VII.8 Renewable Electrolysis Integrated Systems Development and Testing

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

Fiscal Year (FY) 2012 Objectives

- Collaborate with hydrogen production, delivery, storage, and fuel cell industries to test, demonstrate, and track performance of unique integration opportunities for renewable hydrogen systems compared with baseline (incumbent) technologies.
- Validate and work to increase equipment reliability, efficiency, and relevant sub-system performance of state-of-the-art DOE-awarded, prototype and pre-commercial systems.
- Operate, maintain, track durability of, and perform strategic experimentation on the fully-functional integrated renewable hydrogen demonstration project to support industry innovation and DOE Technology Validation goals.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the 2011 Fuel Cell Technologies Program's Multi-Year Research, Development and Demonstration (RD&D) Plan:

(G) Hydrogen from Renewable Resources
(H) Hydrogen and Electricity Co-Production

Technical Targets

This project is focused on validation efforts to better integrate renewable hydrogen systems and measure their ability to deliver low-cost hydrogen. The project work scope includes quantifying system performance, operation and maintenance, durability, and reliability under real-world operating conditions. Innovation and insights gained from this work benefit the hydrogen-based industry and relevant stakeholders as the market for this equipment and products expands.

One of the project's primary goals is to validate hydrogen production and compression systems as they are applied to hydrogen as an energy storage medium for varying renewable electricity sources like wind and solar. The project includes optimization of the electrical pathway (power conversion) between renewable sources and the electrolyzer and storage of hydrogen at various pressures. Finally, this project supports the validation of water electrolysis systems from the DOE Hydrogen Production and Delivery sub-program RD&D plan by testing DOE-awarded electrolyzer stack and system performance to help meet the following DOE hydrogen Technology Validation targets:

- Task 3.3 – By 2nd quarter 2014, validate large-scale (>100 kg/day) integrated wind-to-hydrogen production system.
- Task 3.9 – By 4th quarter 2020, validate large-scale systems for grid energy storage that integrate 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%.
- Validate full-size hydrogen and fuel cell components and systems using NREL's Wind-to-Hydrogen facility and their new state-of-the-art test facility, the Energy Systems Integration Facility, scheduled for completion in October 2012.

FY 2012 Accomplishments

- Completed frequency mitigation testing of alkaline and polymer electrolyte membrane (PEM) electrolyzers on an alternating current (AC) microgrid:
  - Both commercially available technologies provided sub-second response to significantly reduce the magnitude and duration of disturbance.
- Designed, built, and began testing a volumetrically-based mass flow system for high-accuracy determination of electrolyzer hydrogen production.
- Reported detailed reliability metrics for the station relative to other hydrogen stations operating at 350 bar.

Introduction

Management of distributed power systems is expected to become more commonplace as grids and devices become "smarter" and distributed renewable resources become a larger proportion of our energy supply. A critical element for the advancement of smart-grid technologies is managing distributed resources, which includes renewable electricity generation, distributed energy storage, and taking advantage of active (or controllable) loads to provide grid support services like frequency and voltage regulation. Large-scale hydrogen production using renewable electricity is well positioned to produce near-zero greenhouse-gas emission vehicle fuel in the coming years as hydrogen-powered electric vehicles are introduced into the marketplace. An integrated system with advanced sensing and communications will enable grid operators to take advantage of the controllable nature of distributed and central water electrolysis systems to maintain grid stability.

Distributed water electrolysis allows hydrogen to be produced from renewable wind, solar, and geothermal energy sources as well as nuclear power. Additionally, the electrolyzers can be used to produce and subsequently store hydrogen from grid electricity during off-peak periods or from otherwise curtailed wind energy. Electrolyzers and hydrogen storage may be sited with renewable sources; however, with 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 intermittent renewable sources are available, but demand is not.

Approach

The Xcel Energy/NREL Wind-to-Hydrogen (Wind2H2) demonstration project is advancing the integration of renewable electricity sources with state-of-the-art hydrogen production, compression, storage, and dispensing systems. This project provides independent testing and verification of the technical readiness of these advanced integrated systems by operating them from the grid and renewable electricity sources.

Real-world data from daily system operation are revealing opportunities for improved system design and unique hardware configurations to advance the commercialization of this technology. Lessons learned and data-driven results provide feedback to industry and to the analytical and modeling components of this project.

Results

NREL operated both of the commercially available low-temperature electrolyzer technologies, PEM and alkaline, on an AC microgrid (shown in Figure 1) to evaluate their response to commands to increase and decrease stack power to shorten frequency disturbances. Results show that both the PEM and alkaline electrolyzers are capable of adding or removing stack power to provide sub-second response that reduced the duration of frequency disturbances.

Figure 2 compares a control test where electrolyzers are not triggered to shed load and the separate alkaline and PEM response tests where the electrolyzers are commanded to reduce stack power by 10 kW. In each of these three tests from Figure 2, the load simulator instantly applies 10 kW of resistive load to initiate a frequency disturbance on the grid. High-resolution monitoring of the AC microgrid frequency (nominally 60 Hertz) generates a control signal for the electrolyzer when the frequency exceeds ±0.2 Hertz.

Similar tests were performed by removing load from the AC microgrid and commanding the electrolyzers to add 25 kW of stack power to mitigate an over-frequency disturbance (Figure 3). Both the alkaline and PEM electrolyzers reduced the magnitude and the duration of the frequency disturbance compared with the control test where the electrolyzers were not providing load support.

Accurately measuring hydrogen mass flow from an electrolyzer, fuel cell, compressor, and hydrogen dispenser is challenging. Commercially available mass flow sensors are expensive and their accuracy can vary significantly depending on the type of transducer employed. This project, under its role as the DOE test and validation facility for advanced electrolyzer systems, designed, built, and began testing a volumetrically based mass flow device.

FIGURE 1. Frequency regulation experimental system where electrolyzers are powered by diesel generators on an AC microgrid

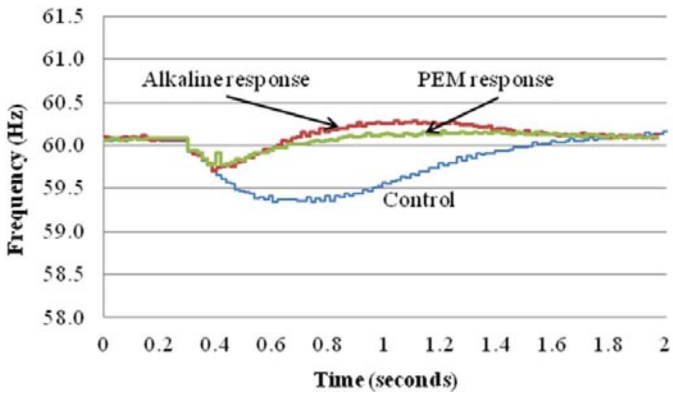

FIGURE 2. Resulting mitigation effects using electrolyzers to shed 10 kW of stack power during an under frequency disturbance on an AC microgrid

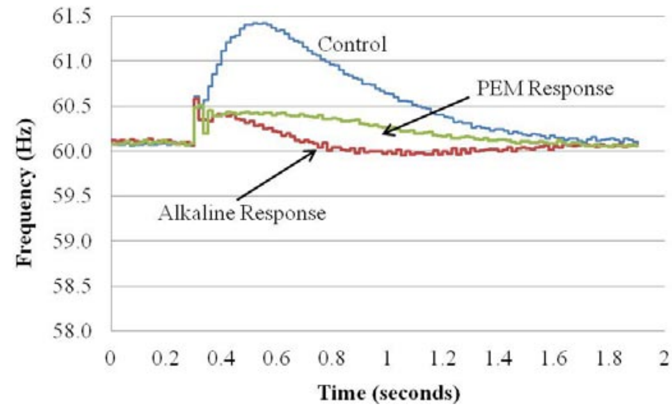

FIGURE 3. Resulting mitigation effects using electrolyzers to add 25 kW of stack power during an over frequency disturbance on an AC microgrid

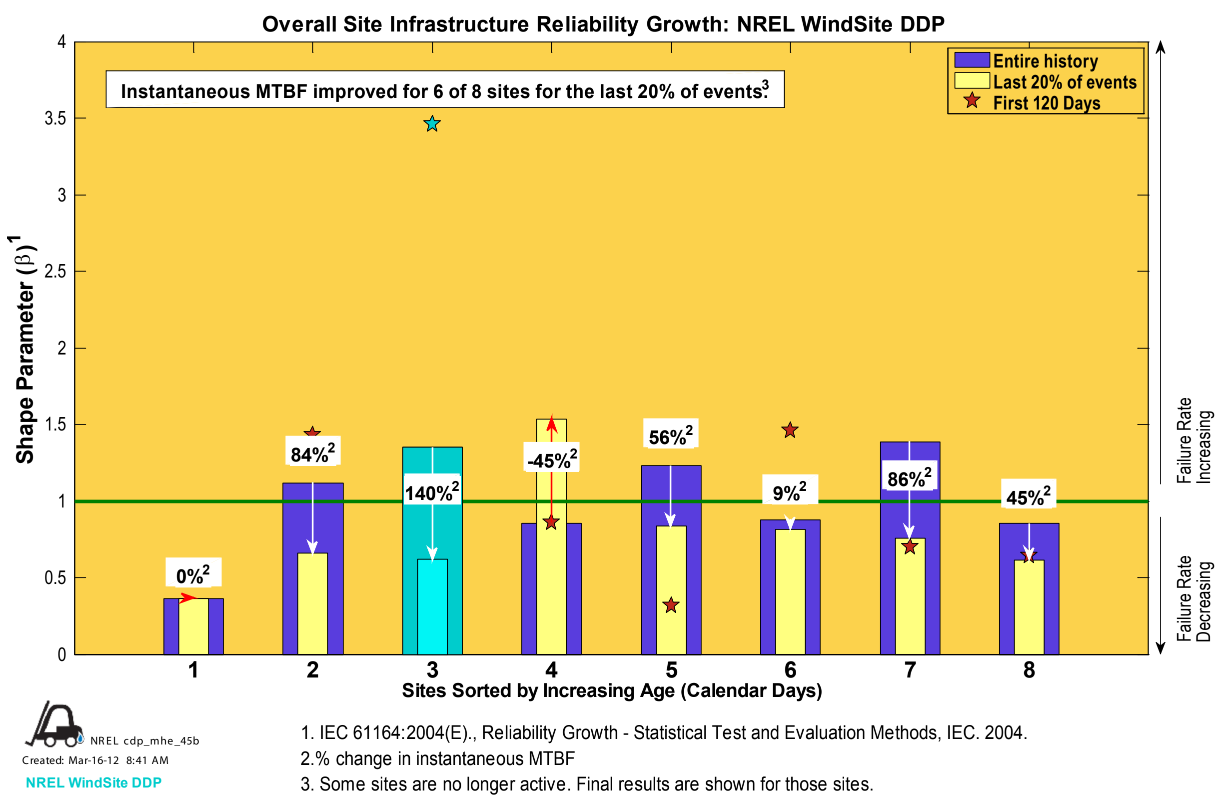

FIGURE 4. Reliability growth, as determined by the Beta shape parameter form a Crow-AMSAA analysis, indicates that reliability growth at Wind to Hydrogen is in line with other similar sites

The design of the mobile mass flow device took advantage of industry partner feedback. The device calculates the mass flow from (or to) a piece of equipment by accurately measuring the pressure and temperature and by knowing the water volume of the composite overwrapped pressure vessel and interconnecting tubing. Using the National Institute of Standards and Technology equations-of-state for hydrogen, the onboard controller determines the mass flow by subtracting the initial from the final mass of hydrogen in the pressure vessel and how long it took to reach the final mass. Preliminary data from the mass flow device for 30+ samples are promising and have resulted in standard deviations of 0.002–0.004 kg per hour while sampling an electrolyzer with a nominal flow rate of 0.5 kg per hour.

NREL compared the reliability growth rate of this project relative to other 350-bar refueling stations for which NREL collects data. The analysis showed good improvement in reliability growth in the most recent 20% of reliability events. The beta parameter of 0.6 shown on Figure 4 indicates that reliability at the Wind-to-Hydrogen site is improving, and is improving on pace with other, similar stations.

Conclusions and Future Direction

By testing the response of these commercially available electrolyzer systems NREL has shown that distributed and central electrolysis systems have another potential (economic) value stream because of their ability to quickly increase or decrease stack power, which could be used to improve grid stability. Finally, the volumetric mass flow device has shown low variability (2–4 g/hour) during initial testing of a 0.5 kg/hour electrolyzer. NREL compared the reliability growth rate of this project relative to other 350-bar refueling stations for which NREL collects data. The analysis showed good improvement in reliability growth in the most recent 20% of reliability events.

In the coming year the team will complete the following;

- Install, commission, and perform 2,500 hours of testing of a pneumatically-driven hydrogen gas booster:
  - Reliability and performance will be monitored and reported
- Substantiate volumetric mass flow measurements by conducting variance and error analysis and integrating a master meter or gravimetric measurement approach.