli, B. Stueve, "Local Variability in PV Soiling Rate," in *35th European Photovoltaic Solar Energy Conference,* Brussels, 2018.

[11] A. Kimber, L. Mitchell, S. Nogradi, H. Wenger, "The Effect of Soiling on Large Grid-Connected Photovoltaic Systems in California and the Southwest Region of the United States," in *IEEE 4th World Conference on Photovoltaic Energy*, Waikoloa, 2006.

[12] T.U. Townsend and P.A. Hutchinson, "Soiling Analyses at PVUSA," in *Conference of the American Solar Energy Society*, 2000.