



# **Residential PV-Energy Storage Testing Collaboration with SunPower**

**Cooperative Research and  
Development Final Report**

**CRADA Number: CRD-14-569**

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## Cooperative Research and Development Final Report

In accordance with Requirements set forth in Article X: REPORTS AND PUBLICATIONS A.(2), of the CRADA agreement, this document is the final CRADA report, including a list of Subject Inventions, to be forwarded to the Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

**Parties to the Agreement:** SunPower Corporation

**CRADA Number:** CRD-14-569

**CRADA Title:** Residential PV-Energy Storage Testing Collaboration with SunPower

### **Joint Work Statement Funding Table Showing DOE Commitment:**

| <b>Estimated Costs</b> | <b>NREL Shared Resources</b> |
|------------------------|------------------------------|
| Year 1                 | \$ 212,500 .00               |
| TOTAL                  | \$ 212,500.00                |

### **Abstract of CRADA Work:**

Residential scale energy storage devices have shown great promise to add value and improve the ability to integrate distributed and variable generation into the distribution grid. Battery energy storage systems combined with PV and advanced inverters can provide many services. These include extended backup power in case of grid failure, reductions in feeder and system level peak load, system level net load ramp reduction, grid management services both locally (e.g., voltage management) and bulk system (e.g., reserves) level, and improved grid reliability through grid voltage and frequency support. Even though the cost of the energy storage systems are decreasing, one of the main challenges related to the widespread deployment of energy storage, as found by the U.S. Department of Energy (DOE), is utility acceptance of storage technologies. Various interconnection challenges exist when connecting distributed PV-energy storage into the electrical distribution grid in terms of safety, reliability and stability of the electric power systems. Some of the urgent challenges, as seen by the manufacturers and installers are: safety of the battery cells and the packs, performance of the power conversion systems, effect of bidirectional power flow on existing utility equipment and qualification of solutions such as volt-ampere reactive (VAR) support and frequency regulation. Under this project, National Renewable Energy Laboratory (NREL) researchers will work with SunPower to address these challenges by research, testing and analysis at Energy System Integration Facility (ESIF) and energy storage testing laboratory at NREL. NREL's unique power hardware-in-the-loop (PHIL) capability will be utilized to evaluate system-level issues such as reverse power flow and VAR support (if available) for these PV-energy storage systems. Through the analysis of test results, the proposed project will demonstrate use of ESIF capabilities in a way that advances both the DOE and SunPower's goals of moving clean, renewable energy technologies onto the electrical grid.

### **Summary of Research Results:**

This project validated holistic PV+storage inverter control applied across an electric distribution system in addition to evaluation and modeling of battery energy storage system performance. Individual inverter efficiency, battery utilization, and control response performance while operating in four key operational modes was validated and NREL provided feedback to SunPower and their partners on how performance could be improved. Then, the system-wide impacts of controlling hundreds of distributed PV+storage units in four key operational modes were examined. The battery management system (BMS), as well as individual battery packs and cells, from the residential PV+storage unit was evaluated for performance under normal operation and various extreme conditions to ensure that the BMS properly monitored, balanced, and protected the battery pack from catastrophic failure. A battery cell lifetime degradation model was developed and life cycle testing of the battery system was performed in order to provide hardware validation needed for the model.

Highlights of this project were (1) validating the individual performance of a 6.6 kW / 11.6 kWh PV-battery inverter at the ESIF; (2) demonstrating that coordinated control of many distributed PV-battery inverter units provided valuable grid services, including voltage smoothing, reduced tap change operations of utility voltage regulators (thus reducing operations and maintenance costs), and reduced peak distribution system power requirements; (3) validating the performance of the BMS and providing suggestions for improvement; and (4) development of a battery cell lifetime degradation model capable of predicting the battery lifetime impacts of operating the PV+storage inverter in different operation modes.

### **Subject Inventions Listing:**

None

### **Report Date:**

12 October 2016

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