VII.D.3 Dynamic Modeling and Validation of Electrolyzers in Real-Time Grid Simulation

Rob Hovsapian
Idaho National Laboratory
750 University Blvd.
Idaho Falls, ID 83406
Phone: (208) 526-8217
Email: rob.hovsapian@inl.gov

DOE Manager: Jason Marcinkoski
Phone: (202) 586-7466
Email: Jason.Marcinkoski@ee.doe.gov

Subcontractors:
- Humboldt State University, Arcata, CA
- Florida State University, Tallahassee, FL

Project Start Date: June 1, 2015
Project End Date: September 30, 2017

Overall Objectives

- Validate the benefits of hydrogen electrolyzers through grid services and hydrogen sale to fuel cell vehicles for full-scale deployment.
- Characterize the potential and highest economic value based on the needs of multiple stakeholders for specific grid regions.
- Demonstrate reliable, fast-reacting performance of hydrogen-producing electrolyzers for at-scale energy storage devices.
- Develop and verify the communications and controls needed for successful participation in electricity markets and demand response (DR) programs.

Fiscal Year (FY) 2016 Objectives

- Perform power hardware-in-the-loop (PHIL) at the National Renewable Energy Laboratory (NREL) using Digital Real-Time Simulator (DRTS) coupled with electrolyzers to verify the operational system and to characterize and validate the existing electrolyzer model.
- Create a distribution network that contains current hydrogen refueling stations, based on Pacific Gas and Electric (PG&E) infrastructure and feeder data in real-time environment used for PHIL testing. This platform will be used to assess the value of electrolyzers under existing DR programs and any other grid services using historical energy and ancillary service prices.
- Define the requirements and implement the front end controller (FEC) that will interpret the utility signals and coordinate multiple hydrogen refueling stations. The FEC will generate the necessary control signals for the lower level controller to respond to different utility signals and hence participate in DR and ancillary service programs.

Technical Barriers

This project addresses the following technical barriers from Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

(B) Lack of Data on Stationary Fuel Cells in Real-World Operation

(G) Hydrogen from Renewable Resources

(H) Hydrogen and Electricity Co-Production

Contribution to Achievement of DOE Technology Validation Milestones

This project will contribute to achievement of the following DOE milestones from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

- Milestone 3.9: Validate large-scale system for grid energy storage that integrates renewable hydrogen generation and storage with fuel cell power generation by operating for more than 10,000 hours with a round-trip efficiency of 40%. (4Q, 2020)

FY 2016 Accomplishments

- Completed design specification document for the FEC for electrolyzer application that enables response of electrolyzers to grid signals.
- Completed development of reduced-order PG&E California Bay Area sub-network in DRTS for testing current and future electrolyzer deployments and related technical aspects.

✧ ✧ ✧ ✧ ✧

INTRODUCTION

The project aims to quantify the value of fuel cells and electrolyzers from a grid integration perspective. This work uses a novel approach of distributed real-time PHIL simulations to use an electrolyzer hardware at NREL working in conjunction with power system simulations at Idaho National Laboratory (INL). The proposed project strives to leverage existing work at both the national labs related to fuel cells, electrolyzers, and grid integration. INL and NREL have performed PHIL simulation using a 120 kW electrolyzer in distributed real time environment. Part of the research resources are focused on developing the FEC for integration with the electrolyzer. The proposed FEC can communicate with supervisory control and data acquisition systems to effectively process the commands from grid management systems. It will also optimize the operation of connected electrolyzers to meet objectives of the power grid, as well as those of electrolyzer owners. Thus, a carefully designed, flexible FEC integrated with a distribution management system will enable an electrolyzer to operate as a revenue generating resource, while extending benefits to the grid.

APPROACH

In FY 2016, INL and NREL performed 200 hours of PHIL simulation using the 120 kW electrolyzer in distributed real-time simulations. Techniques to counter impact of latency on PHIL simulations were also created and tested. Based on the lessons learned during the testing and subsequent data analysis, it was deemed by the DOE leadership, INL, and NREL researchers that 300-hour testing with the electrolyzer would be redundant. The affirmative results obtained from electrolyzer PHIL testing using DRTS in the second quarter of FY 2016 were used for further research and development to enhance the interaction of electrolyzers with the power markets. Thus, in the third quarter of FY 2016 research resources were focused on developing the FEC for integration with the electrolyzer. It is possible to operate the designed FEC in several “modes” to meet varying priorities (ranging from utility-friendly, environment-friendly, and self-preservation).

For the design of the FEC, several review meetings took place between INL and NREL researchers during the development phase. From the discussions, a specifications document that describes in detail the rationale for choosing electrolyzers as a grid service device, technical specifications for parsing utility signals, methods for integration of FEC to distribution management systems, and modes of operation was developed. The design specifications in this document will be followed to create a real-time FEC for enabling grid services from electrolyzers in particular, but can be generalized as necessary. The team also successfully completed the development of a reduced-order PG&E sub-network of California’s Bay Area in the DRTS environment for studying practical cases.

RESULTS

Distributed real-time simulations were performed to demonstrate the real-time PHIL for 200 hours between INL and NREL. These are important from the perspective of understanding the response capabilities of an electrolyzer as a controllable load and the potential to provide services. Data were used to validate the electrolyzer model by operating at an average of 60% (lower heating value) stack efficiency. Typical values of stack efficiency were greater than 90% at times. Scenario 1 (Figure 1) is load step-change and it provides a measure of both response time and accuracy

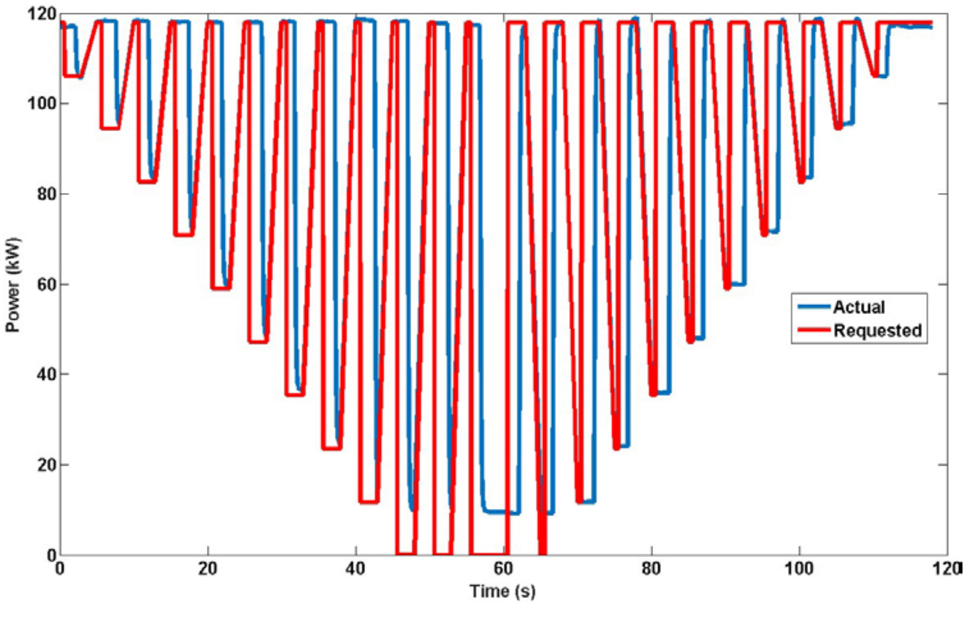

FIGURE 1. Electrolyzer response registered for the reference signal from Scenario 1

when changing load levels of operation of the electrolyzer. Scenario 2 (Figure 2) is the optimal operation for "time-of-use" utility rate by optimizing the operation of an electrolyzer using the PG&E E-20 utility rate. To counter the impact of data latency (15 ms shown in Figure 3) on distributed real-time simulations between INL and NREL, a linear prediction technique was developed. The mechanism to implement automated response of the electrolyzers to grid signals is envisioned to be the FEC as shown in Figure 4. Distributed PHIL and latency mitigation technique (200 hours) contributed to Objectives 1 and 2 whereas FEC development contributed to Objectives 2 and 3.

CONCLUSIONS AND FUTURE DIRECTIONS

Capabilities of an electrolyzer as a controllable load and in providing grid services was realized to be significant. Additionally, the resistive attribute of the electrolyzer imparts a certain level of damping of oscillations in distribution networks. A 200-hour test of distributed PHIL performed in the second quarter of 2016 was a significant accomplishment as it was a one of a kind real-time simulation that yielded accurate results and leveraged laboratory assets. Hardware-based testing in real-time was used to infer and augment the understanding of the role electrolyzers can play in markets for additional revenue. An FEC that will enable

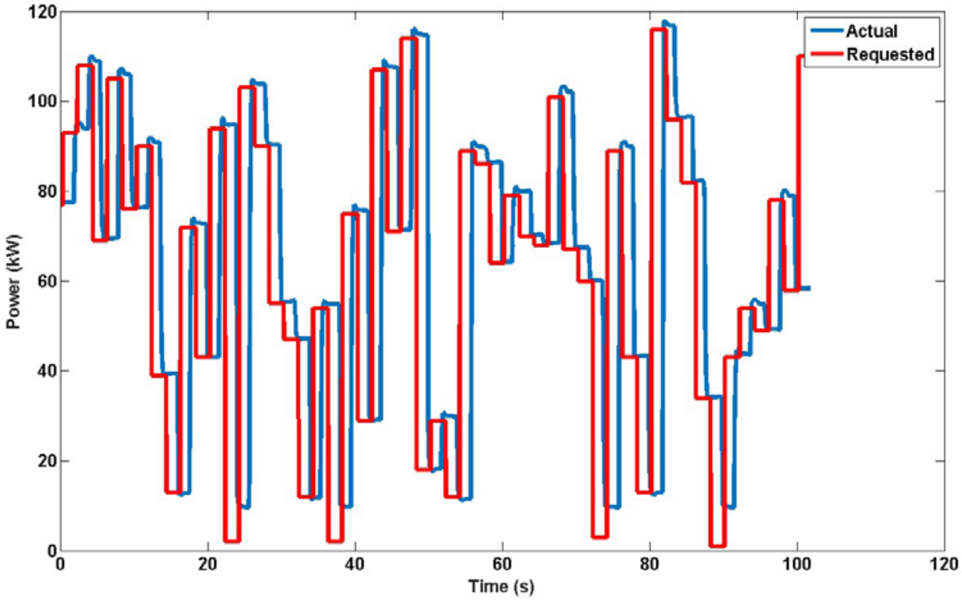

FIGURE 2. Electrolyzer response to PG&E E-20 signals from Scenario 2

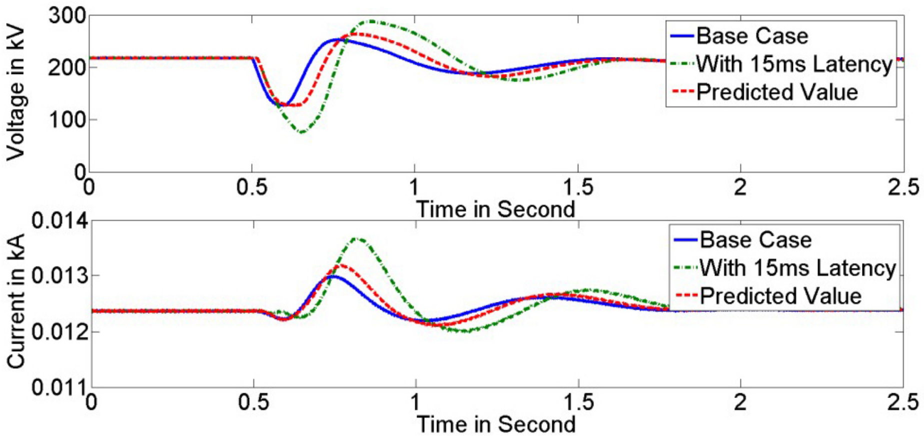

FIGURE 3. Linear prediction technique to counter impacts of latency on distributed PHIL

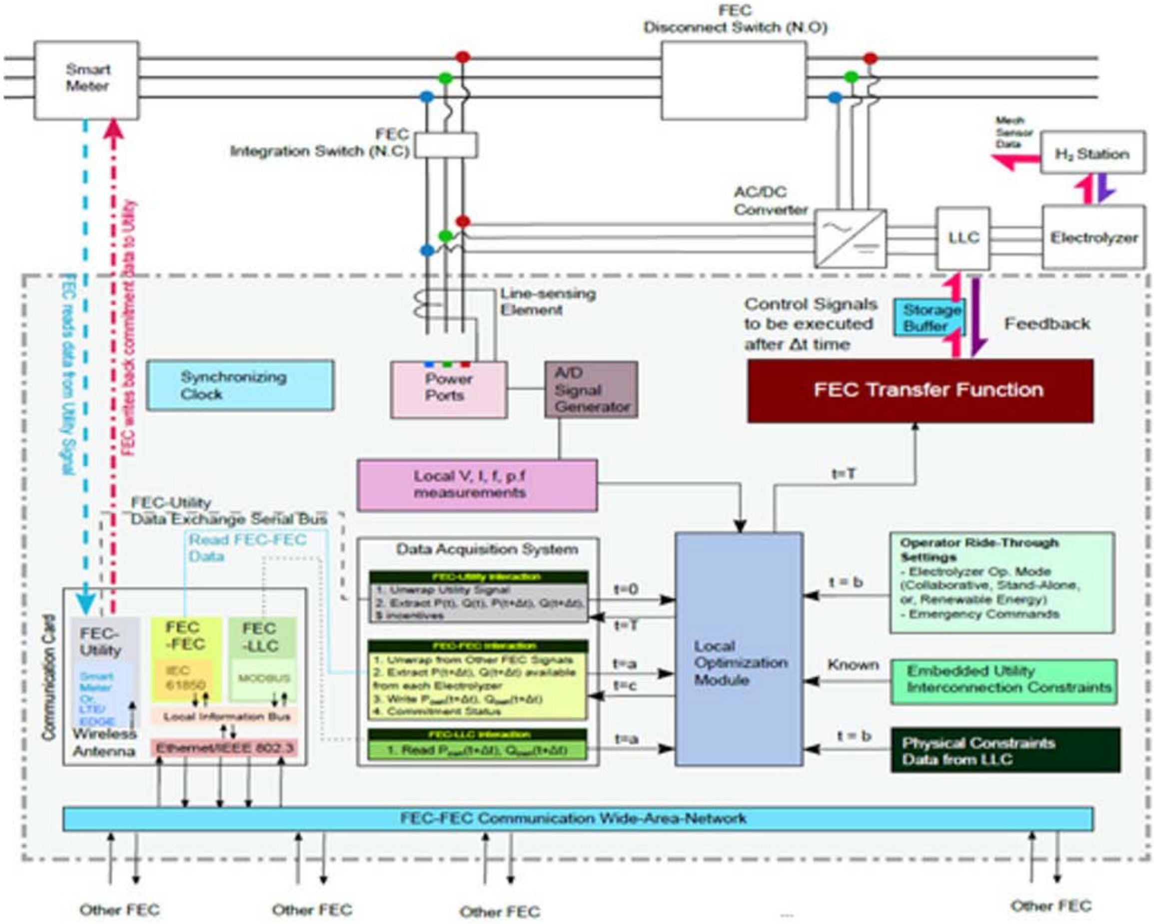

FIGURE 4. FEC schematic representation enabling electrolyzers to provide grid services

automated participation in markets was developed and will be implemented in the DRTS environment to respond to grid signals. Integration of the FEC with the electrolyzer model, and eventually hardware that interprets utility signals to provide reference signals for the lower level controller, are planned. A utility-scale network (PG&E distribution network) was modeled in DRTS in order to accommodate the future refueling stations as planned in the San Francisco Bay Area served by PG&E. This will enable studying the deployment of hydrogen refueling stations in the Bay Area and assessing the technical and economic impacts. Distributed real-time simulation for the expanded distribution networks with future refueling stations under novel DR programs will also be performed. In the future, establishment of multiple value streams for hydrogen refueling stations is anticipated as a result of learnings from this study.

FY 2016 PUBLICATIONS/PRESENTATIONS

1. M. Mohanpurkar, M. Panwar, S. Chanda, M. Stevic, R. Hovsapian, V. Gevorgian, S. Suryanarayanan, A. Monti, ”Distributed Real-time Simulations for Power Systems Engineering,” Cyber-Physical-Social Systems and Constructs in Electric Power Engineering, October 2016, pp. 35.

2. R. Liu, M. Mohanpurkar, M. Panwar, R. Hovsapian, A. Srivastava, S. Suryanarayanan, “Geographically distributed real-time digital simulations using linear prediction,” International Journal of Electrical Power & Energy Systems, Volume 84, 01/2017, pp. 309–317.