Dynamic Modeling and Validation of Electrolyzers in Real-Time Grid Simulation

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Overall Objectives

- Validate electrolyzer network capability to support utility needs for stability with high penetration of renewables.
- Create control logic and communications for networked electrolyzer operation based on stability and economics.
- Quantify the benefit of electrolyzer operation to the power system stability and generalize its impact for multiple units connected in single- and multiple-distribution networks.
- Provide experimental data to H2@Scale modeling, simulation, and analysis team for performance, reliability, durability, and economic assumptions.

Fiscal Year (FY) 2019 Objectives

- Validate the benefits of hydrogen electrolyzers coordinated with renewable energy through grid services and hydrogen sale to fuel cell vehicles.
- Demonstrate the reliable, fast-reacting performance of hydrogen-producing electrolyzers with baseload nuclear and intermittent renewables on the grid.
- Demonstrate the potential for mitigating voltage disturbances by at least 30% with and without electrolyzers.
- Evaluate electrolyzer operation at scale by performing co-simulation of the communication layer with the front end controller operation under various dynamic grid conditions.
- Evaluate the role of hydrogen refueling stations in grid stability and inertia addition in cases of increased renewable energy penetration and decommissioning of thermal power plants.
- Optimize renewable energy generation and controllable loads (i.e., hydrogen refueling stations) based on spatial and temporal scales.

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[1]:

- (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 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

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

power generation by operating for more than 10,000 hours with a round-trip efficiency of 40%. (4Q, 2020)

FY 2019 Accomplishments

- Performed controller hardware in the loop (HIL) testing of the front end controller (FEC) at the National Renewable Energy Laboratory (NREL) with the low-temperature electrolyzer stack and the balance of plant.
    - Deployed processor based (hardware) realization of the FEC at NREL.
    - Completed unit and functionality testing of the FEC.
- Validated availability of hydrogen along with multiple revenue streams in peak hour by slow loop testing of FEC.
- Demonstrated electrolyzer can provide voltage regulation by fast loop testing of FEC under dynamic grid conditions.
- Power system modeling: Identified and modeled sub-transmission utility systems: Pacific Gas & Electric (PG&E) and Santa Fe.
- Started FEC evaluation in-line with distributed energy resources integration and operation as per IEEE 1547.4-2011 for frequency and voltage support. The interconnection of distributed energy resources mandates us to use "IEEE Standard 1547 for Interconnecting Distributed Resources with Electric Power Systems."
- Coordination of renewable generation and hydrogen production: Completed 20%, 30%, and 50% penetration of solar generation for hydrogen production under (a) partly cloudy, (b) cloudy, and (c) sunny scenarios.
- Demonstrated electrolyzers avoid curtailed renewable generation with hydrogen production.
    - Electrolyzers are operated at nearly steady state until photovoltaic (PV) generation, then the electrolyzer network operates during PV transients to dampen impacts of variable generation on a distribution feeder, utilize what would have been curtailed PV generation, and produce high-value hydrogen.
- Leveraged hydrogen technologies for integration of hybrid energy solutions.
    - The number of transformer tap operations can be reduced significantly by including the electrolyzers, which should result in extended life for grid hardware, improved reliability, and reduced maintenance and cost.
    - The location of electrolyzers (e.g., near the PV source or near the substation) does have an impact in all the metrics studied.

INTRODUCTION

This project aims to quantify the value of hydrogen refueling stations from a grid integration perspective to provide energy storage for accommodating renewable energy. Significant emphasis on assessing the potential of H2@Scale (MW level) to provide hydrogen-energy-based storage to reduce the variability stemming from renewable energy. The anticipated value of electrolyzers stems from the fact that they are a controllable load with fast response. They are typically coupled with hydrogen energy storage, dispensers, and compressor units to form the hydrogen refueling stations. They provide the flexibility to meet hydrogen demand with stored hydrogen when responding to the grid demand and store more hydrogen when the grid power demand is low. In addition to this complementary approach, a local energy storage potential from hydrogen infrastructure can be established. The input resource for electrolyzers is electricity and hence allows flexible co-placement of electrolyzers with other distribution energy sources in a power system network leading to an optimal value of the objective function. Real-time simulations of power systems with renewable energy modeling with HIL of electrolyzer with the supplementary systems representing the hydrogen refueling station forms the test setup of this project.

APPROACH

The approach adopted for this work is based on physics-based modeling and HIL of power systems and hydrogen systems. This is a scientifically sound methodology to model dynamic systems including power and energy systems and assess their transient and dynamic interactions. Both power systems and hydrogen systems are represented in a real-time environment. This project leverages the existing work at Idaho National Laboratory (INL), NREL, and Sandia National Laboratories in the areas of power systems, electrolyzers, power markets, renewable energy modeling, optimization, and control systems. The experimental set up is shown in Figure 1.

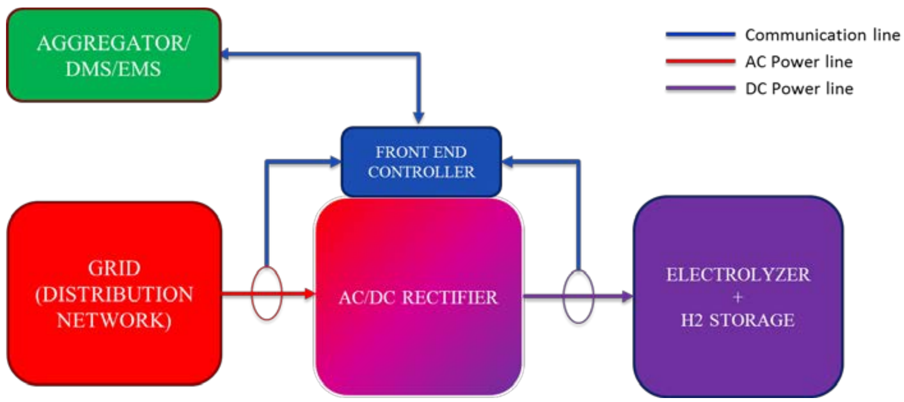

Figure 1. Experimental setup for FEC with hydrogen electrolyzer

Stack characterization was performed sequentially for both the upgraded electrolyzer stack rated 250 kW, which was 120 kW. This essential upgrade at 250 kW provided a modular building block for a MW-level controllability that provides flexibility to the grid while producing hydrogen. In FY 2016, INL and NREL performed 200 hours of power HIL simulation using the 120 kW electrolyzer in distributed real-time simulations. FY 2017 activities involved the recharacterization of the upgraded stack rated at 250 kW. This recharacterization was essential as the project direction hinged on the basic controllability of the electrolyzer stack along with the balance of plant. The characterization revealed the ability of modular, stackable electrolyzers with the ability to provide subsecond-level response. Consequently, connecting this controllability of electrolyzers ability as an extremely flexible load asset with grid controls and assimilating variable renewable energy was pursued. An FEC with slow and fast loop as an open source solution was developed to allow the ability to control the electrolyzer to produce hydrogen economically and provide necessary services as shown in Figure 2.

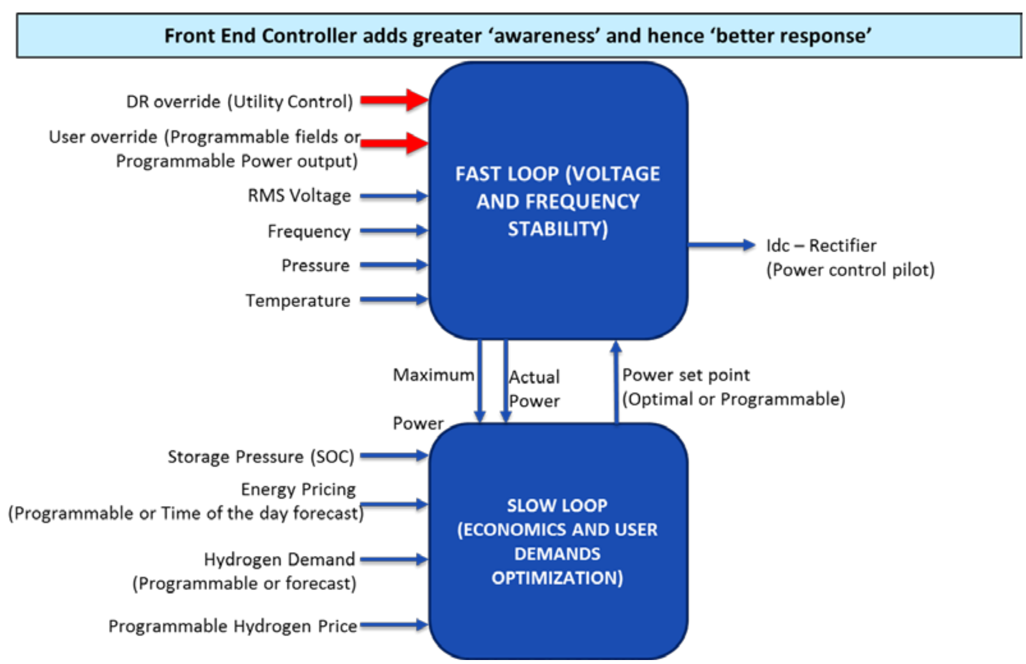

Figure 2. FEC fast (stability) and slow (economic) optimization with hydrogen electrolyzer

RESULTS

Distributed real-time simulations and power HIL were performed utilizing the 250 kW electrolyzer stack and a hardware implementation of the FEC. The functionality of the electrolyzer stack responding to control signals from the FEC was verified for applications including grid services within required time resolutions. There were challenges observed with the utilization of past California power system models, including inherent stability, and hence a standard IEEE 34 node feeder system with characterized info from PG&E was modified and used as shown in Figure 3.

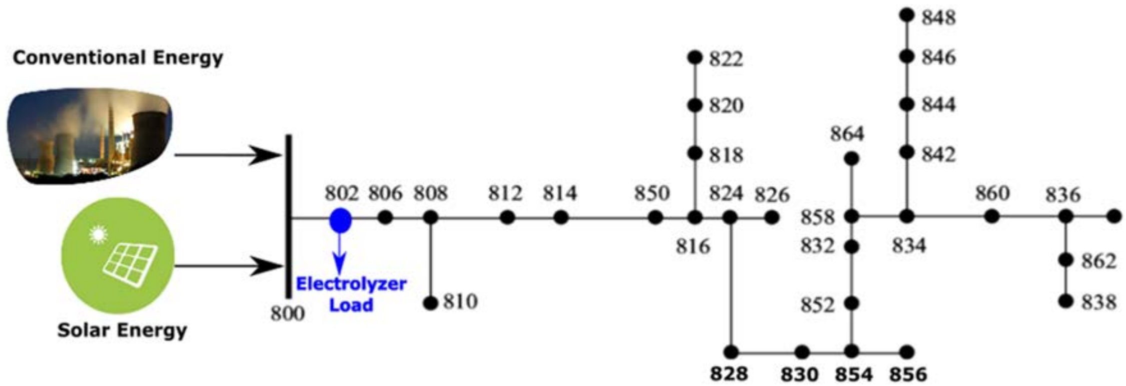

Figure 3. Electric grid model consists of conventional and renewable energy sources

The 250 kW modular electrolyzer stack is utilized for real-time simulations and HIL to generate high-accuracy data and results. The FEC developed in this research helps integrate the operations of the electrolyzer with the grid management systems and add stability as the variability in renewable energy is reduced. The flexibility on account of controllability is utilized to assimilate renewable energy, manage distribution loads, and provide grid support. The adoption of the FEC developed and tested in this project will drive down the cost of generating hydrogen while maintaining requisite reserves for demands.

The solar power output for the renewable energy installed at node 802 shown in Figure 4. The right plot shows the response of the electrolyzer for hydrogen generation based on solar profile. Fast response of electrolyzer can also benefit the grid stability by reducing fluctuations in high penetration of renewable energy sources, such as solar, shown in Figure 5. The flexibility is improved by providing coordinated response through hydrogen production, under both cases of co-siting with solar as well as at the substation.

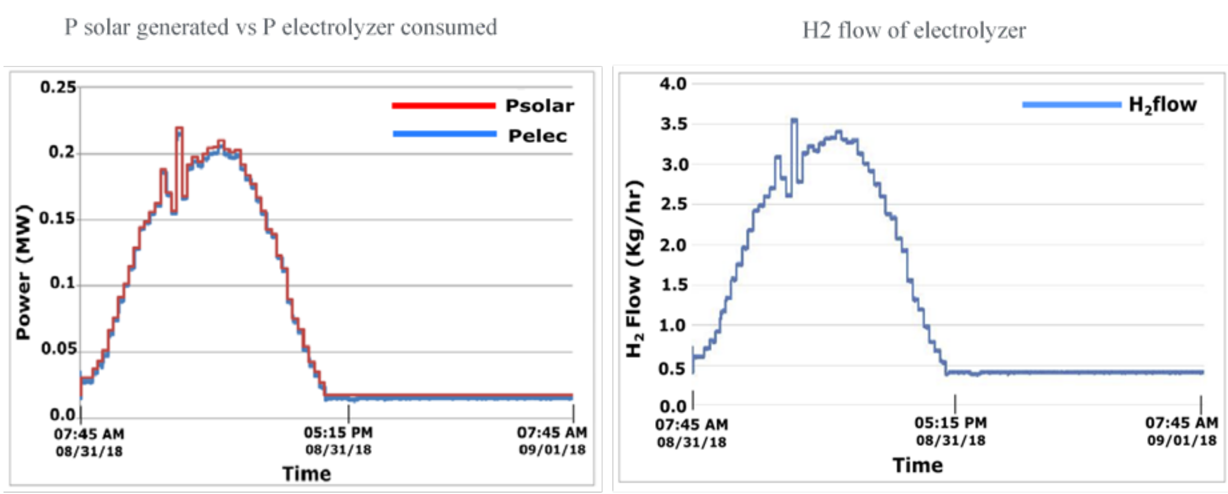

Figure 4. Electrolyzer response for hydrogen generation based on renewable energy sources

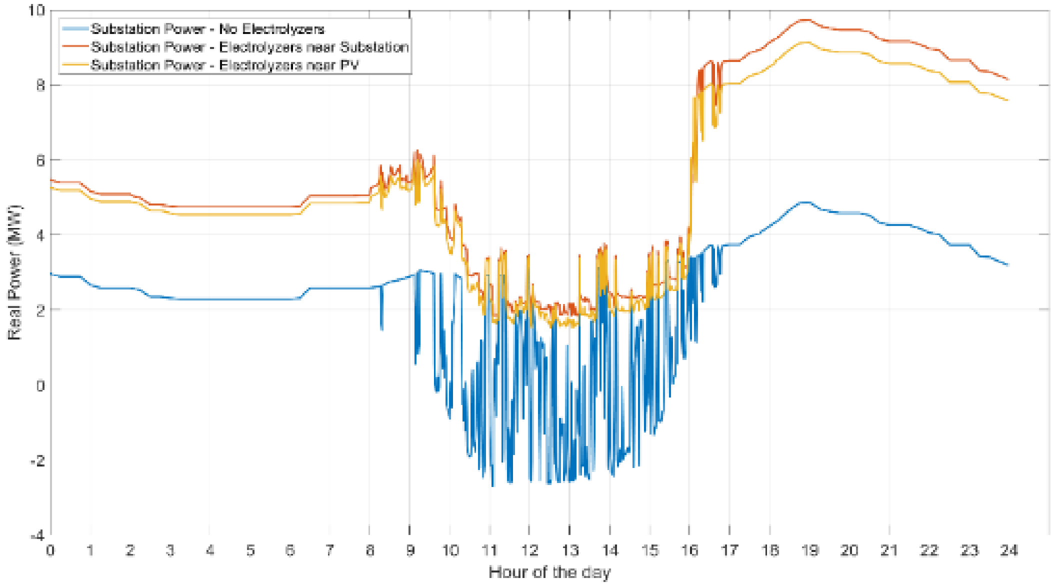

Figure 5. Flexibility and reduced variability provided by electrolyzer under high renewable penetration

CONCLUSIONS AND UPCOMING ACTIVITIES

- First of a kind, distributed real-time simulation with power HIL (electrolyzer) between INL and NREL to remotely operate a 250 kW stack under dynamic grid conditions was completed.
- Electrolyzer including balance of plant (balance of plant) response was demonstrated to be within sub-second to support grid services and reduce variability due to intermittent resources.
- Voltage and frequency response were obtained using the electrolyzer stack and balance of plant under varying penetration of intermittent resources.
- 200 hours of electrolyzer hardware operation on a 120 kW stack was used to demonstrate grid services by characterization and response to control commands in a power HIL.
- Integration of a prototype controller with the electrolyzer stack was completed and successfully deployed to facilitate grid services in real time.
- Integration of fast and slow loop optimization in preparation for implementation on a power converter is being formulated.
- 500 hours of control functionality testing and demonstration on a 250 kW stack was completed.
- A hardware control prototype was deployed at NREL to operate the low-temperature electrolyzer stack and balance of plant.

Future Research Activities

- Grid support demonstration of sub-second level response.
- Integration of high-temperature electrolyzers for stability and flexibility and high-penetration renewable energy.
- Future work is IEEE 1547 Standard for control and interoperability—looking for a vendor to integrate FEC functionality with a power converter that is implemented using the IEEE 1547 standard.
- Validation of electrolyzer performance with base load nuclear and intermittent renewables to provide frequency stabilization and mitigate voltage disturbance.
- Implementation of fast control response as per IEEE 1547 Standard of grid services.

FY 2019 PUBLICATIONS/PRESENTATIONS

1. R. Guttromson, "Rolling Horizon Optimization for a H2 Electrolyzer Station Used to Service H_2 Vehicles," 2018 INFORMS Annual Meeting, Phoenix, AZ, 2018.

REFERENCES

1. AMR Slides and Annual Progress Reports 2017, 2018, 2019.