II.D.3 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

- Validate stack and system efficiency and contributing sub-system performance of DOE-awarded advanced electrolysis systems
- Collaborate with industry to optimize and demonstrate the commercialization of integrated renewable electrolysis systems
- Develop and demonstrate unique integration opportunities for renewable electrolysis systems in the area of energy storage, grid support and industrial gas end-uses

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production section of the Fuel Cell Technologies Program's Multi-Year Research, Development and Demonstration Plan (2011 Interim Update):

(H) System Efficiency
(J) Renewable Electricity Generation Integration

Technical Targets

This project is conducting applied research and development to reduce integration barriers between renewable electricity sources and state-of-the-art electrolyzer systems. Insights gained from this work benefit the hydrogen-based industry and relevant stakeholders as the market for this equipment and products continues to expand. Results from the project have demonstrated opportunities to improve the efficiency of an integrated, renewably coupled electrolysis system. Finally, this project validates stack and system performance of DOE-awarded systems to help meet the following DOE hydrogen production and delivery targets:

- By 2012, reduce the cost of central production of hydrogen from wind water electrolysis to \$3.10/gallon of gasoline equivalent (gge) at plant gate (\$4.80/gge delivered). By 2017, reduce the cost of central production of hydrogen from wind water electrolysis to <\$2.00/gge at plant gate (<\$3.00/gge delivered).
- System efficiency (currently being reevaluated): 69% by 2012 and 74% by 2017 (lower heating value*).

* Note that the highest efficiency obtainable on the basis of lower heating value (LHV) of hydrogen is 33.3/39.4 ≈ 84%

FY 2012 Accomplishments

- Designed and installed a new test facility and supporting infrastructure for validation and performance testing of DOE-awarded electrolyzer systems
- Operated electrolyzer stacks ~5,500 hours with variable wind profile to compare stack decay rate with that of a stack operating under constant power
  - Comparing steady-state and variable stack operation enables better understanding of long-term impacts on stack and system efficiency
- 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 the disturbance
- Designed, built and began testing a volumetric mass flow system for high-accuracy determination of electrolyzer system efficiency

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Introduction

Renewable electrolysis is inherently distributed, but large-scale wind and solar installations are becoming more common and will take advantage of economies of scale. Renewable electricity sources, such as wind and solar, can be closely—and in some cases directly—coupled to the hydrogen-producing stacks of electrolyzers to improve system efficiency and lower the capital costs of this near-zero-carbon pathway.

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.

Approach

The Xcel Energy/NREL Wind-to-Hydrogen (Wind2H2) research, development, and demonstration project is advancing the integration of renewable electricity sources with state-of-the-art electrolyzer technology. 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 (see "Hour-by-Hour Cost Modeling of Optimized Central Wind-Based Water Electrolysis Production," Genevieve Saur and others).

In areas with large hydrogen production, even small increases in system efficiency result in significant reductions in the cost of hydrogen. DOE is funding electrolyzer manufacturers to design and build improved stacks and system balance of plant to reduce the cost of electrolytically produced hydrogen. This project provides independent testing and verification of the technical readiness of these advanced electrolyzer systems by operating them from the grid and renewable electricity sources.

Results

Much of the effort over the past year was focused on completing the installation of a new facility and the required infrastructure to accommodate testing of DOE-awarded electrolyzer systems. The new test facility takes advantage of some of the existing Wind2H2 infrastructure but also required a new facility, power and safety and support systems.

Some of the capabilities of the new test facility include the following:

- 75 kVA, 208 V, 3-phase power and 100 kVA, 480 V, 3-phase power
- Up to 10 MΩ-cm resistive deionized water (flow rate: 2 gallon per minute)
- Two combustible gas detectors integrated into the Wind2H2 system
  - Alarm at 10% lower flammability limit of hydrogen-in-air
  - Activation of high-flow exhaust fan follows gas detector alarm signal
- Local monitoring and archiving of the following data:
  - Stack temperature, voltage, and current
  - AC input voltage, current and power
  - Mass flow – hydrogen product (see volumetric mass flow device below)
  - Mass flow – hydrogen waste (e.g., drying)

NREL is conducting side-by-side testing and comparison of stack voltage decay rates between constant and variable power operation. Two 34-cell stacks of an H-Series PEM electrolyzer from Proton Onsite are being operated with a highly variable wind profile, achieving almost 5,500 hours of operation between November 2010 and April 2012. The third stack has operated over the same time with a constant stack power. All three stacks have the same average current. Varying wind current profile is operated for hundreds of hours continuously and only interrupted to operate all three stacks at their full-current point for a few consecutive days to enable comparison of their steady-state voltage. Table 1 summarizes the preliminary results over the roughly 5,500 hours of operation and shows the variable stacks exhibiting a higher decay rate than that of the constant current stack. However, it is possible that the stack with the lowest decay rate may have been randomly selected.

TABLE 1. Average Cell Decay Rates for Electrolyzer Stacks

Mode	Average Decay μV/cell-h
Variable	11.6
Variable	10.5
Constant	8.9
Hours	5,474

It is worth noting that before delivery to NREL, the electrolyzer stacks currently under test faced severe abuse with no hydration for about a year in a warehouse. Furthermore, this testing is intended only to reveal relative stack decay rates between a variable wind profile and constant current operation, if there is any difference. Normal stack decay rates of today's PEM stacks are 2–5 μV/cell-h. However, some of the latest PEM stack designs have even shown no appreciable voltage decay over 20,000 h of life testing.

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.

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 that 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 reduces the duration of frequency disturbances.

Figure 2 compares a control test where electrolyzers are not triggered to shed load with the separate alkaline and PEM response tests where the electrolyzers are commanded to reduce stack power by 10 kW. In each of the three tests shown in 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 Hz) generates a control signal for the electrolyzer when the frequency exceeds ±0.2 Hz. 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. Both the alkaline and PEM technologies performed similarly in those tests as well.

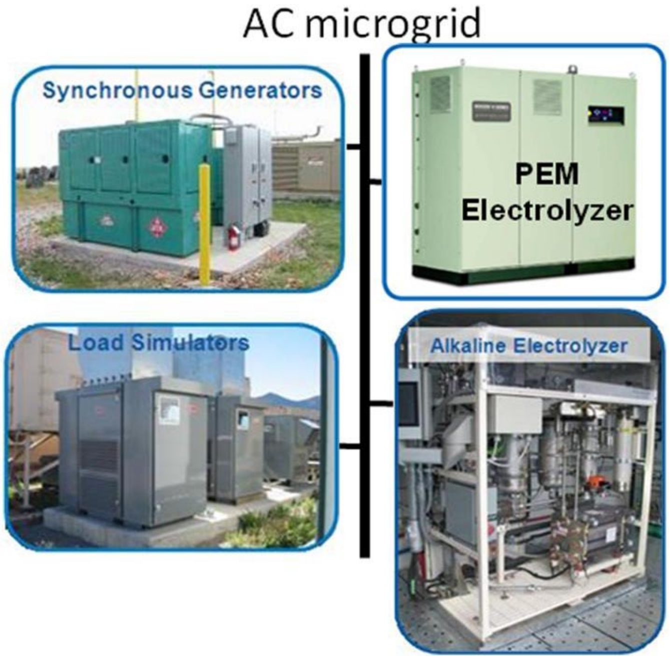

FIGURE 1. Frequency regulation experimental system where electrolyzers are powered by diesel generators on an AC microgrid

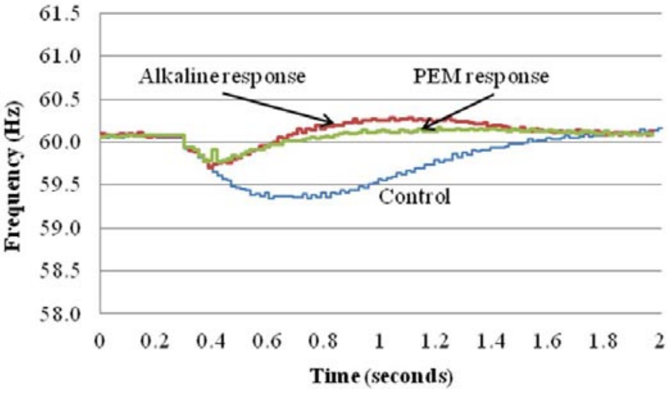

FIGURE 2. Resulting mitigation effects using electrolyzers to stabilize the frequency of an AC microgrid

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.

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.

Conclusions and Future Direction

NREL's newest hydrogen test facility and supporting infrastructure, co-located at the Wind2H2 project, is complete and awaiting the prototype electrolyzer from Giner and their sub-contractor Parker Hannifin. Long-duration testing of three PEM electrolyzer stacks reached roughly 5,500 hours. The preliminary stack decay rate of the variably powered stacks is greater than that of the constant power stack. However, it is possible that the worst-performing stacks were randomly selected at the beginning of the test. 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.

In the coming year the team will complete the following:

- Install, commission and perform 100 hours of initial testing of a DOE-awarded system from Giner/Parker to complete an EE-1 Joule milestone
- Achieve more than 7,500 hours of stack testing using a variable (wind-based) power profile on two (of three) electrolyzer stacks; switch constant power stack with variable profile stack and re-start test
- Substantiate volumetric mass flow measurements by conducting variance and error analysis and integrating a master meter or gravimetric measurement approach