IV.H.3 Renewable Electrolysis Integrated Systems Development and Testing

Benjamin Kroposki
National Renewable Energy Laboratory (NREL)
1617 Cole Blvd.
Golden, CO 80401
Phone: (303) 275-2979; Fax: (303) 275-3835; E-mail: benjamin_kroposki@nrel.gov

DOE Technology Development Manager: Matt Kauffman
Phone: (202) 586-5824; Fax: (202) 586-9811; E-mail: Matthew.Kauffman@ee.doe.gov

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EPC, Inc., Morrison, CO

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

Objectives

This project examines the issues with using renewable energy to produce hydrogen by electrolyzing water.

- Characterize electrolyzer performance under variable input power conditions.
- Design and develop shared power electronics packages and controllers to reduce cost and optimize system performance, and identify opportunities for system cost reduction through breakthroughs in component integration.
- Test, evaluate, and optimize the renewable electrolysis system performance for both
  - Dedicated hydrogen production
  - Electricity/hydrogen cogeneration
- Verify DOE goals of
  - Grid-connected electrolysis cost of $2.85/kilogram (kg) by 2010
  - Renewable hydrogen production cost of $2.75/kg by 2015.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- G. Capital Cost
- H. System Efficiency
- I. Grid Electricity Emissions
- J. Renewable Integration
- K. Electricity Costs

Technical Targets

Table 1. Technical Targets: Water Electrolysis

			1500 kg/day refueling station			Central Renewable
Characteristics		Units	2003 Status	2005 Target	2010 Target	2015 Target
Power Conversion, Cell Stack, Balance of Plant	Cost	$/gge H_2	0.95	0.80	0.39	0.24
	Total Cell Efficiency	%	66	68	76	77
Compression, Storage, Dispensing	Cost	$/gge H_2	0.83	0.77	0.19	0.08
	Efficiency	%	94	94	99	99.5
Electricity	Cost	$/gge H_2	2.57	2.47	1.89	1.32
O&M	Cost	$/gge H_2	0.80	0.71	0.38	0.11
Total	Cost	$/gge H_2	5.15	4.75	2.85	2.75
	Efficiency	%	62	64	75	76

Currently in 2005, hydrogen produced from electrolysis at a centrally located wind farm is approximately $5.70/kg [1]. This cost includes power conversion, cell stack, and balance of plant as well as electricity and operations and maintenance (O&M) costs. The 2015 target for this would be $1.67/kg. These costs and targets do not include compression, storage, and dispensing or delivery. This project conducts research and development on improving the electrolyzer and system efficiency and reducing costs.

Approach

Coordination, Planning, and Stakeholder Development

- Work with DOE and industry to develop roadmap for renewable electrolysis and system development.
- Hold workshops on renewable electrolysis.

Systems Engineering, Modeling, and Analysis

- Develop concept platforms; develop and validate component and system models and system assessment and optimization tools.

System Integration and Component Development

- Work with industry on developing new advanced hardware and control strategies to couple renewable energy systems to electrolyzers.

Characterization, Testing, and Protocol Development

- Install equipment, characterize performance, and develop standard test procedures for renewable electrolysis systems.

Accomplishments

- Held the Electrolysis-Utility Integration Workshop to explore issues associated with providing electricity to support the widespread deployment of electrolysis-based hydrogen production in the United States to meet demand from hydrogen fuel cell vehicles in the 2020 time frame (September 2004).
- Completed draft multi-year research and development (R&D) plan for renewable electrolysis integrated systems development and testing (May 2005).

- Completed report on identification of modeling tools for renewable electrolysis integrated systems (June 2005).
- Conducted initial technical/economic assessment of wind-electrolysis systems for three system designs and locations with Xcel Energy (June 2005).
- Completed modification to power electronics to interface 10-kilowatt (kW) wind turbine to 5-kW electrolyzer (May 2005).
- Completed characterization of proton exchange membrane (PEM) electrolyzer with photovoltaic (PV) and simulated wind input power directly to stack (March 2005).

Future Directions

FY 2006 Plans

- Install and test small alkaline electrolyzer.
- Update power electronics interface to reduce components and costs.
- Complete standard test protocol development for renewable-electrolyzer performance and operation.
- Start modeling and simulation of renewable-electrolyzer performance.

FY 2007–FY 2010 Plans

- Design and test larger integrated systems: First, wind turbines around 100kW with 50kW electrolyzers; then, 1.5-megawatt (MW) wind turbines with larger electrolyzers.

Introduction

Renewable energy sources such as PV, wind, biomass, hydro, and geothermal can provide clean and sustainable electricity for our nation. Today, several of these options are already cost-competitive and are contributing nearly 10% of the U.S. electricity supply. Limiting greater penetration of these renewable energy sources, however, is their intermittent and seasonal energy production. One solution to this problem is to produce hydrogen through the electrolysis of water and use that hydrogen in a fuel cell to produce electricity during times of low power production or peak demand. Currently, this approach is hindered, in part, by the ability to produce hydrogen from these renewable sources in a cost-competitive manner. In addition to the ongoing efforts to reduce the cost of renewable technologies and to lower the capital requirements for electrolyzers, these renewable electrolysis systems must be optimized and tailored to realize the most cost-competitive option for electricity and hydrogen production.

DOE has identified the integration of renewables with electrolysis as one of the barriers for hydrogen production from electrolysis. This subtask examines the performance of renewable electrolysis systems and optimizes both the components (single-power electronics packages and controllers) and system operations that will not only eliminate redundancy, thereby achieving gains in system cost and robustness, but will also allow matching of a renewable power system to electrolyzer power requirements, thereby achieving gains in system efficiency. Success in this area is imperative if DOE is to meet its technical targets for renewable integrated advanced electrolysis technologies. Long-term research in this area is a collaborative effort between NREL and electrolyzer manufacturers. The research integrates testing knowledge from laboratory and field testing of renewable-based electrolyzers into commercially available power packages that meet the DOE cost goals.

Approach

This project seeks to meet the DOE goals for renewable electrolysis by working with DOE and industry to develop and follow a roadmap for renewable electrolysis and system development. This includes holding workshops on renewable electrolysis. To understand basic principles of the renewable electrolysis systems, system engineering, modeling, and analysis is conducted. Research is done to develop concept platforms, develop and to validate component and system models and system assessment and optimization tools.

This project also works with industry on developing new advanced power electronics hardware and control strategies to couple renewable and electrolyzer systems. This can lead to reduced costs and increase system efficiencies. Once these advanced systems are designed and built, this project installs the equipment, characterizes system performance, and develops standard test procedures for the evaluation of renewable elctrolysis systems. Research in FY 2005 focused on completing the building and testing of a power electronics interface package for the proton exchange membrane (PEM) electrolyzer and on installing and characterizing the performance of the PEM electrolyzer.

Results

Coordination, Planning, and Stakeholder Development

The Electrolysis-Utility Integration Workshop, held in September 2004, explored issues associated with providing electricity to support the widespread deployment of electrolysis-based hydrogen production in the United States to meet demand from hydrogen fuel cell vehicles in the 2020 time frame. More than 40 individuals from DOE, the national laboratories, utilities, and industry participated. At the meeting, participants identified key opportunities for understanding the role of hydrogen production via electrolysis for grid efficiency, functionality, reliability, emissions, capacity and demand, utility products, systems integration, and renewable energy utilization. The attendees also identified key barriers including market issues, electricity pricing issues, and electrolysis system costs and operation.

Characterization, Testing, and Protocol Development

For this work, we used a Hogen 40RE electrolyzer from Proton Energy Systems. This electrolyzer is a commercially available production model designed for utility grid connection with the capability of connecting to a photovoltaic (PV) array (RE version only). Direct current (DC) is supplied to a PEM electrolyzer to split water into its two constituent parts, hydrogen and oxygen. In this project, we examined the effect of varying DC input power on the performance of the HOGEN 40RE electrolyzer by running various frequency sine waves through the electrolyzer stack. The results showed that frequency has no effect on hydrogen output (Figure 1).

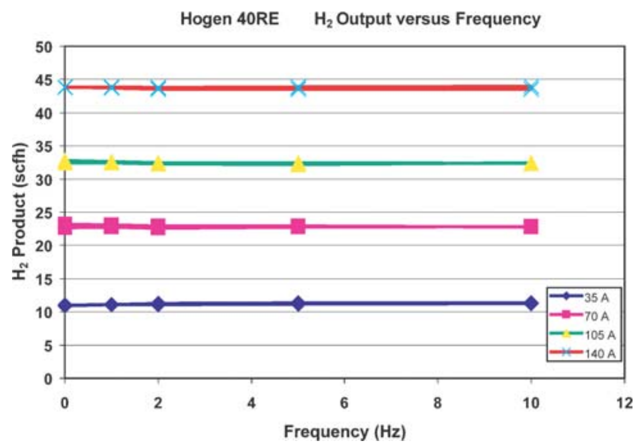

Figure 1. Hydrogen Production Versus Frequency

Using this information, we designed a power electronics interface that used readily available components to interface a wind turbine to the electrolyzer. The electrolyzer used in this work is rated to produce 40 standard cubic feet per hour (scfh) of 200 pound per square inch gauge (psig) dry hydrogen (H_2) gas. Its factory setup is arranged to accept power from either a 3-phase, 208V_{AC} or a 60 - 200 V_{DC} source. In these arrangements, each of the power sources are conditioned via power electronics devices to provide the steady DC energy necessary for PEM stack operation. Because the overriding goal of this project is to eliminate the redundancy of energy conversion devices, these power connection options will be bypassed and PEM stack energy will be provided directly by the PEM-wind power electronics interface. As a result, the stack input voltage and current characteristics are the critical design parameters.

Figure 2 illustrates the voltage and current characteristics of the PEM stack. Note: the maximum allowable PEM stack current is 150 amperes (A), which corresponds to approximately 6.3 kW of power at full capacity.

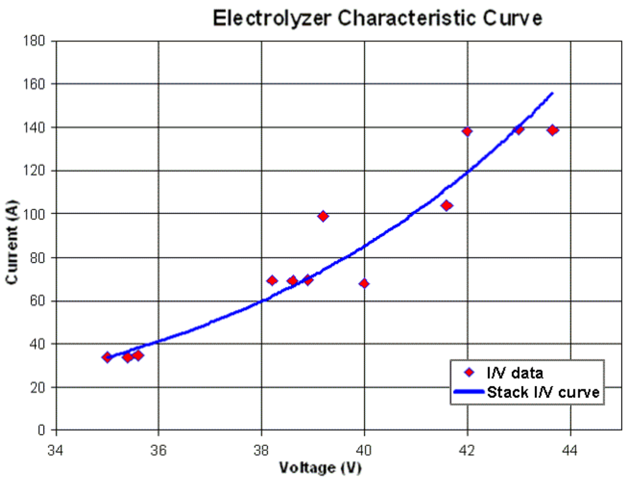

Figure 2. PEM Stack Voltage, Current, and Resistance Relationships

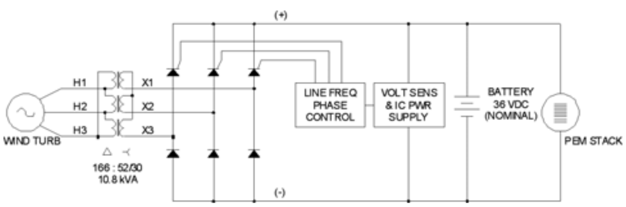

Figure 3. Wind Turbine-PEM Electrolyzer Power Electronic Interface

According to these data, the stack current varies greatly for a relatively small change in voltage. For instance, as shown in Figure 2, a 6-volt (V) change in voltage corresponds to a 110-A change in current. This is exacerbated by the nonlinear resistance response of the stack from low-power to high-power operations. Finally, as determined by previous testing, the PEM stack is fairly resilient to input voltage and current fluctuations. As a result, some relaxing of DC voltage ripple requirements is allowed from the power electronic interface. This accommodates a simplification and corresponding cost reduction for the interface.

The system voltage is controlled using line frequency phase control. As available wind energy is increased, the triggering duty cycle of the silicon-controlled rectifiers is modified to achieve a higher amount of input energy to the stack and battery. Currently, we are taking steps to ensure operability and to verify the safe interaction between the battery and the electrolyzer. Figure 3 is a diagram of the power electronics interface used in this research. We have constructed the system and will continue testing through September 2005.

Conclusions

- There are a variety of modeling tools for technical/economic analysis and engineering system simulation for renewable electrolysis systems. NREL investigators are evaluating several of these models for use in this project.
- Our analysis of the performance of PEM electrolyzers showed that they are capable of handling the varying inputs from renewable power systems. The analysis also revealed that, in short-term tests, the frequency of modulation of the input power source has little effect on the PEM electrolyzer's hydrogen production.
- Power electronics can be developed that reduce the redundancy and costs in interfacing current renewable energy systems to electrolyzers.

FY 2005 Publications/Presentations

1. Kroposki, B. (2005). "Renewable Electrolysis Integrated System Development and Testing," presented at 2005 DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program Review, Washington, DC, May.
2. Kroposki, B., Levene, J., Harrison, K., and Mann, M. (2005). "*Model Identification Report for Renewable Electrolysis Internal Report,"*. NREL internal report, Golden, CO, June.
3. Harrison, K., and Kroposki, B. (2005). "*Electrolyzer Characterization Report—Proton Energy Systems HOGEN 40RE,"* NREL internal report, Golden, CO, June.

References

1. Levene, J (2005) "*An Economic Analysis of Hydrogen Production from Wind*," WINDPOWER 2005, Denver, CO, NREL/CP-560-38210, May.