Specifying a Soiling Measurement System

Introduction

Soiling losses at PV power plants can have significant impacts on energy production. In order to quantify these losses, both during pre-construction forecasting and post-construction operations, many developers are specifying the inclusion of soiling measurement as part of the overall monitoring system, especially in large commercial and utility-scale systems [1].

Nearly all soiling measurement systems compare the output of a naturally soiled PV device with that of a clean PV device to determine a derate factor for soiling.

However, there are many ways to implement this concept, and deployed stations range in sophistication. For the engineer specifying such a system, there are many options to consider, including what types of PV devices the system will use, what electrical parameters to measure, and how to implement the routine washing of the clean device. Each of these questions has different answers depending on budget, site conditions, and objectives. In addition, engineers must decide how many stations to deploy at a given site.

Here we address all of these questions in order to guide the equipment selection process.

Figure 1: Three choices for soiling measurement systems.

Optical, Cells, and/or Modules?

The first question the engineer normally faces is what types of PV devices the soiling measurement system should employ.

- **Optical:** The Mars™ technology allows for the measurement of soiling without water, without maintenance, and without no site-specific calibration requirements.
- **Cell-Cell:** In this configuration, two identical reference cells are deployed, and one is routinely cleaned.
- **Module-Module**: In this configuration, two identical full-size reference modules are used, with one routinely cleaned.
- **Cell-Module**: In this configuration, a continuously cleaned reference cell is used as the clean device, and a full-size reference module is used as the soiled device.

What are the advantages and disadvantages of these choices?

The optical soiling sensors are the lowest cost-of-ownership systems because they do not require water or maintenance. The Mars™ system [6][7] also has no site-specific calibrations. This system is shown in Figure 2.

The cell-cell configuration typically has a low installation cost, due to its simple, compact hardware. The small size of this solution minimizes the cost of racking and allows deployment at nearly any site. However, it is important to realize that reference cells may soil differently than the modules in the actual PV array, reducing the accuracy of this approach.

One of the main reasons for different soiling rates for reference cells vs. modules is their different cover glass types. Reference cell providers cannot match the glass properties used by every module manufacturer. However, different glass types may soil differently. For example, a recent study found that textured glass soiled 7% more than standard glass at one test site [2]. Major module manufacturers have published reports [3][4] stating that their PV module anti-reflective coating (ARC) resulted in reduced soiling, and an academic study [5] also found a similar result. The ARC coatings were found to suppress soiling in these studies by 10% to 60% [4][5] depending on conditions. As glass treatment and coatings development continues, it is likely that there will be a diverse set of module glass types with different soiling rates. In addition, the soiling properties of various glass treatments may depend on manufacturing reliability; for example, one study [8] found that module cover glass contamination during manufacturing resulted in a higher-than expected soiling rate.

In addition, modules in the field often soil non-uniformly, with accumulations of soil particles near module edges, especially at the bottom, as shown in Figure 3. These

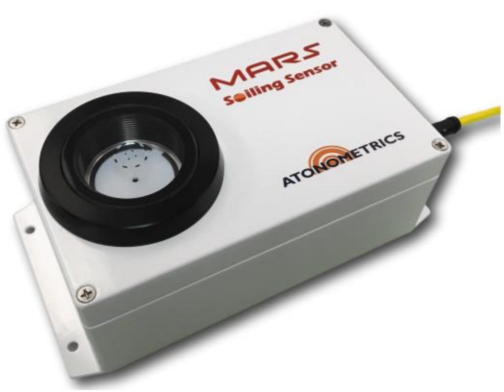

Figure 2: Mars™ Optical Soiling Sensor.

Figure 3: Non-uniform soiling on PV modules. Soiling accumulation near module edges is typical.

effects, which will be discussed more below, are not captured well by cell-cell soiling measurement systems.

Therefore, while cell-cell soiling measurement systems are low cost and convenient, they may measure only an approximation of the actual PV module soiling rate.

The module-module configuration can eliminate these technical concerns. By selecting two modules identical to those in the PV array, the measurement system soiling will be the same as the array. However, this configuration increases installed cost because of the extra rack space required. In addition, it adds to either labor or equipment cost to wash the full-size clean PV module.

The cell-module configuration combines the benefits of the other two approaches. Because of its small size, the reference cell can be continuously cleaned by an economical automated washing system, eliminating daily labor requirements. It also saves racking space and cost. However, soiling is measured on an actual PV module identical to those used in the array, so measurements are accurate. The PV module is simply calibrated against the reference cell during initial installation.

Power or Current?

For the module-module or cell-module configurations, the next question to answer in specifying a soiling measurement system is whether the system will measure the actual power output of the soiled PV module or only its short-circuit current. For high-quality non-shaded modules, short-circuit current is proportional to output power, once temperature corrections are made. Therefore one measurement approach is to measure just the PV module short-circuit current and temperature, which can be done with relatively simple instrumentation. However, under certain soiling conditions the relative loss in output power is not proportional to the relative loss in short-circuit current. For example, one study [9] showed soiling produced losses in short-circuit current of only 3-9% when losses in power were almost 50% larger, in the range of 8-12%. Similar examples are found in other studies [10][11].

One of the main potential reasons for differences between soiling measurements based on short-circuit current versus power is the effect of any non-uniformity in soiling deposition across the module. For example, Figure 3 shows a typical case where soiling has accumulated near the bottoms of the modules. This type of pattern occurs due to condensation or light rain which redistributes the dust particles without fully cleaning the modules. Additional examples are shown in [12][11] .

Non-uniform soiling-induced shading of a module alters the shape of the module's I-V curve. A typical example is shown in Figure 4. The figure shows I-V curves for a 72-cell crystalline silicon module under three conditions: clean, uniformly soiled, and non-uniformly soiled with a concentration of dust particles along the bottom edge.

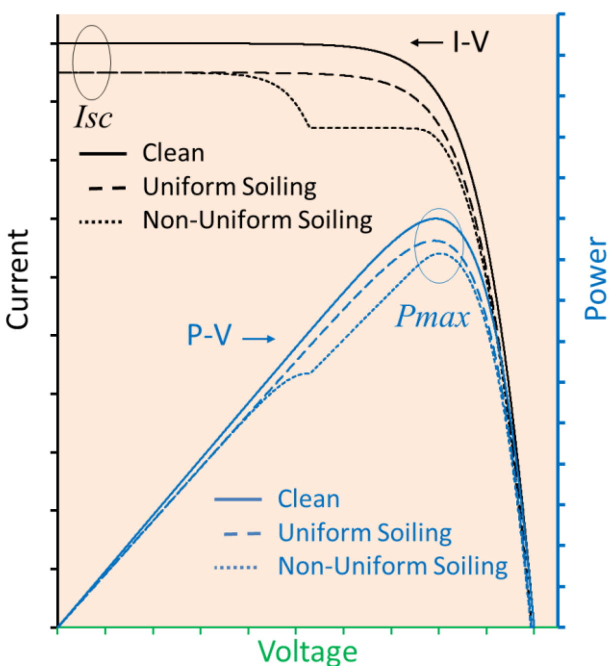

Figure 4: Effect of soiling on module I-V curves. Non-uniform soiling affects *Pmax* and *Isc* differently.

Table 1: Measurement uncertainty ranges for different system configurations at 10% soiling level

Soiling System Configuration	Measured Parameter	Module Type	Soiling Ratio Measurement Uncertainty	Maintenance and/or Water Required	Wash Frequency
Cell-Module	Power	cSi	1 - 2%	Yes	Daily
Module-Module	Power	cSi	3 - 5%	Yes	Weekly
Cell-Module	Current	cSi	3 - 5%	Yes	Daily
Module-Module	Current	cSi	4 - 7%	Yes	Weekly
Cell-Module	Current	cSi	4 - 7%	Yes	Weekly
Cell-Module	Current	CdTe	1 - 2%	Yes	Daily
Module-Module	Current	CdTe	3 - 5%	Yes	Weekly
Mars	Optical	All	4 - 7%	No	None
Other optical (if not field calibrated)	Optical	All	10 - 20%	Yes (site specific calibration)	None

The non-uniform soiling causes steps in the I-V curve which results in the relative loss in power (*Pmax*) being 70% greater than the relative loss in short-circuit-current (*Isc*). In some cases the relative power loss could also be much less than the relative short-circuit current loss. The effects of non-uniform soiling on module power are further explained in [11][13].

Although soiling may often be uniform, it is difficult to predict when the conditions that lead to non-uniform soiling will occur. Including module power measurements in the soiling measurement system provides greater accuracy for measuring actual losses in all conditions.

Measurement Uncertainties

Table 1 summarizes the impact of the system configuration choices on the soiling ratio measurement uncertainty, for a hypothetical example when soiling-induced losses are about 10%. For a cell-module configuration that measures the actual module power output, uncertainty is in the 1-2% range. If only short-circuit current is measured, some soiling effects on the power output may be lost and the measurement uncertainty should be considered larger, in the 3-5% range. If a cell-cell configuration is used, the soiling accumulation may not reflect the soiling of the actual modules, and uncertainty is 4-7%. These estimates are based on the examples discussed above.

Automated Cleaning?

In all soiling measurement configurations, the clean reference must be routinely cleaned. When the natural soiling rate is relatively low, cleaning once per week may be sufficient. For areas with higher soiling rates or unpredictable conditions, such as sand storms, daily cleaning is advised.

Figure 5: Automated cleaning of the clean reference can reduce labor requirements & improve data quality.

Cleaning may be performed manually by operations and maintenance personnel at the site. However, in cases where personnel are not stationed at the site or have too many duties, an automated cleaning system can be beneficial.

For automated cleaning, the cell-module configuration is ideal, because only the small area of the reference cell needs to be cleaned, minimizing the cost and complexity of the system. Figure 5 shows an example of a reference cell with automated cleaning from a daily high-pressure water spray. Automation not only eliminates labor requirements but also improves reliability and repeatability, allows for daily instead of less-frequent cleaning, and allows for automated collection of cleaning records in maintenance logs.

The choice of manual or automated cleaning depends on capital versus labor budget as well as technical goals.

How Many Stations?

Just as weather conditions are not constant across a large site, soiling conditions can also vary from one part of a power plant to another. In fact, soiling may vary even more than weather conditions, since it can be influenced by dust sources such as roads, fields, industrial facilities, and other aspects of the neighboring environment, as well as by wind and temperature. A standard for PV system monitoring has been released by the International Electrotechnical Commission (IEC) recommends including one soiling measurement station per meteorological station on sites that include soiling measurement. This standard is 61724-1.

Conclusions

The selection of a soiling measurement system for a particular project will depend on many factors, including the equipment budget, accuracy required, and availability of labor at the project site. For many cases it may be sufficient to use an optical or cell-cell configuration, for example at a prospecting or pre-construction site where the final PV module selection is not known, or for operating plants where equipment budget is more important than measurement uncertainty. For larger projects requiring higher accuracy, a module-module or cell-module configuration are preferred. When soiling rates are relatively low and on-site labor is available, a manually washed system is sufficient, while sites with higher soiling rates or unavailability of labor for daily cleaning benefit from an automatically washed system.

References

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