Validation of In-Situ I-V Measurement Device for PV System Monitoring Applications

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Introduction
IV sweeps are useful for system monitoring

- Soiling
- Irradiance (including bifacial effective irradiance)
- Degradation
- Temperature
A clean and dirty module can be used to calculate soiling loss.

Gostein, M. & Duster, T. & Thuman, C. PVSC 2015
Accurately Measuring PV Soiling Losses With Soiling Station Employing Module Power Measurements.
Bifacial rear side irradiance is non-uniform

Gostein, Michael & Ayala Pelaez, Silvana & Deline, Chris & Habte, Aron & Hansen, Clifford & Marion, Bill & Newmiller, Jeff & Sengupta, Manajit & Stein, Joshua & Suez, Itai.
Measuring Irradiance for Bifacial PV Systems. PVSC 2021
Bifacial reference modules measure total front + rear irradiance

Effective Irradiance Monitoring Using Reference Modules
Jennifer L. Braid, Joshua S. Stein, Bruce H. King, Christopher Raupp, Jaya Mallineni, Justin Robinson, Steve Knapp. Sandia National Laboratories, Albuquerque, NM, USA. SOLV Energy, San Diego, CO, USA. GroundWork Renewables, Holladay, UT, USA

Intelligent cloud-based monitoring and control digital twin for photovoltaic power plants
Andreas Livera, Georgios Paphitis, Loucas Pikolos, Ioannis Papadopoulos, Javier Lopez-Lorente, George Makrides, Juergen Sutterlet, George E. Georgiou. PV Technology Laboratory, FOSS Research Centre for Sustainable Energy, University of Cyprus, Nicosia, Cyprus. Gantner Instruments GmbH, Schruns, Austria

Best Student Presentation Award Finalist – Measuring Irradiance with Bifacial Reference Panels
Nicholas Riedel-Lyngskær, Jan Vedde, Peter B. Poulsen, Sergiu Spataru. Technical University of Denmark, Department of Photonics Engineering, Roskilde, Denmark. European Energy A/S, Soborg, Denmark
RDE300i provides in-situ IV curves for any module in an array

- Existing module IV sweep units require a standalone module alongside the array
- Using power producing modules for measurement reduces engineering and racking costs
Connect RDE300i between target module and array
During normal operation string current passes through RDE300i
During full IV sweeps string current bypasses RDE300i
Mini-sweep mode measures $P_{\text{max}}$ without disconnecting

- Allows for more frequent measurements (10 seconds instead of 1 minute)
- Measured module continuously produces power
A clean and dirty module can be used to calculate soiling ratio.
Use a reference module to get total effective bifacial irradiance

Use any module in your array

Actual module = perfect matching
RDE300i is rated for the new generation of PV modules

- Up to 30 amps
- Up to 250 volts
- Up to 1,500 watts
- String up to 1,500 volts
Validating RDE300i at Sandia National Labs
Sandia provided a number of systems for testing

- Used 5 different arrays
  - Monofacial and bifacial silicon modules
  - Various string level inverters from different manufacturers
- Strings selected for testing have output power up to 4.8 kW
RDE300i installed on a test rack at Sandia National Labs
RDE300i measures $I_{sc}$, $V_{oc}$, $P_{max}$, $V_{mp}$, $I_{mp}$, $V_{out}$, and $I_{out}$.
Test Protocol
Inverter operation must not be disturbed by RDE300i

Testing goals:
• Verify RDE300i functionality
• Ensure no inverter faults
• Ensure inverter follows MPP Tracking
• Quantify any impact on inverter energy output
Functionality Test: ensure no inverter fault events

- Objective: Inverter functions are not interrupted
  - Data is monitored for irregularities indicating faults
  - Module power is correlated with the power measured at the inverter input
  - Quantify spikes to string Voc at the inverter

- Objective: Measured Pmax correlates with system behavior
  - The module’s potential Pmax and actual operating point are compared
Energy Harvest Test: ensure no inverter power loss

- Compare two strings to calculate a Performance Index
  - String 1 does not have RDE300i inserted
  - String 2 has RDE300i inserted after an initial set of data is collected
- Baseline comparison included to account for differences between the strings
- We expect PI to be very close to 1

\[
PI = \frac{\left( \sum P_2 / \sum P_1 \right)_{after}}{\left( \sum P_2 / \sum P_1 \right)_{before}}
\]

- Power of String 2
- Power of String 1
- RDE300i has been inserted into String 2
- No RDE300i, baseline comparison
Uncertainty due to fluctuations in irradiance, temperature, etc.

- Performance Index (PI) is calculated from all collected data
  \[
  PI = \frac{(\sum P_2 / \sum P_1)_\text{after}}{(\sum P_2 / \sum P_1)_\text{before}} + \text{uncertainty}
  \]

- Data is separated into single days to calculate uncertainty
  - The “before” and “after” days are paired
    - Day 1, day 2, ..., day k, ..., day N
  - A Performance Index PI\(_k\) is calculated for each day pair k

- Final uncertainty \(\sigma_N = \frac{\sigma}{\sqrt{N}}\)
  - \(\sigma = \text{Standard deviation of the set of PI}_k\)s: \((PI_1, PI_2, ..., PI_N)\)
Data collection and filtering

- During this testing the RDE300i unit was performing mini-sweeps once every 10 seconds and full sweeps once every 60 seconds
- No filtering when searching for faults
- For calculating PI, data were filtered to exclude days with low insolation
- Inverter data provided by Sandia from dedicated inverter monitoring system
- Sandia also provided irradiance
Results
No excess power loss from inserting RDE300i

- No inverter faults observed in any system
- Observed power loss in line with expected power loss from series resistance and sweep duty cycle
- No adverse effect on inverter

<table>
<thead>
<tr>
<th>System</th>
<th>Hours of Collected Data</th>
<th>Minutes of Inverter Fault</th>
<th>Performance Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>System 1</td>
<td>916</td>
<td>0</td>
<td>0.9984 ± 0.0017</td>
</tr>
<tr>
<td>System 2</td>
<td>648</td>
<td>0</td>
<td>0.9983 ± 0.0017</td>
</tr>
<tr>
<td>System 3</td>
<td>570</td>
<td>0</td>
<td>0.9963 ± 0.0009</td>
</tr>
<tr>
<td>System 4</td>
<td>1080</td>
<td>0</td>
<td>1.0026 ±0.0009</td>
</tr>
<tr>
<td>System 5</td>
<td>384</td>
<td>0</td>
<td>0.9945 ±0.0012</td>
</tr>
</tbody>
</table>
Test results indicate RDE300i is well suited for PV plant deployment

• We developed a protocol for validating in-situ I-V tracing equipment
  – Identify any fault conditions caused by I-V sweeps
  – Quantify any power losses due to adverse impact on inverter MPP tracking
• Test results showed no faults or impact on inverter power production
• RDE300i enables efficient use of PV reference modules for system monitoring applications
  – Utilize power producing modules for measurements
Thank you!