II.H.3 Renewable Electrolysis Integrated System 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:
Roxanne Garland
Phone: (202) 586-7260; Fax: (202) 586-9811
E-mail: Roxanne.Garland@ee.doe.gov

Subcontractors:
Northern Power Systems, Waitsfield, VT

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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.
- 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 work is being conducted under DOE's Task 3 – Advanced Electrolysis Technologies to Reduce Cost and Increase Efficiency in the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan (section 3.1.4.2.2). NREL's work addresses the following technical barriers:

(G) Capital Cost
(H) System Efficiency
(J) Renewable Integration

Technical Targets

In 2005, hydrogen produced from electrolysis at a centrally located wind farm was approximately $5.70 [1]. This cost includes power conversion, cell stack, and balance-of-plant as well as electricity and operations and maintenance (O&M) costs. This project focuses on improving the electrolyzer and system efficiency and reducing costs by integrating the power electronics between wind turbines and electrolyzers. The cost targets are: Grid-connected electrolysis cost of $2.85/kilogram (kg) by 2010 and renewable hydrogen production cost of $2.75/kg by 2015.

Accomplishments

- Helped coordinate the first and subsequent Hydrogen Utility Group (HUG) meetings.
- Developed informal renewable electrolysis collaborative with Xcel Energy, Ft. Collins Utilities, Basin Electric, University of Minnesota, and University of North Dakota.
- Demonstrated that distributed wind electrolysis can produce hydrogen for $4.03/kg based on Xcel wind electricity costs and high capacity factors.
- Developed Simulink and PSCAD models for 10 kW wind turbine, advanced power electronics interface, and 5 kW PEM electrolyzer.
- Developed hardware for and implemented a wind turbine simulator that can reproduce wind turbine power output up to 200 kW.
- Designed, built, and tested advanced power electronics interface between a 10 kW variable speed wind turbine and a 5 kW proton exchange membrane (PEM) electrolyzer.
- Assisted in designing the Wind2H2 Project with Xcel Energy. This project consists of one 100 kW wind turbine, two 5 kW PEM electrolyzers, one 50 kW alkaline electrolyzer, hydrogen compression, storage, and a 60 kW hydrogen internal combustion engine.

Introduction

Renewable energy sources such as photovoltaic (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 inherent variability and seasonal energy production. One solution to this problem is to produce hydrogen through the electrolysis of water and use the hydrogen in a fuel cell or internal combustion engine to produce electricity during times of low power production, peak demand or as a transportation fuel. Currently, this approach is hindered, in part, by the difficulty of producing 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. This approach 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, electrolyzer manufacturers and universities. The research integrates testing knowledge from the laboratory and field testing of renewable-based electrolyzers into commercially available power electronics 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 test and validate the performance of electrolyzers and improve integration with renewable technologies. This project also works with the utility industry on the integration of electrolysis into electric power systems. To understand basic principles of the renewable electrolysis systems we conduct system engineering, modeling, and analysis. Researchers develop concept platforms, develop and validate component and system models, and design system assessment and optimization tools.

Project researchers also work with industry to develop new advanced power electronics hardware and control strategies to more closely couple renewable and electrolyzer systems. This can lead to reduced costs and increase system efficiencies. Once these advanced systems are designed and built, we install the equipment, characterize system performance, and develop standard test procedures for evaluating renewable electrolysis systems. Research in FY 2005 focused on building and testing a power electronics interface package for the PEM electrolyzer and on installing and characterizing the performance of the PEM electrolyzer.

Results

Coordination, Planning, and Stakeholder Development

DOE, NREL, the Electric Power Research Institute (EPRI), and the National Hydrogen Association (NHA) supported the formation of the Hydrogen Utility Group (HUG). The Founder's Chartering Session of the HUG was held in Detroit, Michigan on October 6 and 7, 2005. The group developed a charter for the formation of a utility interest group and focused on how utilities may best contribute to the development of the future hydrogen-electric economy. The group determined that the founding utilities (Arizona Public Service, DTE Energy, Entergy, Ft. Collins Utilities, Nebraska Public Power District, New York Power Authority, Sacramento Municipal Utility District, Southern Company, and Xcel Energy) would comprise the HUG Steering Committee for the first year. The next meeting was held on December 7 and 8, 2005 at the New York Power Authority offices in White Plains, New York. This meeting served as the official kick-off of the HUG group, and introduced the HUG to new utilities outside the steering committee. HUG also participated in a Senate caucus with auto industry members in February 2006, co-sponsored a session at the 2006 NHA meeting, and a HUG meeting on electrolysis in May 2006.

Also as part of this work, an informal collaborative on renewable electrolysis was formed between DOE/NREL, Xcel Energy, Basin Electric, Ft. Collins Utilities, University of Minnesota, and the University of North Dakota. This collaborative shared information on the development, testing, and safety aspects of renewable-hydrogen systems.

Systems Engineering, Modeling, and Analysis

We conducted a techno-economic analysis of the central production of hydrogen from wind. This technology involves hydrogen production at a wind site with hydrogen delivered to the point of use. The results of this study are that hydrogen can be produced at the wind site for prices ranging from $5.55/kg in the near term to $2.27/kg in the long term (Figure 1). A research opportunity in this scenario is the elimination of redundant controls and power electronics in a combined turbine/electrolysis system. We completed

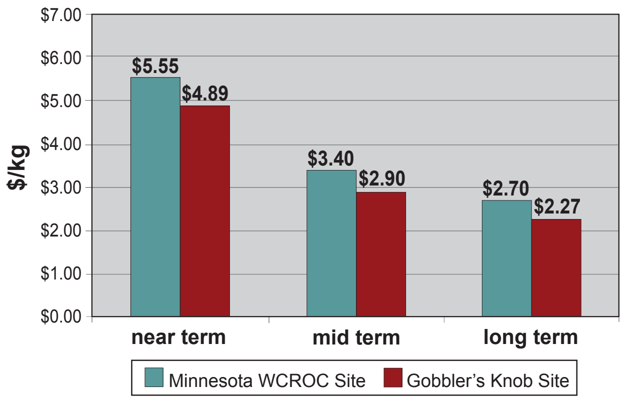

FIGURE 1. Central Electrolysis – Cost of Hydrogen at Two Wind Sites

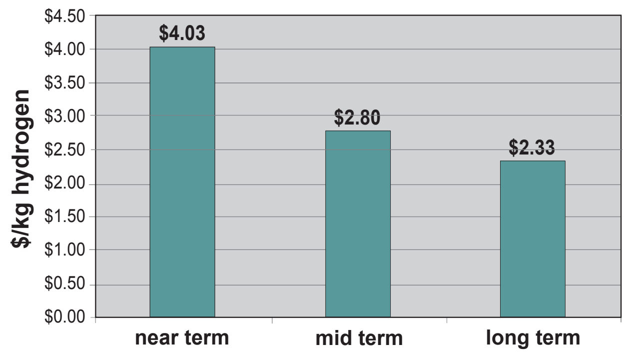

FIGURE 2. Distributed Electrolysis – Cost of Hydrogen at Forecourt

a second analysis in which wind power was used in a distributed fashion for hydrogen production. The wind farm provides a signal to a remotely located electrolyzer, which allows the electrolyzer to run only when the wind is blowing. An advantage of this scenario is that signals from many different wind farms could be used, which would increase the capacity factor and thus decrease the cost of the hydrogen production system. The results of this second study are that hydrogen can be produced at the point of use for prices ranging from $4.03/kg in the near term to $2.33/kg in the long term (Figure 2). This novel approach results in low production costs and could minimize delivery costs if the electrolyzer was located at the filling station.

NREL also developed PSCAD and Simulink models for a 10 kW wind turbine, an advanced power electronics interface, and a 5 kW PEM electrolyzer. Figure 3 shows the model for the system in PSCAD. The PSCAD model is used to size the silicon-controlled rectifier switches and output filter. The Simulink model is used to develop the overall control algorithm for the system.

System Integration and Component Development

NREL developed hardware for and implemented a wind turbine simulator that can reproduce wind turbine power output up to 200 kW. This was necessary because of the lack of consistent wind during the summer months at the test facility. The simulator is built around a three-phase AC source with an impedance that is matched to the impedance of the wind turbine generator.

We also worked on developing the specifications for a power electronics interface between the Bergey 10 kW wind turbine and Proton Energy Systems HOGEN® 40RE electrolyzer. Testing in fourth quarter of FY 2005 showed that a standard off-the-shelf wind-powered battery charge controller makes an ineffective hydrogen producing device. To optimize wind-hydrogen production, a power electronics interface that can operate in harmony with the unique characteristics of the PEM stack should be developed. If done correctly, this system could operate independently and not require a DC bus voltage dominating battery. Independent control power could be supplied by a small power supply that turns on when sufficient wind energy is present. Simple relay logic with properly selected time delays could accomplish this task. This would continue to facilitate smooth startup and shutdown of the power electronics interface, and would eliminate the need for the battery and its associated semi-complex charging and maintenance requirements. DC voltage grooming could be achieved by a less expensive filter capacitor. The new power electronics interface has been designed and modeled. Testing will be completed in the fourth quarter of FY 2006.

Characterization Testing and Protocol Development

The 5 kW PEM electrolyzer from Proton Energy Systems was characterized for performance with renewable energy sources. This electrolyzer is a commercially available production model designed for utility grid connection with the capability of connecting to a PV array (renewable energy version only). DC is supplied to a PEM electrolyzer to split water into its two constituent parts, hydrogen and oxygen. This year we examined the effect of varying DC input power on the performance of the electrolyzer by running the electrolyzer stack directly coupled to a PV array, wind turbine and external programmable power supplies. Initial testing with the off-the-shelf power electronics interface between the wind turbine and the electrolyzer showed that it was not optimized for use with the wind turbine. A new power electronics interface was designed, modeled, built, and will be tested in the fourth quarter of FY 2006.

A Cooperative Research and Development Agreement (CRADA) was signed between NREL and Xcel Energy on the Wind2H2 Project in January 2006. This multi-year collaborative project is designed to gain knowledge and insight about producing hydrogen from

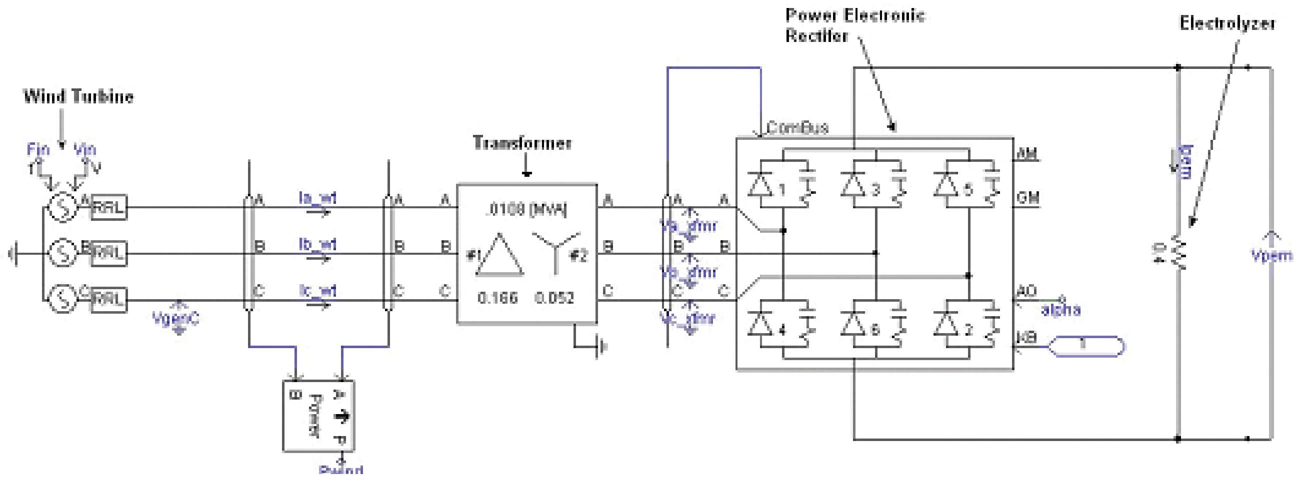

FIGURE 3. PSCAD Model of Wind Turbine, Transformer, Rectifier, and Electrolyzer

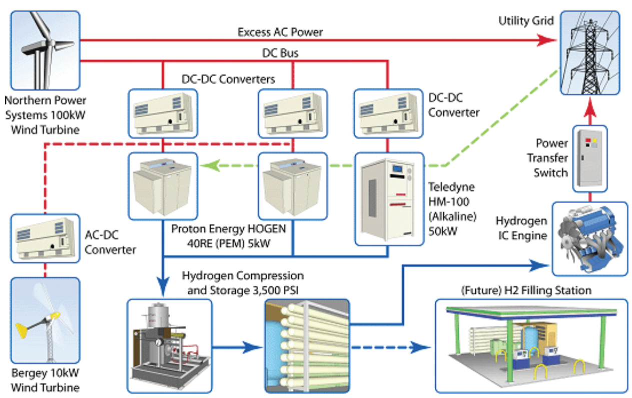

FIGURE 4. Xcel-NREL Wind2H2 Project Diagram

electricity for use as a vehicle fuel and as “stored wind.” Figure 4 shows a diagram of the proposed system. In this project we will analyze hydrogen production directly from wind as well as from the electric grid via electrolysis. In addition, we will look at compressing and storing the hydrogen and then using it to put electricity back into the grid through a hydrogen internal combustion engine.

Several unique features of the planned wind-electrolysis system will be analyzed including:

- Direct DC feed from the wind turbine to the electrolyzer to enable gains in system efficiency and realize capital cost savings in future control system integration.
- Concurrent AC feed to the electrolyzer to provide a comparison to direct DC feed performance.
- Comparison of alkaline and PEM electrolyzer technologies.
- Commercial grade higher pressure electrolyzer and low/medium pressure range compression and storage for reduced operability risk.
- Use of a hydrogen engine/generator for peak power demand reduction.
- System transportability for redeployment for Xcel Energy value after R&D.

Major equipment items for the Wind2H2 Project including the 50 kW Teledyne alkaline electrolyzer, 5 kW PEM electrolyzer, compressor, storage tanks, and a 60 kW hydrogen internal combustion engine have been ordered and the system is expected to be operational with the AC grid feed (green line) by October 2006. The DC converters between the 100 kW wind turbine and electrolyzers will be constructed in FY 2007.

Conclusions and Future Directions

- Formation of the HUG has started momentum within the utility industry to examine the use of hydrogen.
- Simulation models developed for the wind turbine, electrolyzer, and power electronic interface have proven valuable in the design and optimization of the power electronics interface.
- Techno-economic analysis has shown that wind-electrolysis has the potential to meet the DOE cost targets in the mid- to long-term.
- 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. Work next year will examine alkaline electrolyzers for effects due to variable input power.
- Power electronics will be developed that reduce the redundancy and costs in interfacing current renewable energy systems to electrolyzers. The

power electronics can also be optimized to allow for the maximum amount of power to be sent to the electrolyzer.

- The Wind2H2 Project will develop a collaborative effort between DOE/NREL and industry partners to examine several issues with integrating renewables and electrolyzers on a mid-size scale. Once completed, plans are to scale the demonstration up to the utility-scale (1 MW) level.

FY 2006 Publications/Presentations

1. J. Levene, B. Kroposki, and G. Sverdrup, "*Wind Energy and Production of Hydrogen and Electricity - Opportunities for Renewable Hydrogen*," NREL Report No. CP-560-39534, 2006.

2. K. Harrison, B. Kroposki, and C. Pink *"Characterizing Electrolyzer Performance for use in Wind Energy Applications"*, WINDPOWER 2006, June 2006.

3. B. Kroposki, "*Renewable Electrolysis Integrated System Development and Testing*", DOE HFC&IT Program Review, May 2006.

4. B. Kroposki, J. Levene, K. Harrison, P. Sen, and F. Novachek, "*Electrolysis: Opportunities for Electric Power Utilities in a Hydrogen Economy*" submitted to the North American Power Symposium, September 2006.

References

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