Sandia National Laboratories

Energy, Climate, & Infrastructure Security

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PHOTOVOLTAIC MODULE AND STRING LEVEL CONVERTER AND MICRO-INVERTER PERFORMANCE EVALUATIONS at SANDIA NATIONAL LABORATORIES

Vision

To enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems.

Sandia National Laboratories' Distributed Energy Technologies Laboratory (DETL) testbed conducts controlled evaluations of new module and string-level solar photovoltaic (PV) conversion devices. Sandia uses this testbed to develop standard evaluation protocols, verify performance and reliability, and create best practices that will then lead to new measurement and operational standards for these devices as well as overall systems integration.

As market penetration of residential-scale and distributed solar PV systems increases, manufacturers are devising a new suite of power conditioning devices to optimize the electricity produced and fed into the local electric grid. The manufacturers of new devices such as module-scale inverters (often called micro-inverters) and DC-to-DC converters offer promises of enhanced performance, improved safety, and increased reliability. Potential enhancements come through several inherent features, including

- Minimizing the effect of partial shading of a module or an array;
- Embedding an ability to detect and mitigate arcs, which could lead to failures and even fires;
- Eliminating limiting effects of module mismatch within a string by converting all module outputs to either a single-voltage DC or AC signal; and
- Reducing wire losses by employing higher DC voltages and optimizing conversion efficiency by designing inverters to operate at a high DC voltage.

In the case of micro-inverters, the DC balance-of-system (BOS) component is completely removed, including eliminating high-voltage DC. Because such devices result in PV systems that are configured differently from traditional designs, Sandia is developing new methods to evaluate and verify these performance and reliability differences.

Critical Analysis for a Developing Industry

While micro-inverters and DC-to-DC converters are not new to the solar industry, few benchmark standards exist for the rapidly developing residential and commercial PV market. Sandia is addressing this deficiency by (1) collecting and analyzing data that measure performance of currently available products, (2) exploring design strategies that may improve energy harvest, and (3) investigating possible limitations of grid-connected PV systems.

Sandia's research explores module-level converter performance, power quality, and interoperability. It also quantifies energy harvest, assessing controlled shading effects, and compares module-level vs string-level applications. Experiments to date include several micro-inverters of U.S. manufacture and module-level DC-to-DC converters. The micro-inverter portion of the testbed comprises up to 6 kW of separate PV systems, while we can assess the DC-to-DC converters on all or part of a DETL 50 kW array.

Sandia collects data in one-second increments including real power, apparent power, and reactive power using a LabView®-based data acquisition system. We also assess interoperability and anti-islanding capabilities via system utility loss at an interruptible service entrance, where different manufacturers' components share a point of common coupling. Our assessment will analyze

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components' adherence to UL 1741 and IEEE 1547-2008.

Recognizing that micro-inverter configurations can help minimize the effects of shading and module mismatch when compared to string inverter designs, Sandia will use a controlled shading evaluation to quantify and compare energy harvest in various configurations.

- Micro-inverter-to-string-inverter comparison under comparable shading percentage(s)
- Micro-inverter operation among multiple manufacturer configurations
- DC-to-DC conversion in a 50 kW array

Sandia evaluates utility compatibility to determine voltage and frequency operating ranges and an inverter's response to voltage and frequency sag or swell. A response to anomalies on the utility service that includes the loss of utility is measured against the following utility interconnection compatibility conditions that comply with UL 1741:

- High- and low-voltage range tests
- High- and low-frequency range tests
- Low-voltage sag tests with either slow or fast response
- High-voltage surge tests with either slow or fast response
- Anti-islanding in a multi-inverter configuration

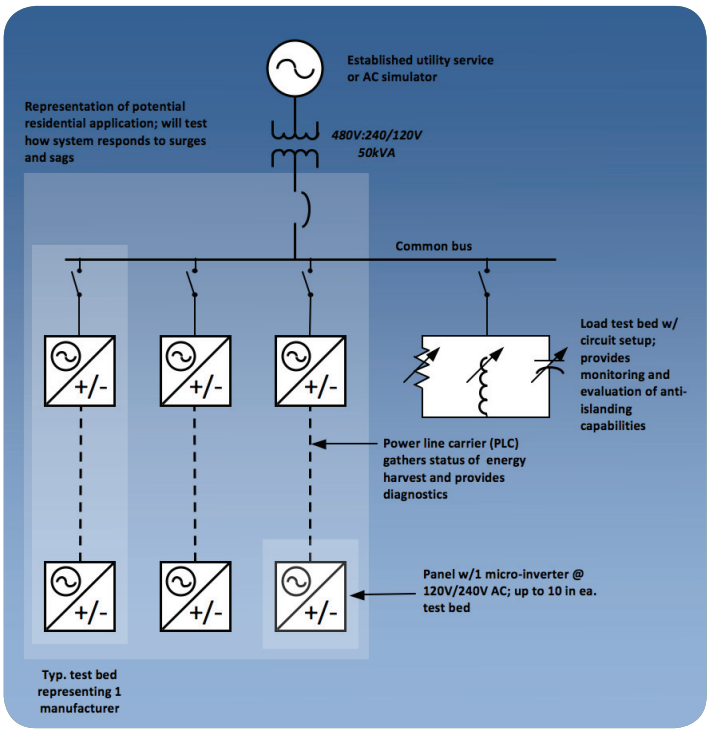
Sandia's Research Will Influence Future Developments in Residential PV

Sandia recognizes that improving micro-inverter performance offers benefits for residential and commercial PV systems, including removing DC BOS requirements, removing exposure to PV-system high DC voltage, possibly mitigating DC arc faults, and mitigating the negative impacts on PV system power production (e.g., component mismatch, shading). Sandia is partnering with other organizations to test in additional climates, increase capabilities for DC-to-DC boosting at the module level, and further mix module-level component combinations for testing. Additionally, Sandia will use the information gained through these experiments to provide leadership in developing new performance, reliability, and interconnection standards related to these devices and their functioning in PV systems.

Sandia's DETL

Sandia's DETL staff conducts research to integrate emerging energy technologies into new and existing electricity infrastructures—to facilitate the nation's increasing demands for clean, secure, and reliable energy. DETL researchers analyze the effects of high penetration of renewable technologies and distributed energy on the grid and resolve issues related to grid interconnectivity, communications, controls, security, safety, performance, reliability, and interoperability. The DETL's reconfigurable infrastructure simulates a variety of real-world scenarios such as intentional islands and campus grids, including military installations; remote operations such as forward operating bases; and scaled portions of utility feeders and the transmission infrastructure.

DETL leverages Sandia's long history of expertise in fundamental sciences and applications. Sandia National Laboratories is a globally recognized leader in PV research and technical expertise to the solar PV industry. Through support from the U.S. Department of Energy as well as industry partnerships, the lab addresses complex issues and barriers to high penetration of PV in the U.S. and around the world.



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