Laboratory and Field Characterization of the Electrical Response of Modules Containing Configurable Current Cells (C3) Under Non-optimal Conditions Such as Shading

Cooperative Research and Development Final Report

CRADA Number: CRD-19-00834

NREL Technical Contact: Michael Deceglie

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5K00-84423
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Suggested Citation
Deceglie, Michael. 2022. Laboratory and Field Characterization of the Electrical Response of Modules Containing Configurable Current Cells (C3) Under Non-optimal Conditions Such as Shading*: Cooperative Research and Development Final Report, CRADA Number CRD-19-00834.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5K00-84423. https://www.nrel.gov/docs/fy23osti/84423.pdf.

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NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

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Cooperative Research and Development Final Report

Report Date: October 25, 2022

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Solar Inventions, LLC.

CRADA Number: CRD-19-00834

CRADA Title: Laboratory and Field Characterization of the Electrical Response of Modules Containing Configurable Current Cells (C3) Under Non-optimal Conditions Such as Shading

Responsible Technical Contact at Alliance/National Renewable Energy Laboratory (NREL):

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Sponsoring DOE Program Office(s): Office of Energy Efficiency and Renewable Energy (EERE), Solar Energy Technologies Office (SETO)

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1 Year 2, Modification #1	$37,500.00 $12,500.00
TOTALS	$50,000.00

Executive Summary of CRADA Work:

This work is to be conducted in support of the American Made Challenges Solar Prize. The intent is to connect competitor teams with national laboratories that can help accelerate the development of innovative solutions and products. Teams who have won the Set! and Go! Contests are eligible to utilize vouchers at national laboratories to advance their ideas. Laboratory and field characterization of the electrical response of modules containing Configurable Current Cells (C3) under non-optimal conditions such as shading.

CRADA benefit to DOE, Participant, and US Taxpayer: Uses the laboratory's core competencies.

Summary of Research Results:

Task Descriptions:

Note: The task listing begins with 3.1.

3.1. Incoming inspection: NREL shall perform Standard Test Conditions STC flash test and electroluminescence on all incoming modules (Isc, 0.1 Isc), up to 8 modules.

NREL received the modules and performed the specified tests. A first batch of modules was observed to have cell cracks due to shipping. A second batch was determined to be suitable for testing. STC flash test current voltage curves allowed selection of 4 modules with power output with 0.5% relative of one another for outdoor testing.

3.2. Design shade scenarios: NREL shall work with Participant to design shade scenarios/mask for testing.

We designed an outdoor shade scenario as shown in the Figure 1. The design is intended to cast a variety of shadows across partial cells throughout the day and to avoid activation of the bypass diodes so the reverse bias characteristics of the cells could be probed.

Figure 1: Shade structure in front of modules used in this experiment

3.3. Hot spot testing: On two Configurable Current Cells (C3) and two standard modules provided to NREL by Solar Inventions, NREL will perform IEC 61215-based hot spot tests, showing cells of maximum temperature under shading, maximum reverse bias current in the hottest cells found, and maximum power dissipation in such substrings or cells.

We performed the test and observed no failures per the IEC standard nor any substantial differences between the C3 and standard modules.

3.4. Field performance: NREL shall collect module-level Current-Voltage (IV) curves and back-of-module temperature on 4 modules simultaneously outdoors for up to a total of one year with the shade scenarios agreed upon under Task 3.2. This will be performed on two C3 and two standard modules provided to NREL by Solar Inventions.

IV curves were collected on the modules automatically at 5-minute intervals. The modules were first installed without the shade structure for a period of about 5 months to establish a shade-free baseline. Then the shade structure was erected, and the modules tested for another approximately 5-month period. Figure 2 shows power vs. irradiance for both a standard module and a module with Solar Inventions C3 technology with and without the shade structure; we observe no substantial differences power output patterns in either the shaded or unshaded configuration.

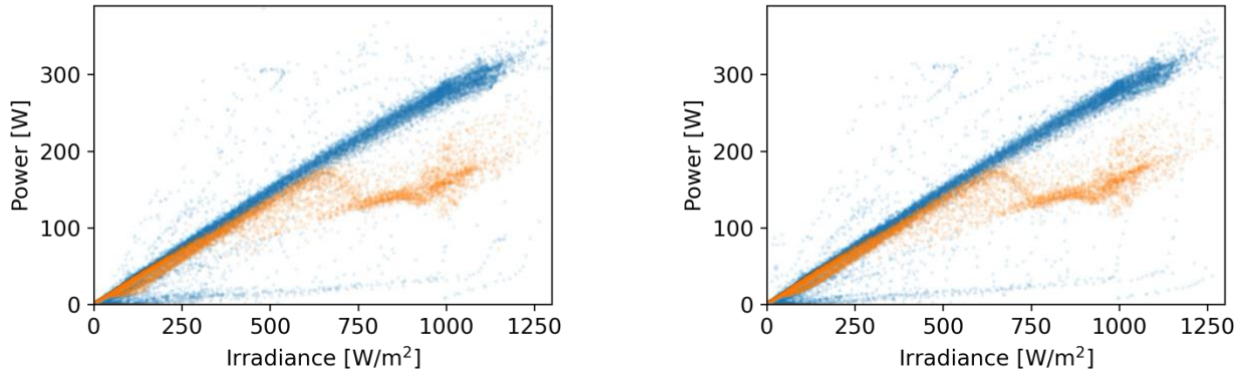

Figure 2: Power vs. irradiance measured outdoors for a standard (left) and C3 (right) module. Blue shows data collected before the shade structure was erected, orange shows data after.

NREL also performed time lapse infrared imaging of the modules from the back side on consecutive sunny days. A frame from this thermal imaging series is shown in Figure 3. We observe that under some shade conditions cells on the C3 module become hotter, suggesting that they are operating in reverse bias. The power vs. voltage curve for the corresponding images do show a "knee" in the C3 curve consistent with cells being in reverse bias rather than the bypass diode for the module substring being activated. While this is not inherently an advantage, further circuit modeling and understanding of this behavior may help Solar Inventions derive advantages from future generations of the C3 technology.

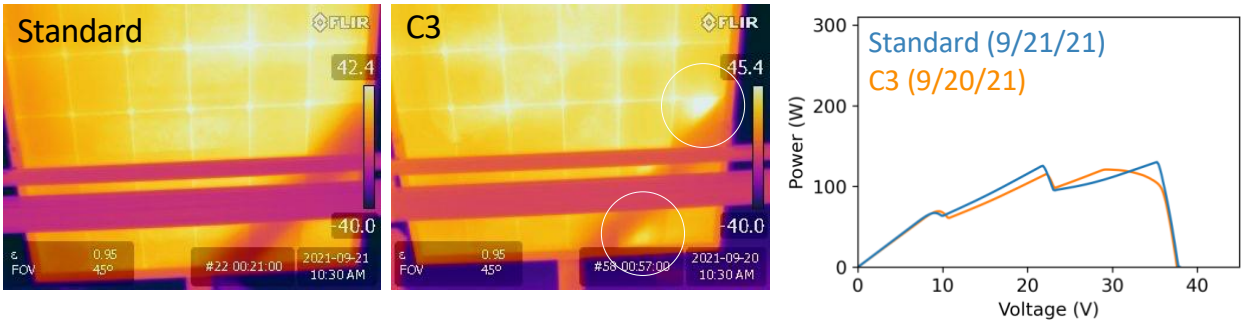

Figure 3: Difference in shade behavior of modules under outdoor operation. The left two panels show infrared images. The right most panel shows plots of power vs. voltage corresponding to the images. White circles indicate cells with elevated temperature on the C3 modules.

3.5. Low-light performance: NREL shall characterize at least 2 C3 modules under simulated sunlight at irradiances of 200, 400, 600, 800, 1000 W/m2 at 25±1°C. Using modules on hand or acquired,

NREL shall apply the same characterization to at least 2 commercial half-cell modules. NREL will compare the low light performance of the C3 modules to the half-cell modules. Results from the half-cell modules may be normalized and anonymized at NREL's discretion.

C3 and standard modules were measured at multiple irradiances along with two commercial half-cell modules. In these plots shown in Figure 4, each parameter is normalized to the module's parameter value at 1000 W/m^2. In addition, power and Isc are linearly corrected for irradiance to 1000 W/m2. Care should be taken not to generalize to all commercial half-cell modules from these limited results.

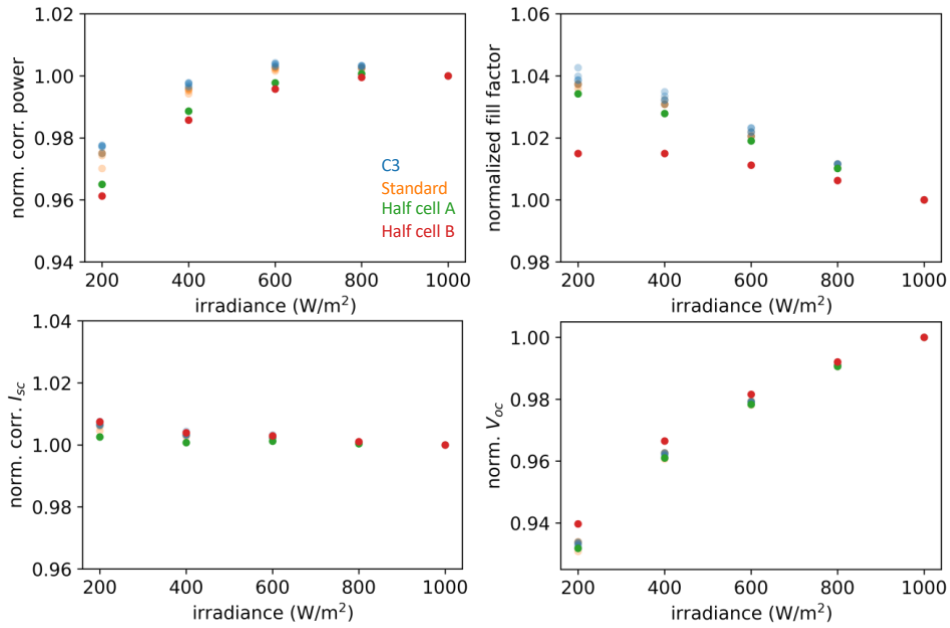

Figure 4: Normalized room temperature current-voltage curve parameters for 4 module types.

Subject Inventions Listing:

None

ROI #:

None