Mitigating Interconnection Challenges of the High Penetration Utility-Interconnected Photovoltaic (PV) in the Electrical Distribution Systems

Cooperative Research and Development Final Report

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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: SolarCity Corporation

CRADA Number: CRD-14-563

CRADA Title: Mitigating Interconnection Challenges of the High Penetration Utility-Interconnected Photovoltaic (PV) in the Electrical Distribution Systems

Joint Work Statement Funding Table Showing DOE Commitment:

Estimated Costs	NREL Shared Resources
Year 1 Year 2	$52,500.00 $180,000.00
TOTAL	$232,500.00

Abstract of CRADA Work:

Various interconnection challenges exist when connecting distributed PV into the electrical distribution grid in terms of safety, reliability, and stability of the electric power systems. Some of the urgent areas for research, as identified by inverter manufacturers, installers and utilities, are potential for transient overvoltage from PV inverters, multi-inverter anti-islanding, impact of smart inverters on volt-VAR support, impact of bidirectional power flow, and potential for distributed generation curtailment solutions to mitigate grid stability challenges. Under this project, NREL worked with SolarCity to address these challenges through research, testing and analysis at the Energy System Integration Facility (ESIF). Inverters from different manufacturers were tested at ESIF and NREL's unique power hardware-in-the-loop (PHIL) capability was utilized to evaluate various system-level impacts. Through the modeling, simulation, and testing, this project eliminated critical barriers on high PV penetration and directly supported the Department of Energy's SunShot goal of increasing the solar PV on the electrical grid.

Summary of Research Results:

Four tasks were completed under this project. The objective of the first task was to test inverters from different manufacturers to determine duration and magnitudes of transient overvoltages they could create during load-rejection and ground-fault conditions. The detailed results from this task can be found in papers and NREL technical reports [1]-[4]. As an independent third party, NREL's test reports gave Hawaiian Electric Companies (HECO), the PV community, and other stakeholders confidence that advanced inverters could mitigate transient overvoltage concerns. Following the testing at NREL, HECO cleared its interconnection queue and raised its

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limit of distributed PV from 120% of minimum daytime load to 250%, specifically citing NREL's report as a reason for this change in policy. The objective of the second task was to validate through testing that the active onboard anti-islanding capability of inverters did not degrade when numerous inverters were present and interacting together on one feeder. Additionally, the anti-islanding capabilities were tested with and without advanced inverter functionality. The testing introduced realistic impedances between the inverters through PHIL techniques. The detailed results from this task can be found in references [5]-[6]. This research was the first reported laboratory testing of multi-inverter, multi point-of-common-coupling anti-islanding and will increase utility's confidence on safe interconnection at high PV penetration. The objective of the third task was to conduct an impact assessment study of distributed PV systems with smart inverter reactive power control on conservation voltage reduction (CVR) energy savings and distribution system power quality. Both the CVR and power quality assessment methodologies were applied to two distribution system models: one obtained from the HECO and another obtained from Pacific Gas and Electric Company (PG&E). The detailed results can be found in two upcoming publications [7]-[8]. The final task of the CRADA was to evaluate SolarCity's PV generation curtailment hardware and software integration. That part of the project contained proprietary information from SolarCity and was not resulted in any public report.

1. A.Nelson, A.Hoke, S.Chakraborty, J.Chebahtah, T.Wang and B.Zimmerly, "Inverter load rejection over-voltage testing", National Renewable Energy Laboratory (NREL) technical report, http://www.nrel.gov/docs/fy15osti/63510.pdf.

2. A.Hoke, A.Nelson, S.Chakraborty, J.Chebahtah, T.Wang and M.McCarty, "Inverter ground fault overvoltage testing", National Renewable Energy Laboratory (NREL) technical report, http://www.nrel.gov/docs/fy15osti/64173.pdf.

3. A. Nelson, A. Hoke, S. Chakraborty, J. Chebahtah, T. Wang and B. Zimmerly, "Experimental evaluation of load rejection over-voltage from grid-tied solar inverters", 2015 IEEE Photovoltaic Specialists Conference (PVSC), 2015.

4. M. Ropp, A. Hoke, S. Chakraborty, D. Schutz, C. Mouw, A. Nelson, M. McCarty, T. Wang and A. Sorensen, "Ground fault overvoltage with inverter-interfaced distributed resources", IEEE Transaction on Power Delivery (PWRD), DOI: 10.1109/TPWRD.2016.2577884.

5. A. Hoke, A. Nelson, B. Miller, S. Chakraborty, F. Bell, M. McCarty, "Experimental evaluation of PV inverter anti-islanding with grid support functions in multi-inverter island scenarios," NREL/TP-5D00-66732, July 2016.

6. A. Nelson, A. Hoke, B. Miller, S. Chakraborty, F. Bell, M. McCarty, "Impacts of Inverter-based Advanced Grid Support Functions on Islanding Detection," 2016 IEEE Innovative Smart Grid Technologies Conference (ISGT), 2016.

7. F. Ding, A. Nagarajan, M. Baggu, S. Chakraborty, A. Nguyen, S. Walinga, M. McCarty and F. Bell, "Photovoltaic (PV) impact assessment of smart inverter volt-var control on

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distribution system conservation voltage reduction (CVR) and power quality," NREL Technical Report, to be published in 2016.

8. F. Ding, A. Nguyen, A. Nagarajan, M. Baggu, S. Chakraborty, S. Walinga, M. McCarty and F. Bell, "Impact assessment of autonomous smart inverter volt-var function on energy savings and power quality in electric distribution systems", conference paper under prepertaion.

Subject Inventions Listing:

None

Report Date:

14 November 2015

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