

VII.3 FCTO INTEGRATE Stack Test Bed and Grid Interoperability

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Project End Date: Project continuation and direction determined annually by DOE

- Use the flexible and fully-instrumented electrolyzer test platform to enable advanced research, development, and demonstration (RD&D) using real time digital simulation (RTDS) and hardware in the loop (HIL) testing between Idaho National Laboratory (INL) and NREL's Energy Systems Integration Facility (ESIF)

Technical Barriers

This project is conducting applied RD&D to reduce the cost and accelerate the deployment of hydrogen production systems via low temperature water electrolysis at the megawatt scale. This project addresses the following technical barrier from the Technology Validation section of the FCTO Multi-Year Research, Development, and Demonstration Plan:

(G) Hydrogen from Renewable Sources

Technical Targets

This project aims to inform DOE and industry of the cost, durability, and efficiency of state-of-the-art, grid-connected electrolyzer and fuel cell systems.

FY 2015 Accomplishments

- NREL designed, built, and began operating an electrolyzer stack test bed capable of hydrogen flow rates in the range of 100 kilograms (kg) per day. Stack power is provided by two programmable DC power supplies with upper limits of 250 V and 2,000 A.
 - Giner Inc. was the first industry stakeholder to partner with NREL to perform factory acceptance testing on three of their newest 150 kW stacks at very high current densities.
- Communications and information, and computation data services were developed for integrated system testing. The work accomplished provides the required hardware and cyber connectivity to establish a fast and secure network connection to enable detailed data exchange between the two RTDS at INL and NREL.
- The first of its kind, bidirectional, high speed simulation between ESIF RTDS and INL RTDS over a secure virtual private network (VPN).



INTRODUCTION

Electrolyzers, hydrogen storage, and fuel cells may be sited with renewable electricity sources. However, with

Overall Objectives

INTEGRATE Project Objectives

The Integrated Network Testbed for Energy Grid Research and Technology Experimentation (INTEGRATE) project conducts energy systems integration research by evaluating the benefits and values of energy efficiency, renewable energy, and distributed energy resource technologies at high penetrations into the energy infrastructure at a variety of physical scales (i.e., single location, campus, distribution systems, regional areas).

Fuel Cell Technologies Office (FCTO) Objectives

- Establish an industry-accessible, flexible electrolyzer stack test bed where integrated systems can be modeled, simulated, and evaluated to identify and overcome challenges and accelerate technology deployment
- Gather industry feedback on qualitative and quantitative performance data to identify grid services that can be provided by hydrogen-based technologies (i.e., electrolyzers and fuel cells)

Fiscal Year (FY) 2015 Objectives

- Establish a fully-instrumented, large-active-area electrolyzer stack test bed capable of variable direct current (DC) stack power up to 500 kW (250 V, 2,000 A)

appropriate communication, the electrolyzer does not need to be located in the immediate vicinity of the renewable resource to effectively use it. Electrolyzers may be controlled remotely to use inexpensive electricity that is produced when renewable sources are available but demand is not.

The grid must balance generation with demand nearly instantaneously and provide additional capacity to maintain system reliability. Energy and ancillary service markets have been established to procure the necessary resources. Ancillary service markets include load following, fast energy markets, flexibility, regulation, spinning reserve, non-spinning reserve, and other reserves (i.e., replacement or supplemental). Load following, fast energy markets, and flexibility provide similar products by reconciling energy mismatches; these products are often separated into “up” product (increasing generation or reducing demand) and “down” product (reducing generation or increasing demand) [1].

The anticipated value to the electrical utility grid of electrolyzers and fuel cells stems from the fact that they are a controllable load/generator with fast (~1 s) and stable response. In the case of electrolyzers, these systems are typically coupled to hydrogen energy storage. **This allows an integrated system the flexibility to meet hydrogen demand by storing more hydrogen when grid power demand is low and/or renewable energy supply is high, while helping to stabilize the grid by responding to ancillary service requests.**

APPROACH

Projects in Technology Validation are both (1) a “learning demonstration” to help guide and manage the hydrogen and fuel cell component and materials research and development activities and (2) a validation of the technology under real-world operating conditions against durability and performance targets. Specifically, the approach of this project includes the following.

- Develop a flexible industry accessible platform to test large active area electrolyzer stacks (up to 1 MW) and next generation balance of plant (BOP) subsystems to improve system cost and performance
- Provide actionable data to electric utilities and industry stakeholders demonstrating the ability of electrolyzers and fuel cells to participate in ancillary grid support markets
- Develop and demonstrate advanced RTDS, HIL, monitoring, and control of electrolyzer and fuel cell systems to improve overall system efficiency and grid participation effectiveness to enable higher penetrations of renewable electricity generation

RESULTS

Task 1: Design, Build, and Characterize Performance of Electrolyzer Stack Test Bed

NREL completed the design, fabrication, and commissioning of an electrolyzer stack test bed. Multiple beginning-of-life polarization current-voltage (IV) curves were obtained; six of them on three 150 kW polymer electrolyte membrane (PEM) stacks for work covered under a technical services agreement with Giner Inc. and two others on a 120 kW stack procured from Proton Onsite.

The stack test bed provided nearly 1,000 A, controls, and the required BOP to complete the work with Giner Inc. The factory acceptance tests included obtaining polarization curves and individual cell voltages for the three PEM stacks at 70°C, various cathode pressures, and very high current density. In Figure 1, which shows polarization curves for one of the 150 kW stacks at two different pressures, the y-axis values are intentionally removed to protect Giner’s data.

NREL also procured a 50-cell, 120 kW, 2.5 kg hydrogen per hour PEM stack from Proton Onsite. A beginning-of-life IV curve was captured at 50°C and 300 psig (Figure 2). Operation of this stack will provide onsite hydrogen production for ESIF fuel cell labs, vehicle refueling, and infrastructure component testing projects (e.g., hoses, pressure relief devices, compressors), as well as a test platform for grid integration, stack decay testing, and BOP optimization under variable power.

Demonstrated grid ancillary services—frequency regulation

In an electric power system, automatic generation control is a system for adjusting the power output of multiple generators at different power plants, in response to changes in the load. An electrolyzer system can quickly reduce or increase its load (stack and BOP) to have the same effect on the grid.

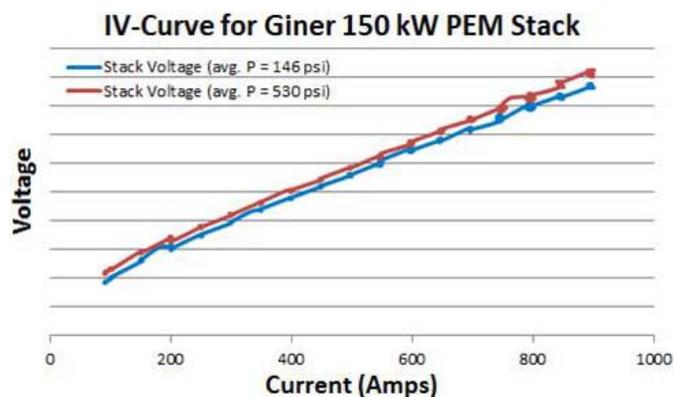


FIGURE 1. Polarization curves (146 psig and 530 psig at 70°C) taken during factory acceptance tests performed on the electrolyzer stack test bed for Giner Inc.

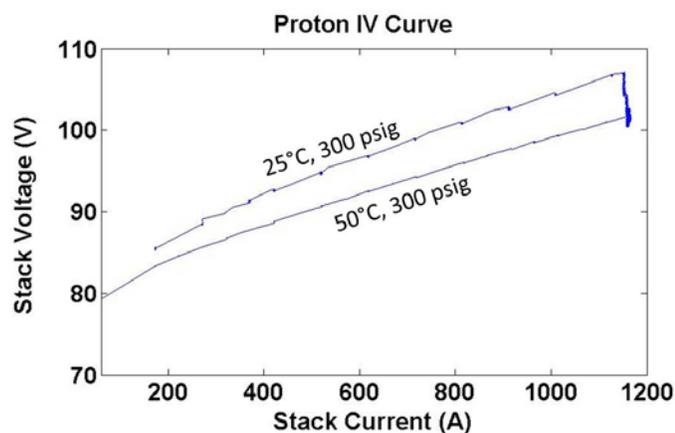


FIGURE 2. Beginning-of-life polarization curves (25°C and 50°C at 300 psig) of a 50-cell, 120 kW PEM electrolyzer stack from Proton Onsite operating on the electrolyzer stack test bed

The large active area stack test bed, operating the 120 kW stack, demonstrated grid ancillary services by following a traditional 4 s simulated frequency regulation signal. The stack DC power supplies were programmed to read a file containing normalized historical frequency regulation signals obtained from Xcel Energy.

Task 2: Develop Communications and Information and Computation Data Services for Integrated System Testing

Communications

The work under this task provided the required hardware and cyber connectivity to establish a VPN to enable detailed data exchange between the two RTDS at INL and NREL from the context of electrolyzers connected to distribution and large scale transmission networks. The data exchange and its properties dictate largely the type of simulations that can be performed under this configuration.

Information and computation data services

In this task, research datasets are collected into secured projects with permissions managed by the principal investigator. Research data can be curated by assigning metadata through the use of tags and classifying the data structure and permissions. Finally, search and filtering capabilities easily locate data across projects and datasets.

This work established two main data connectivity components: (1) the electrolyzer stack test bed data acquisition system was uploaded to the data repository in the ESIF's data center, and (2) data analytics components were developed through a website to visually interpret and share the data with clients. The project takes advantage of the data system components in the ESIF data center—such as a Time Series cluster to manage large amounts of time series data and a file repository that is redundant and backed up—

ensuring very secure and reliable data storage and a database for managing metadata.

Task 3: Demonstrate Integrated Systems to Deliver Grid Services

The project team successfully demonstrated a first of its kind, bidirectional, high speed simulation between ESIF RTDS and INL RTDS. The connection between the two RTDS is over the DOE-owned Energy Sciences Network. It was the first time, as we understand, that two RTDS machines communicated over a wide area network. The simulation consisted of the exchange of voltage values between the distribution grid node where the electrolyzer is connected and the electrolyzer input node located on the RTDS at NREL. The data exchange occurs at each time step and simulation proceeds with updated data received at each iteration.

Similarly, the electrolyzer model can be replaced with actual electrolyzer hardware. In this case the data exchange latency would also depend on the internal characteristics of the electrolyzer hardware connected to the RTDS. The time step for simulations in RTDS can be adjusted as per the requirement of a specific simulation to mitigate the effect of data communication latency (~27 ms) and response time. The two parts of the experimental system shown in Figure 3 exchange data across the internet in real time.

CONCLUSIONS AND FUTURE DIRECTIONS

- Conclusion: NREL completed the design, build, and commissioning of an electrolyzer stack test bed and obtained beginning-of-life IV curves on four stacks: three 150 kW PEM stacks under a technical services agreement with Giner and one 120 kW stack procured from Proton Onsite being used for onsite hydrogen production.
 - Future: Operate the 120 kW stack under variable power to demonstrate advanced grid functionality, quantify stack decay rate, and provide a test platform for state-of-the-art stacks and BOP optimization
- Conclusion: NREL established connectivity via a VPN to enable detailed data exchange between the two RTDS at INL and NREL. To provide data connectivity, NREL uploaded the electrolyzer stack test bed data acquisition system to the data repository in the ESIF's data center and developed data analytics components through a website to visually interpret and share the data with clients.
 - Future: Improve industry involvement by coordinating meetings with electric utilities to share NREL's electrolyzer stack test bed performance data and understand the value of electrolyzers and fuel

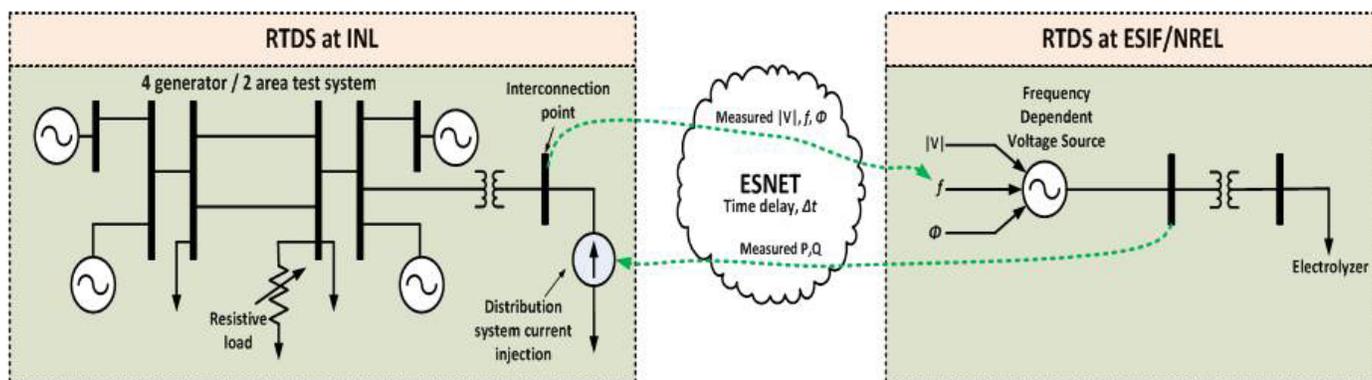


FIGURE 3. The diagram describes the experimental design of the RTDS testing conducted between INL and NREL.

cells if they were to participate in established and potential future markets

- Future: Attend technical workshops (e.g., energy storage, Smart Grid) that are coordinating national efforts to modernize the grid with advanced monitoring/controls for loads/generators to support the grid enabling the increased penetration of renewable energy
- Conclusion: The project team successfully demonstrated a first of its kind, bidirectional, high speed communication test between the ESIF RTDS and the INL RTDS.
 - Future: Explore new RTDS research applications. Real time simulations by geographically distributed RTDS are a relatively newer concept and require significant efforts to be reliably established. The applications based on geographically distributed RTDS are an unexplored research area for performing dynamic and transient analysis of energy sources. The geographically distributed RTDS can also lead to simulations between remote sites that facilitate testing and characterization. One such application is the ability to utilize real time simulators with standard communication for troubleshooting remote hardware at challenging locations.

FY 2015 PUBLICATIONS/PRESENTATIONS

1. P. Denholm, O. Ma, T. Markel, and J. Eichman, "Summary of Market Opportunities for Electric Vehicles and Dispatchable Load in Electrolyzers" (Technical Report), NREL/TP-6A20-64172 (Golden, CO: National Renewable Energy Laboratory, 2015).
2. K. Harrison, O. Smith, M. Peters, D. Terlip, P. Denholm, and M. Mann, "FC/TO INTEGRATE Stack Test Bed and Grid Interoperability," (presented at the DOE Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation Meeting, Arlington, VA, June 10, 2015).

REFERENCES

1. J. Eichman, K. Harrison, and M. Peters, "Novel Electrolyzer Applications: Providing More than Just Hydrogen" (Technical Report), NREL/TP-5400-61758 (Golden, CO: National Renewable Energy Laboratory, 2014).