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INTEGRATED RENEWABLE HYDROGEN UTILITY SYSTEM

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Abstract

This paper describes the progress of Proton Energy Systems, Inc. (Proton), as of May 31, 1999, on the implementation and analysis of an Integrated Renewable Hydrogen Utility System currently being deployed under a cooperative agreement with the Department of Energy (DOE).

The goal of this project is to demonstrate a pathway to a sustainable energy system using a Proton Exchange Membrane (PEM) hydrogen generator coupled to a SunDish™ system. The SunDish system generates electricity during daytime operation by concentrating solar energy into a Stirling external heat engine. The hydrogen generator generates and stores hydrogen during daytime operation and feeds the hydrogen into the Stirling engine to generate electricity at night or on cloudy days. The system is being installed at the Ocotillo Power Plant owned by Arizona Public Service in Tempe, Arizona.

Since the inception of the program on April 15, 1998, Proton has worked closely with its' partners, Science Applications International Corporation (SAIC), STM Corporation (STM) and Arizona Public Service (APS) to coordinate the installation of the SunDish and the PEM hydrogen generator. All of the components of the system were installed during the last week of May of this year.

Approach

The approach for the project is to link proven technologies that are on the verge of commercial availability to provide for a system that is capable of providing power for off-grid and/or select on-grid applications requiring 25 kilowatts (kW) of power. The system is comprised of four key elements, which include a PEM hydrogen generator, a carbon steel storage tank, a solar

™ SunDish is a trademark of STM Corporation concentrating dish, and an external heat engine. These units are being integrated to provide a pathway to a completely renewable and sustainable, hydrogen based utility system. Unlike many Phase I programs, Proton has elected to install full scale hardware combined with the typical business plan analysis. This approach allows for a quicker, and more cost effective, commercial penetration strategy. The ability to field working hardware and minimize cost for the phase I activity is made possible through the collaborative efforts of two DOE programs. The SunDish fabrication and installation costs are part of a cooperative agreement with the DOE solar program, and the hydrogen generator and storage system costs are part of a cooperative agreement with the DOE hydrogen program.

PEM Technology

To date, PEM electrolysis technology has shown unquestioned reliability with over 1 million cell hours in critical submarine life support applications for the U.S. and U.K. Navy. In fact, PEM electrolysers have replaced alkaline electrolysers as the preferred method of gas generation aboard new submarines. PEM has also made forays into commercial markets. Over 20,000 lab scale hydrogen generators (125 cc/min – 500 cc/min) have been sold commercially to service the gas chromatography industry, and the market share of PEM has made steady gains on the current alkaline based market share leader.

In application after application, PEM technology is fast becoming the preferred choice amongst electrolysis alternatives. A significant reason for that fact is the dramatic efficiency gains of electrochemical compression versus traditional mechanical compression. Do to the physical characteristics of alkaline electrolysers, gas can only be generated at differential pressures of approximately 30 psi. Higher pressure can be achieved as long as the alkaline system is pressure balanced, but that adds the immediate complexity of high pressure hydrogen as well as oxygen. Therefore, mechanical compression is typically utilized for pressurizing the required hydrogen gas, and these compressors are inherently expensive, unreliable, and require a large amount electricity to operate (Cox 1996). Moreover, there are limitations in the discharge temperature, which means that compression ratios are considerably lower than conventional compressors, and specialized designs are often required to guard against leakage past the pistons. Conversely, the nature of PEM technology allows for the membrane to be used as a method of facilitating electrolysis as well as a method of internal differential pressure generation. The technology has demonstrated differential pressure generation of 3000 psi in historical applications without any means of mechanical compression. Furthermore, the energy increment required to increase the pressure capability of a PEM electrochemical cell is phenomenal. Increasing the pressure output of the cell by one order of magnitude results in a voltage rise of approximately 30 mV per cell due to the Nernst effect. This fact coupled with the dramatic decrease in system maintenance and a reduction in the number of moving parts has helped advance PEM electrolysis into new technologies and markets.

The Hydrogen Generator

The HOGEN (Hydrogen-Oxygen GENerator) produces hydrogen gas at a rate of 300 standard cubic feet per hour (SCFH), at a hydrogen pressure of 150 pounds per square inch (PSI).

Oxygen is generated at ambient pressure and vented. The generator is a fully integrated, automated, weatherized, site-ready package capable of producing gas at a purity of 99.999%. The generator monitors the pressure level of hydrogen gas in the storage tank and automatically refills the tank as required. Due to the nature of PEM technology, gas is produced with only water and trace air gases present. The system is designed to adjust to variable power loads and has rapid on/off capability. Furthermore, because the electrolyte is solid, there are no caustics in the system. The generator is a standard commercial product offered by Proton usually sold into industrial applications such as heat treating and semiconductor fabrication.

The generator installed in Arizona is the standard product described above with an evaporative cooler and water cooled power supply being used to adapt to the high temperature conditions at the installation site. The generator is programmed as a tank filler. It continuously monitors the hydrogen pressure in the storage tank and will go to an idle mode when the tank is at the desired pressure of 150 psi. As the tank is discharged into the Stirling engine, the generator monitors the pressure and turns back on when the pressure reaches 100 psi. The unit operates unattended and has been installed with a remote monitoring package in the control room at the power plant. The software monitors all of the conditions and parameters on the generator and shows any warnings or shutdowns. Proton has trained APS personnel on how to do routine maintenance and basic troubleshooting of the system.

The Hydrogen Storage Tank

The hydrogen storage tank installed in Arizona is a standard product offered by Trinity Industries, Inc. for the storage of gaseous hydrogen at pressures below 250 psi. Dimensionally, the tank is seven feet in diameter and is 26 feet long with a capacity of 6,565 gallons of water volume. The current Department of Transportation guideline concerning the safe handling and storage of hydrogen was consulted to ensure the proper tank was selected for this particular application. In addition to the Department of Transportation guidelines, NFPA 50-A was also used to ensure the safe operation of the storage tank and generator combination at the site.

The capacity of the storage tank is such that at a storage pressure of 150 psi the system can deliver 610 kWh of stored energy to the STM engine for conversion back to electric power when needed. Assuming engine efficiencies of 30-40%, that translates to approximately 8 hours of full power (25 kW) run time. Alternatively, if the hydrogen generator were delivering gas at 250 psi, the equivalent energy storage would be 1175 kWh. Again, assuming engine efficiencies of 30-40%, the full power run time of the engine increases to approximately 19 hours. Our Phase I business plan will show that this low pressure hydrogen storage tank allows for an inexpensive energy storage system in comparison to a battery system with equal energy storage capability. Due to a battery systems high cost, both capital and maintenance, the 10 year life cycle cost of a battery system is almost four times more expensive than the hydrogen system.

Figure 1 – Hydrogen Generator & Tank Installed in Arizona

The SunDish

The SunDish is an economical, viable way to generate renewable electricity using solar energy. The unit is a modular, self-contained power system, approximately 50 feet in diameter and requires no external cooling. The system utilizes concentrated solar power during the day and other gaseous fuels at night or on cloudy days. The SunDish provides up to 25 kW of electricity. The engine has demonstrated performance and fuel efficiency equivalent to a diesel engine, NOx emissions, which are approximately 75% lower than diesel emissions and a noise output significantly less than diesel engines.

Figure 2 –SunDish System Installed in Arizona

The system is a marvelous fusion of advanced technology and incisive simplicity. The engine itself is about the size of a four cylinder automobile engine. The concentrating solar power heats the tubes of the engine's heater head and the enclosed working gas inside these tubes. The gas expands from the heat and is routed to the four double-acting pistons of the STM engine. As the pistons work up and down, they operate a specially designed swash plate that converts the reciprocating motion of the pistons into rotating motions for the driveshaft. The swash plate varies the stroke, which provides a very fast power control with low losses at partial as well as full load. The generator is mounted directly to the STM engine and provides 25 kW of electricity. The cutaway section shown below depicts the basic inner workings of the heat engine. The specifics on the fuel combustion system are proprietary and are not shown in detail.

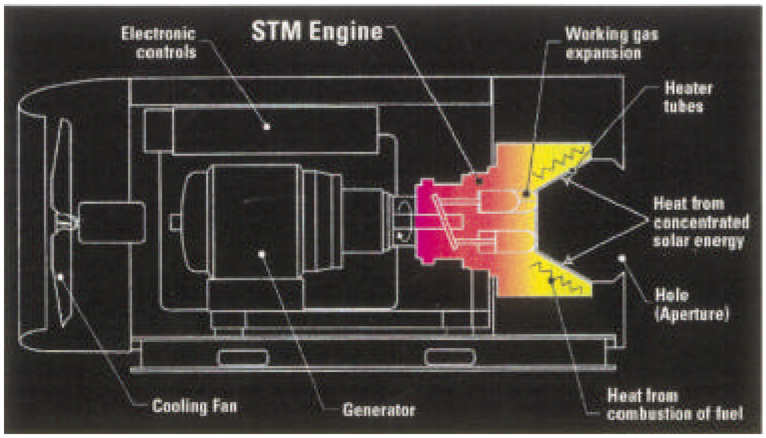

Figure 3 – Cross-Section of Stirling Heat Engine

Project Status

The SunDish had been installed at the Pentagon in Washington D.C. and successfully operated for over six months. It was transferred to the APS facility in Tempe at the beginning of this year and has operated on and off for over four months. The engine delivered with the dish had a burner designed and proven to run on natural gas. In order to run on hydrogen, one part of the burner was changed to a higher temperature alloy to accommodate the higher flame temperature that hydrogen has over natural gas. The modified burner was installed into a different engine and can now run on either hydrogen or natural gas. The engine was successfully tested and was swapped out with the engine on the SunDish system on May 24, 1999.

The hydrogen generator was installed at the APS site on May 24, 1999 and began to fill the storage tank with hydrogen that same day. The unit is designed so that installation and startup can be accomplished in less than four hours.

The integration of all of the pieces of equipment was originally scheduled to be completed by the end August of 1998. Contract issues on the SunDish program coupled with a longer than planned test period at the Pentagon in Washington, D.C. delayed the installation of the dish by six months. In addition, the SunDish contract specifies that their system must complete a 50 hour hands off test before the dish can be integrated with the generator and allowed to burn the hydrogen from the storage tank. On May 26, 1999 a test readiness and safety review meeting was held at the APS facility. The system was deemed safe to run on hydrogen pending the completion of the previously mentioned test. It is anticipated that the system will be fully operational during the month of June. In the meantime, the hydrogen generator will be exercised by continuous fill and drain cycles on the hydrogen storage tank.

In addition to the hardware portion of the program, a business plan that describes the market outlook and projections for commercialization of this activity is being developed. Crucial to that plan is the performance data of the fully integrated system as well as the individual components. The business plan will be submitted by the end of the 1999 fiscal year.

Conclusions

Over two billion people around the world lack electric power (Ogden 1996). In some countries like China and Africa over 50% of the populations are without this critical utility. Proton has established a framework of proven technologies that can provide electricity to these regions in a technically simple system, and at a price that the program intends to prove is reasonable.

This integrated utility system offers a unique flexibility based on its energy storage capability and built in energy conversion device. Like most solar systems, energy is produced continuously at the maximum output condition. When demand drops off, a solar system typically has nowhere to put the excess electric capacity. With the hydrogen generator added to the system, excess energy can be diverted to the generator to increase production of hydrogen. Similarly, when clouds hamper full output of the solar system, hydrogen can be used to augment the output to bring the system to full capacity. In essence, the generator acts as a load-leveling device for continuous power generation. Furthermore, having the Stirling heat engine on the dish allows for a “free” energy conversion device for use as required.

While the delays on the SunDish program have caused a substantial slip in the schedule. Proton has been able to absorb the delay with no additional cost to the program. In addition, the tangible benefits of having a full scale, operating, proof of concept system installed at a utility has allowed for realization of many of the “real world” issues that arise on installations that are not always evident in the laboratory.

Plans for Future Work

Proton, in partnership with SAIC, STM and APS proposes to leverage the Phase I activity to ready the integrated system for commercialization. This will include several different tasks to be managed and implemented.

The first task is to take the system characterization data from the Phase I testing and understand the specific requirements for the hydrogen generation and storage system. Cost reduction, pressure capability increase, and system enhancement activities will follow this data analysis. While the industrial gas products produced by Proton do not require pressures much higher than 150 psi, greater storage efficiency can be achieved by increasing generation pressures to 400 psi and possible higher. This pressure increase must be balanced with the possible increased costs of storage and increased issues of hydrogen embrittlement. The outcome of this task would be an appropriately sized generator and storage system with an achievable production cost.

The second task is to do some design modifications to the SunDish system. Currently, the dish has been designed to operate attached to an electric grid for control and tracking. SAIC and STM have completed preliminary designs to have the dish run in a totally off-grid mode. Completing this activity and field testing the system are paramount to commercializing the entire utility system.

The third task planned would be to use the APS installation to implement as many of these improvements as are practicable, and establish a brand new installation to showcase the next step toward commercialization. This new system would most likely be with an additional utility partner, several of which are discussing the opportunity at this time.

In addition, Proton is looking to stratify the commercial architecture of the utility system to broaden the potential market opportunity. It is understood that different types of energy input and different fuel conversion devices may be more economical in certain applications. Proton proposes to study the overall system architecture to enable alternate power sources and energy conversion devices. These may include alternate inputs such as photovoltaics, wind or hydroelectric and other outputs such as fuel cells or other heat engines. Proton would do preliminary design work on these concepts including cycle efficiency estimates and limited testing.

References

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Listing of Figures