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Design, calibration and installation

Preprint

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2015 IEEE 42nd Photovoltaic Specialists
Conference (PVSC)

2015
Regional Soiling Stations for PV: Design, Calibration and Installation

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Abstract — Soiling rate (g/m²/day) and daily/annual soiling loss (%) of photovoltaic (PV) modules are primarily influenced by climatic condition of the site and tilt angle of PV modules. Therefore, for all the performance and energy prediction models used by the industry, accurate climate-specific and tilt-angle-specific soiling rate and daily/annual soiling loss data are needed. The primary focus of this work is to demonstrate the effectiveness of regional soiling stations designed to systematically collect this data and they are deployed in five regions in the United States. This paper presents information on the design, calibration and installation of soiling stations. Four of the sites are at the U.S. Department of Energy Regional Test Centers (RTC) in Albuquerque, NM; Golden, CO; Cocoa Beach, FL; and Essex Junction, VT, while a fifth site is in Mesa, AZ. Each soiling station is equipped with a data acquisition system and 10 laminated coupons tilted at angles of 0°, 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°. Each coupon contains two identical half-cells cut from a single monocrystalline silicon cell. In this test setup, the right half-cell is periodically cleaned and left half-cell is allowed to soil naturally so the above stated data can be collected throughout the year.

Index Terms — angle of incidence, soiling, soiling monitoring, tilt angle vs. soiling.

I. INTRODUCTION

To quantify the site-specific soiling rate (g/m²/day) and daily/annual soiling loss (%) over long term in the field, the current output of a soiled photovoltaic (PV) sensor needs to be compared with that of a coplanar installed clean sensor. Module tilt angle plays a major role in the soiling deposition rate. The primary focus of this work is to demonstrate the effectiveness of regional soiling stations designed to systematically collect this data and they are deployed in five regions in the United States. This paper presents information on the design, calibration and installation of soiling stations and presents initial regional soiling information for each site. Four of the sites are at the U.S. Department of Energy Regional Test Centers (RTC) in Albuquerque, NM; Golden, CO; Cocoa Beach, FL; and Essex Junction, VT, while a fifth site is in Mesa, AZ.

The influence of tilt angle on soiling loss has been studied previously by Cano et al at Arizona State University Photovoltaic Reliability Laboratory (ASU-PRL) [1, 2]. The current study is an extension of the previous study but with an upgraded version of the remote soiling stations and sensors. The new stations have the following major improvements over the previous station:

- In the previous setup, 18 series cells connected in a mini-module were used to measure the short-circuit current as a measure of irradiance. In the new setup, only one cell is used to avoid the possible influence of cell-to-cell variation on the short-circuit current over long period of time in the field.
- In the previous setup, the sensor size was very small (1 x 5 cm). In the new setup, a large sensor size (15.6 x 7.8 cm) is used to minimize the influence of small bird dropping spots on soiling loss calculation.
- In the previous setup, individual soiled and cleaned sensor coupons were used. In the new setup, only one coupon with two integral sensors is used to avoid possible coplanarity issue and azimuth angle issue during long-term operation in the field. This eliminates AOI differences at high AOI as a source of uncertainty.
- In the previous setup, polycrystalline silicon cells were used. In the new setup, high quality monocrystalline silicon cells are used so the field reflectance measurements on the deposited soil layer can be carried out with greater accuracy and repeatability.

II. METHODOLOGY

A. Design

As shown in Figure 1, each soiling station is equipped with a data acquisition system and 10 laminated coupons tilted at angles of 0°, 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°. Each coupon contains two identical half-cells cut from a single monocrystalline silicon cell. In this new test setup, the right half-cell is periodically cleaned and left half-cell is allowed to soil naturally so the above stated data can be collected throughout the year. The construction of these coupons is identical to a commercial PV module containing solar glass, encapsulant, solar cell, encapsulant and backsheet. The sensor coupons used in these stations were specially designed and constructed by PV Measurements Inc., Boulder, Colorado. Each coupon (20cm x 20cm) consists of two half cells (15.6cm x 7.8cm each) which are coplanar to each other and separated by 1cm. The right side half-cell of each coupon is cleaned regularly, while the left side half-cell of each coupon is left to soil naturally. Each half-cell sensor is fitted with two durable cables and a durable junction box containing two precision low temperature coefficient current shunts (0.020 ohm each with TCR of ±20ppm/°C) between the positive and negative terminals of the cell. Short circuit current of each half cell is determined by measuring the voltage drop across the current shunt. The temperature of each half-cell is measured at the center of the backsheet using a T-type thermocouple.

B. Calibration

In the previous setup, the sensor calibration was performed by the industry. In the new setup, the sensor was calibrated using a standard light source and a precision current shunt.
data acquisition system (DAS) monitors and records the all signals once a minute. Each station is powered by a 30 W PV module and a 12 VDC battery. With the help of calibration factors, described in next section, the obtained raw data is translated into irradiance (W/m²). The whole setup is mounted on a custom built, lightweight aluminum structure. The DAS, battery and the battery charger are contained in a weatherproof enclosure. The length, depth and height of each station are 160cm x 98cm x 125cm, respectively.

![Schematic representation of the soiling station.](image)

**B. Calibration**

The calibration process for the soiling stations involves activities in four stages as described below:

**Stage 1:** Obtain calibration factor for individual sensors from PV Measurements, Inc. (in “mV” at 1000 W/m² and 25°C)

**Stage 2:** Adjust the individual sensor calibration factor for individual sensor systems (includes uncertainties involved in DAS, pre-amplifier etc.) (in “mV” at 1000 W/m² and 25°C)

Note: At constant irradiance level around noon on a clear sunny day, all 100 sensors from 5 stations tilted at 30° shall read exactly same irradiance. If not, the individual system calibration factor needs to be obtained by adjusting the calibration factor of individual sensors. This adjustment was done on the multiplier based on a measurement done at 12 noon on a clear sunny day [Irradiance reported by DAS (in W) = sensor calibration factor (in mV) x sensor system multiplier (in W/mV)]

**Stage 3:** As shown in Figure 2 (a), verify to see all 100 sensors are reading exactly same irradiance within +/- 1% at or around solar noon on a clear sunny day.

**Stage 4:** As shown in Figure 2 (b), obtain temperature coefficient for the calibration factor (W/°C) by the shading-unshading/warming method at or around solar noon on a clear sunny day. The temperature coefficients for all 100 sensors were obtained at the same time at identical irradiance, wind speed and ambient temperature.

![Calibration of all 100 sensors on a clear day around noon at identical irradiance, wind speed and ambient temperature. (a) Stage 3 calibration; (b) Stage 4 calibration using shading-unshading/warming method](image)

**C. Installation**

Five climatologically diverse locations in the US were chosen for deploying the soiling stations:

- ASU-PRL, Mesa, AZ
- Sandia National Labs, Albuquerque, NM
- National Renewable Energy Lab, Golden, CO
- Florida Solar Energy Center, Cocoa Beach, FL
- IBM, Essex Junction, VT
With the exception of the site at ASU-PRL in Mesa, AZ, all other sites are RTC locations. Upon calibration, the stations were shipped as a whole unit to the designated locations, where they would be installed with ease as a standalone unit with no need of electrical supply from the grid to the DAS unit. Special care was taken while packing the stations to ensure that the sensors were not damaged during shipping. Once unboxed at the site, the stations were oriented towards true south and anchored to a leveled concrete pad or ground with the help of anchor bolts. The coupon tilt angle is fixed at 5° increment as shown in Table I and Figure 3. The stations at Mesa, Albuquerque, Cocoa Beach and Golden have already been installed and the data collection has been initiated. The last station at Essex Junction is scheduled to be installed in the near future.

### TABLE I
SENSOR POSITION VS. TILT ANGLE

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Tilt</th>
<th>Sensor</th>
<th>Tilt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&amp;2</td>
<td>0°</td>
<td>11&amp;12</td>
<td>25°</td>
</tr>
<tr>
<td>3&amp;4</td>
<td>5°</td>
<td>13&amp;14</td>
<td>30°</td>
</tr>
<tr>
<td>5&amp;6</td>
<td>10°</td>
<td>15&amp;16</td>
<td>35°</td>
</tr>
<tr>
<td>7&amp;8</td>
<td>15°</td>
<td>17&amp;18</td>
<td>40°</td>
</tr>
<tr>
<td>9&amp;10</td>
<td>20°</td>
<td>19&amp;20</td>
<td>45°</td>
</tr>
</tbody>
</table>

An extensive analysis on the collected data is being performed including soiling rate, soiling loss, angle of incidence effect dependence on soiling density and chemical/physical properties as described in the literature [3]. The odd numbered sensors are left to collect dirt, while the even numbered sensors are periodically cleaned. Before the sensors are cleaned, a dust sample is collected from the even numbered sensors to measure the soiling density, rate and loss. A summary of standard operating procedure (SOP) for the dust sample collection on each of the even numbered sensors is provided below:

1. Using a microbalance, measure the weight of the supplied lint roller (m1).
2. Gently roll the already weighed roller over the predefined right sensor area (A).
3. After sampling, each roller is kept in an individual Ziploc bag and sealed.
4. Measure the mass of the roller after sampling using the same microbalance (m2).
5. Calculate the soiling density (SD) using the following equation:

\[ SD = \frac{m2-m1}{A} \]  

6. The sensor surface is cleaned with the help of a lint-free towel moistened with de-ionized (DI) water. DI water is preferred as it does not leave any calcium deposits on the sensor surface.
7. Raw data (W/m²) will be periodically downloaded and translated to 25°C using a customized Excel spreadsheet.

### III. SUMMARY

Five soiling stations with improved design, as compared to the previous design, have been successfully constructed and shipped to five different sites having diverse climatic conditions. The existing DAS stores the data locally for each system. It is planned to be upgraded to remotely communicate with a central server and provide a real time data for downloading and processing. The data would be made accessible over a secure network for further analysis. The collected data will be analyzed and presented in a future publication.

### ACKNOWLEDGEMENTS

We would like to thank NREL, FSEC and IBM for agreeing to install these soiling stations in their locations. This work was supported by the U.S. Department of Energy SunShot Initiative. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.

###REFERENCES