WHITEPAPER

Photovoltaic vs. Optical Soiling Measurement

Introduction

The world now has one terawatt of installed solar power. At this level, $3 - 5 billion dollars will be lost this year as a result of soiling loss, to which Fracsun provides an intelligent and automated solution.

Soiling sensor technology has evolved over the last couple years and there are now a variety of soiling measurement devices available on the market. While the technologies used to measure soiling are vastly different from each other, improving solar operational efficiency is a common goal. Engineers have been measuring soiling for years, but the new sensors on the market have simplified this measurement process. Soiling sensor products typically fall into two categories: PV reference and optical.

The classical method to measure soiling is to trace the I-V curves of two closely matched solar modules (one soiled, one cleaned) and compare the results. The primary issue with this method is the high cost associated with manually washing the module and the period between cleaning events, which yields coarse data throughout the year. With that in mind, Fracsun's ARES soiling monitoring system provides a PV reference sensor with an automated approach.

Optical soiling sensor technologies have been introduced to the market, though they have struggled to elate users. We may be attracted to the "maintenance-free" and "no moving parts" aspects of them, but how accurate are they? How do they compare against PV-based soiling measurement systems? This whitepaper will discuss the major differences between soiling sensor technologies, showcase the pitfalls of optical sensors, and examine real site data from two co-located sensors.

Operational impact

Soiling is often one of the largest factors contributing to system losses, so accurate soiling data is critically important for diagnosing and mitigating performance issues. Acting on inaccurate soiling data could lead to misguided maintenance decisions like cleaning too little, too often, or at non-optimal times - not to mention potential confusion over the true cause of system underperformance! The single most important question to ask is this: *is the soiling sensor data strongly correlated to the soiling on the plant's modules?*

How optical sensors work

The DustIQ optical soiling sensor, developed by Kipp & Zonen, estimates soiling through the changes in reflectance measurements. A specific wavelength of light is emitted from a light emitting diode (LED), directed at the bottom of a glass coupon that has accumulated dust particles on the top side. As more dust accumulates, more light is scattered from the top surface. A photodiode measures the LED's light reflected from the glass coupon and the DustIQ converts the reflectance measurement into a soiling ratio number.

How ARES soiling measurement works

ARES accurately measures the instantaneous and daily soiling loss by comparing the short-circuit current difference between two identical polycrystalline large-area reference cells. One cell is washed daily, while the other is left to soil naturally. The soiling ratio and transmission loss values are calculated in accordance with IEC 61724. The Wash Extension hardware automatically cleans one reference cell on a daily basis, eliminating the need for manual cleaning. ARES sensors have an integrated cellular modem that communicates with the nearest cellular tower to publish data, though Modbus is an option that many Fracsun clients use.

Differences in soiling sensor technology

Spectral response

The key difference between a PV based measurement and an optical measurement comes down to spectral response. PV cells convert sunlight from across the light spectrum into energy. Optical sensors such as DustIQ measure only the reflectance from a single wavelength of light. This response is shown in Figure 2. When soiling loss occurs, certain wavelengths of light are impacted more than others. Depending on the soiling material, which may change throughout the year, different components of the incoming sunlight will be blocked from reaching the cell.

We look to the archetypal masterpiece of the Italian Renaissance, the Mona Lisa, to enlighten us. If your eyes responded to the light spectrum the same way that a PV cell does, you can imagine that you would see every color wavelength in all their glory. If you were looking at Mona Lisa with eyes that can only see the red colors, it would be impossible to discern the entire picture. In order to see what Leonardo da Vinci saw when he was painting, we need to use eyes that see the same spectrum as his eyes. In a similar way, a PV based comparison will discern all wavelengths blocked from a given type of soiling loss.

Figure 1 : Mona Lisa, viewed in full spectrum vs. as a single wavelength.

Using this analogy, optical soiling sensors have poor correlation with a module's soiling loss. This is especially true before calibration or when a site has various soiling types.

Optical sensors must be finely tuned to the site-specific soiling for various reasons:

- Optical sensors utilize LEDs, which emit an extremely narrow range of light
- Some optical sensors utilize CCD imaging which also focus on non-correlating spectra
- Both scenarios above require interpreting limited spectral information into a full picture
- Soiling material varies in type due to factors such as agricultural/industrial activity and seasonal wind patterns
- Incident angle produces different effects on a PV cell not captured by transmission loss
- Calibrating soiling color and composition from site material doesn't represent wind blown soiling sources

Building on the last point, if calibration of an optical sensor is performed using one type of soiling, and later a different type of soiling is present on the sensor, the data is unreliable. For example, a solar plant installed adjacent to a field typically experiences dust from agricultural activity throughout the year and the optical sensor was originally calibrated to this dust type. But later in the soiling season, wildfire ash or pollen accumulates on the plant's modules. Because the soiling material deposited onto the sensor has a vastly different composition than the dust it was calibrated to, the soiling value does not correlate well with the modules.

The figure below shows the broad solar spectrum compared to the responses of a PV device and an LED/Photodiode pair. This chart further illustrates the missing component of information when using an optical sensor. Using a PV based soiling loss measurement system we ensure that the response of the sensor closely matches that of the array. In this way, no onsite calibration is required and all soiling material that settles on the array will be accounted for.

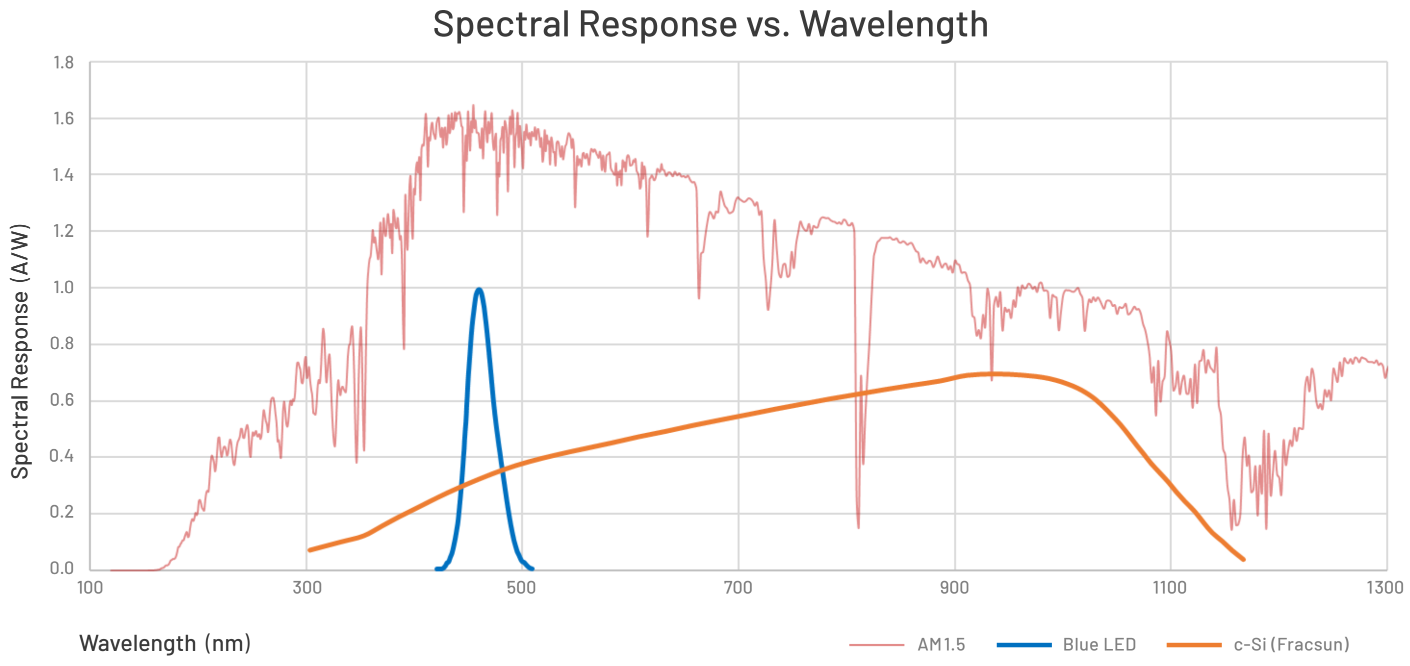

Figure 2: Spectral responses of c-Si PV sensors vs LED/Photodiode pair overlaid on the broad solar spectrum

Fracsun sensors utilize precalibrated PV reference cells made of c-Si, which very closely match the spectral response of the plant's modules. This spectral response is also very similar to other technologies, such as CIGS, CdTe, and other thin film modules. The sensor does not have to be categorized or calibrated to a specific soiling type. When the soiling composition changes throughout the year, the sensor will still accurately measure soiling without the need for recalibration.

> Returning to our analogy with the Mona Lisa, if we want to truly appreciate the full picture of how soiling loss is impacting a solar asset we need to see the impact of every wavelength of light. Viewing the loss as a full-color image allows us to make informed cleaning decisions for PV plants.

Soiling collection surface area

Also worth noting is the measurement area that is responsible for collecting soiling material. Fracsun's ARES sensor utilizes a full 156 × 156 mm polycrystalline cell, which is industry standard size in most PV modules. This means that the total surface area capable of measuring soiling is 246 cm^2. With a surface area of this size, Fracsun's reference cell can easily detect the same soiling patterns that develop on the solar glass of adjacent modules. These unique soiling patterns often develop when nightly dew accumulates on top of the dust and leaves streak marks after it drips down.

Other sensors like DustIQ and MARS utilize a circular soiling measurement area. MARS has a surface area of 33 cm^2 and DustIQ has an area of 28 cm^2. Not only does this design reduce the potential surface area for soiling matter to collect on, but it's also less likely to detect the same soiling patterns as what's occurring at module-level. Figure 3 shows the differences in soiling collection surface areas of the three sensors.

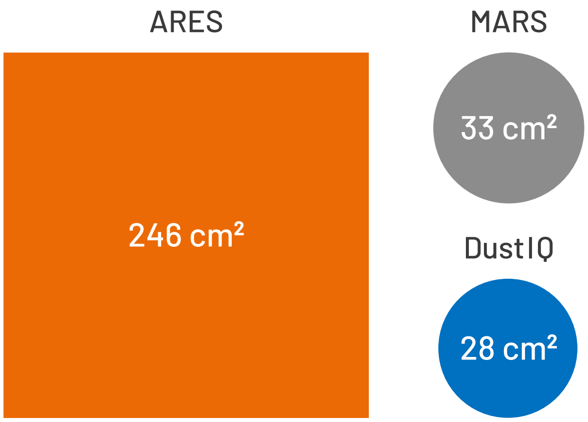

Figure 3: Size comparison of the soiling collection surface area of ARES, MARS, and DustIQ sensors.

Field data comparison

As part of an on-going study at a PV plant in California, Fracsun has compared soiling loss data between the ARES PV-based sensor and a calibrated DustIQ optical sensor from a 6 month period. The two sensors are co-located in similar regions of the plant which experience equal soiling levels. The soiling loss, also referred to as the "transmission loss due to soiling", is charted from February 2 to August 2 of 2022. Each DustIQ device has two optical sensor windows, which are displayed as two different blue lines on the chart.

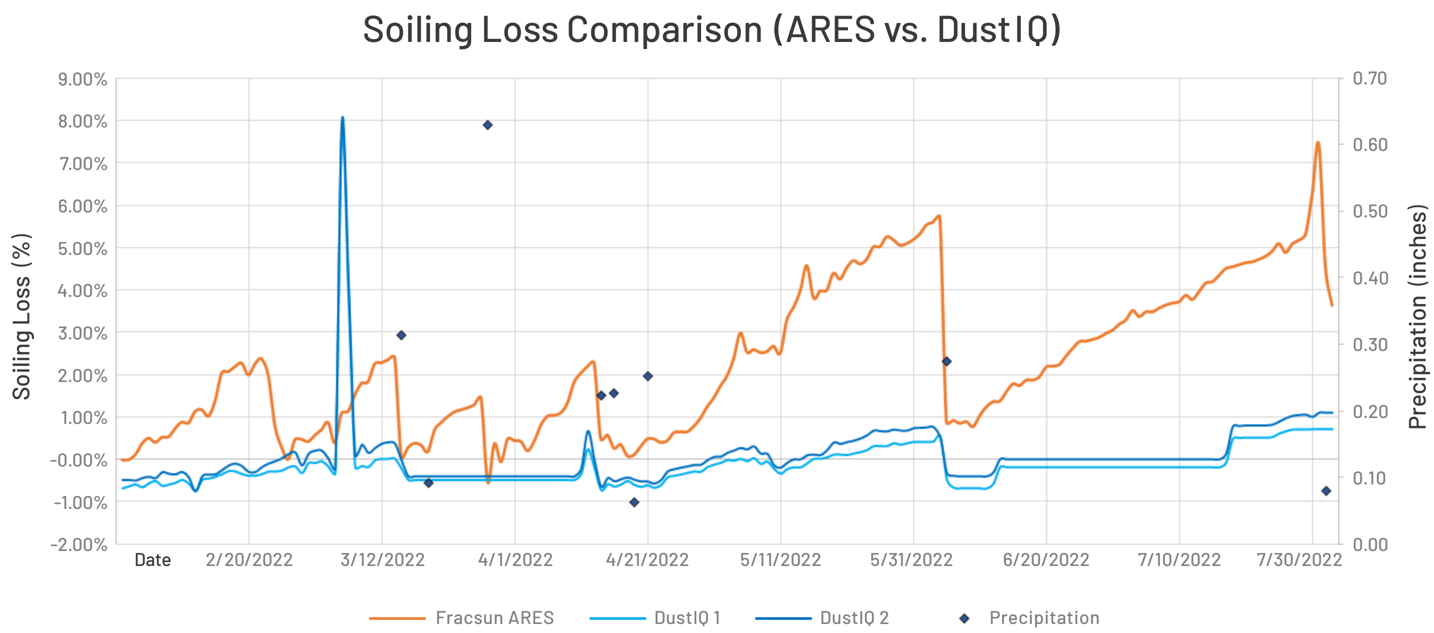

Figure 4: Soiling loss comparison between Fracsun ARES and DustIQ sensors.

Observations

Clearly, the DustIQ optical sensor is missing the full picture. Compared to the normalized array performance, the ARES PV-based measurement closely tracks the soiling loss that the array is experiencing. The DustIQ optical sensor, however, is not tracking soiling loss appropriately. The key observations are summarized below:

1. The ARES sensor has clear and concise upward ramps due to increased daily soiling, followed by precipitation events that decrease soiling.
2. The DustIQ sensor is not reporting high soiling loss values, while module soiling is certainly present and above 1%.
3. The DustIQ sensor is reporting negative soiling loss and appears to have an offset. The soiling data must be post-processed even further to remove the offset.
4. The large soiling loss spike measured by the DustIQ sensors on March 6, 2022 is an unknown glitch picked up by the sensor.
5. The two optical sensor windows (DustIQ 1 and DustIQ 2 on the chart) follow similar trends but appear to be scaled differently.

Summary

When comparing the soiling data between the ARES and DustIQ sensors, it is clear that the DustIQ sensor is not providing meaningful or actionable soiling data for the array owner. The optical sensor's data is not strongly correlated to the soiling on the plant's modules. The data has obvious issues with scale, offset, and glitching. While some of these issues could be remedied by recalibrating the sensor, the soiling type at this location could change throughout the year, resulting in more erroneous data. The DustIQ sensor cannot provide accurate guidance on array cleaning events with the soiling data it provides.

The ARES sensor, however, is providing credible soiling data for the array owner when comparing against the plant's estimated performance loss. The sensor does not have to be categorized or calibrated to a specific soiling type, unlike the DustIQ optical soiling sensor. Fracsun's ARES soiling measurement solution is supplying the customer with the hardware, data, and analytical tools required to easily mitigate soiling loss at the plant.

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