Proton Exchange Membrane Fuel Cell Power System on Ethanol

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Subcontractors:
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Aventine Renewable Energy, Inc. (formerly Williams Bio-Energy), Pekin, Illinois

Objectives

Caterpillar, Nuvera Fuel Cells, and Aventine Renewable Energy have teamed up to develop and demonstrate a 10-15 kWe ethanol-fueled proton exchange membrane (PEM) fuel cell system. The primary objectives of this project are to:

- Demonstrate performance, durability & reliability via field demonstration
- Remove technical uncertainties
- Understand correlation and reduce gaps between stationary and transportation applications
- Collect data to evaluate economic feasibility
- Assess commercial viability of the total system

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- E. Durability
- G. Power Electronics
- K. Emissions and Environmental Issues

Approach

- Nuvera will assess and modify advanced fuel cell power module (processor and fuel cell stack) designs that are now under development in separate projects to develop the power module for this project.
- Caterpillar will design the power converter module and will integrate the system.
- Aventine will supply the ethanol and the host site to test the unit and conduct endurance testing.

Accomplishments

- The fuel cell power module accumulated 200 hours at various fuel cell power levels, while the fuel processor had been operating in idle mode for more than 600 hours.

- The power converter (laboratory direct current [DC] power supply to alternating current [AC] into utility grid) has operated in the range 8 to 16 kW for over 300 hours.
- The Aventine site in Pekin, Illinois has been prepared for system installation.
- The data acquisition system has been run with real-time field data.
- The web site for external reporting of field operation is 90% complete.
- The safety review of operations is complete, and all permits have been approved.
- The response plan for field operations and supportability is close to completion.

Future Directions

- Operate the power module at rated power (>5 kWe) for 250 hours with full automation (Nuvera in 3Q, 2003).
- Following above, operate integrated power module and power converter with full automation and complete acceptance testing (Nuvera and Caterpillar in 3Q, 2003).
- Ship the functional unit to the test site and start the endurance-testing phase (Nuvera, Caterpillar, and Aventine starting in 4Q, 2003).

Introduction

Nuvera will design, build, test, and deliver a 10-15 kWe DC fuel cell power module that will be specifically designed for stationary power operation using ethanol as a primary fuel. Two PEM fuel cell stacks in parallel will produce 250 A and 60 volts at rated power. The power module will consist of a fuel processor and CO clean-up, fuel cell, air, fuel, water, and anode exhaust gas management subsystems. A state-of-the-art control system will interface with the power system controller and will control the fuel cell power module under start-up, steady state, transient, and shutdown operation. Temperature, pressure, and flow sensors will be incorporated in the power module to monitor and control the key system variables under these various operating modes. The power module subsystem will be integrated with the power converter, tested at Nuvera and subsequently delivered to the Aventine site in Pekin, Illinois.

Approach

Nuvera plans to modify advanced fuel cell power module designs that are now under development in separate projects for use in this project. They will start with a power module that is a multi-fuel design for transportation (light-duty vehicle) applications. The purpose of using this design baseline is twofold.

- By using an existing design, Nuvera will avoid much of the design effort and technical risk associated with a completely new power module design.
- By using a transportation-based design, this demonstration will simultaneously illustrate that renewable ethanol can be used in fuel cell power systems applied to stationary power generation as well as transportation.

Caterpillar will design, build, test and deliver a power converter module that converts the DC output of the power module into AC power. Caterpillar will also provide system level control to ensure all major subsystems work in harmony and provide constant power to the industrial load on site. The fuel cell system will deliver power to the grid at the Aventine ethanol production site in Pekin, Illinois.

The power converter design will rely on Caterpillar's experience with state-of-the-art solid-state power converters that employ switches, inverters and pulse width modulation to shape a sinusoidal voltage and current in time with the existing power source on site.

Caterpillar also aims to demonstrate technology to the greatest extent possible that can meet the dual requirements of the transportation industry and the stationary electric power generation industry. In addition to low levels of emissions, we intend to demonstrate high efficiency, durability, and reliability. These technical objectives will enable us to calculate the cost of electricity ($/kW-hr) for transportation and stationary power applications.

Aventine will host the industrial site for this demonstration. Aventine provided site electrical load

Figure 1. Power Converter at Caterpillar Technical Center

and ethanol fuel requirements. They have prepared the site to ensure the fuel cell system links to their power network, supply of ethanol fuel and other utilities. During the demonstration, Aventine's personnel will monitor and service (general maintenance and where feasible, troubleshoot and repair) equipment and permit visitors to witness the demonstration in comfort and safety.

Results

The cooperative team has achieved several milestones to date since project inception and commencement. The results are highlighted below for the two major subsystems.

Power Converter. The power converter has been built and tested. Figure 1 shows the unit at Caterpillar's Technical Center, and Table I summarizes the test data to date.

Power Module. The power module has been built and continues to be tested. Figure 2 shows the unit at Nuvera Technical Center, and Table II summarizes the test data to date.

Industrial Demonstration Site. Aventine has completed the site preparation at their plant in Pekin, Illinois, where the integrated power system will be tested for endurance. Figure 3 shows the fully prepared site ready for system installation.

Table I. Summary of the Power Converter Laboratory Test Results

Description	Physical Units	Numerical Value	Comments
Maximum DC input power (230 A, 70 V)	kW	16	
Maximum AC output power	kW	13.5	Into local utility grid
Energy efficiency at rated power (15 kW)	%	90	
Total Harmonic Distortion at rated power (15 kW)	%	2	Meets UL 1741 & IEEE 519
Total laboratory time operating above 4 kW	hours	85	Design & Packaging are complete, 2nd unit under construction as spare

Table II. Summary of the Power Module Laboratory Test Data

Criterion	Specification	Status
Power	Idle to 15 kWe	Idle to 11 kWe
Start-up time	60 min	Less than 60 min
Efficiency	>25%	29%
Laboratory Hours	500 hours for Factory Acceptance Testing	145 hours at various power levels
Start-up	Afterburner free	Afterburner free
Controls Automation	Unattended operation	Combination of manual and automated operation

In addition, Nuvera, Aventine, and Caterpillar have worked together to generate data collection and retrieval. Table III summarizes accomplishments related to data collection, data display, and field operation with remote control.

Figure 2. Power Module at Nuvera Test Laboratory

Figure 3. Aventine Industrial Site for 4000-hour Demonstration

Table III. Summary of Data Collection, Data Display, and Remote Control

Utility grid interactive connections are installed at test site.
Ethanol storage and handling is installed at test site.
Data acquisition system running on laboratory data is 90% complete.
Remote monitoring, data backup and Internet viewing is 90% complete.
Visitor parking and observation amenities are installed.
Hazardous operations procedures are complete.

Conclusions/Future Work

A Final Design Review was hosted by and held at Nuvera in Cambridge on June 10, 2003, with DOE and Caterpillar focusing on critical issues and plans for resolution while refining the project plan with milestones, targeting critical test and review dates. The plan identified critical paths and methodologies to follow them in order to stay on track within budget and time. Also reviewed were the power converter and module integration plans and acceptance criteria to allow shipment. A facility tour to witness the on-going factory acceptance testing of the power module was provided by Nuvera.

Nuvera will continue the automation of the controls and factory acceptance testing and prepare for the shakedown integrated testing (power module and power converter). Caterpillar has completed the second (spare) power converter and will test it, while fine-tuning the first one and also preparing it for integration. Aventine will finalize and fine-tune all installed equipment to date on site in preparation for the endurance testing.

The team expects to commence field demonstration of possibly the nation's first ethanol-powered PEM fuel cell unit in 4Q, 2003.

FY 2003 Publications/Presentations

1. Midwest Regional Hydrogen Infrastructure Forum, 10 October 2002, Chicago, Illinois

2. Renewable Fuels Association Booth, Fuel Cell Seminar, 18 to 21 November 2002, Palm Springs, California

3. Illinois Coalition Meeting, 17 April 2003, Des Plaines, Illinois

4. DOE Merit Review, 21 May 2003, Berkeley, California