A SOLAR POWERED HYDROGEN GENERATION AND FILLING STATION

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ABSTRACT

A hydrogen filling station has been installed in Southern Nevada to demonstrate how renewable energy can be used to generate fuel for transportation. The hydrogen is generated by a Proton Exchange Membrane (PEM) electrolyzer, and stored on site for use in hydrogen fueled vehicles converted as a part of this project. Power for the equipment is provided by a solar photovoltaic (PV) array. A data acquisition system was installed at the station to monitor the performance of the equipment and weather conditions. Based on the hydrogen system's performance and solar radiation data for Las Vegas, this station has the capability to produce over 350 kg of hydrogen per year purely from solar energy.

1. INTRODUCTION

Hydrogen has the potential to be an important fuel in the future because of its ability to be produced, stored and used at one location, for a variety of applications where fossil fuels are currently used. Producing hydrogen from electrolysis has been a significantly researched area because it allows for the use of renewable energy as the source of electricity (1, 2). In particular, several solar photovoltaic (PV) hydrogen systems have been designed and modeled to show how they might operate in different conditions and under different loads (3, 4). Operational stations include stand alone and grid tied systems, designed for various applications (5, 6). Stations specifically designed for vehicle use, have been modeled and installed (7, 8). From this research, it is noted that solar intensity, ambient temperature, and the current costs of other energy sources have major effects on the performance and economic viability of solar PV hydrogen systems. Additionally, it has been shown that hydrogen production from a grid connected solar PV hydrogen system is a more economic way to become independent from fossil fuels for transportation.

To test the performance of such a system in Las Vegas, the University of Nevada, Las Vegas (UNLV), the Las Vegas Valley Water District (LVVWD), and Proton Energy Systems have installed a solar powered Hydrogen Filling Station (HFS). The objectives of the project were to demonstrate current and future renewable energy based hydrogen generation technology, and to provide the LVVWD with source of hydrogen for three converted hydrogen vehicles. This station was designed to use solar energy to power a Proton Exchange Membrane (PEM) electrolyzer, which would supply hydrogen to those vehicles (9). This paper describes the Phase II configuration of the station, prior to the Phase III installation which started in October 2007.

A data acquisition system (DAS) was installed at the station to allow the UNLV Center for Energy Research to remotely monitor the systems' performance. This DAS system measures the energy use of the HFS equipment, the energy generated by the solar photovoltaic (PV) array, and the meteorological conditions at the site.

Three vehicles provided by LVVWD were converted by UNLV engineering students to run on hydrogen. The first vehicle converted was a battery powered flatbed utility vehicle. A Nuvera 5.5 kW_e Proton Exchange Membrane Fuel Cell was added to the vehicle to make it a hybrid battery/fuel cell vehicle. The second vehicle converted was an all terrain vehicle with an internal combustion engine converted to run on hydrogen (10). A Ford F-150 is currently in the process of being converted.

2. HYDROGEN FILLING STATION EQUIPMENT

The HFS (Figure 1) generates hydrogen from water and electricity using PEM electrolysis. The hydrogen generation system is comprised of both low and high pressure cycles.

Fig. 1: HFS in its Phase II Configuration.

TABLE 1: HFS SPECIFICATIONS

	Hydrogen Pressure (barg/psig)	Stored Hydrogen (kg)	AC Voltage (VAC)
Unit # 1	15/435	0	240
Buffer Tank	15/435	~0.35	N/A
Unit # 2	431/6250	~6.6	480
Unit # 3	70/1015	0	240
Unit # 4	431/6250	~2	480
Chiller	N/A	0	480

Table 1 gives the specifications of the equipment installed at the station. The low pressure PEM electrolyzer (Unit 1) is a Proton Energy Systems FuelGen ® HG-1, capable of producing 2.2 kg of hydrogen per day (11). The electrolyzer provides hydrogen to the dispenser (Unit 2), an Air Products 100E compression, storage, dispensing module. An intermediate buffer tank provides low pressure storage between the electrolyzer and the compressor of the dispenser to allow the systems to run separately. Additionally, an experimental high pressure electrolyzer (Unit 3), which is capable of producing 0.2 kg of hydrogen per day, and an additional compressor (Unit 4) have also been installed. The high pressure electrolyzer is a Proton Energy Systems FuelGen HG-2 PEM electrolyzer, which by generating hydrogen at a higher pressure has the potential to reduce the energy requirements needed to compress the hydrogen for storage. The additional compressor is an Air Products Hydro-Pac Compressor with 2 kg hydrogen storage capacity which is used to compress and store the hydrogen from the experimental electrolyzer. A chiller is required to cool the Hydro-Pac Compressor.

Figure 2 shows a flow diagram of how water and hydrogen flow through the equipment at the HFS.

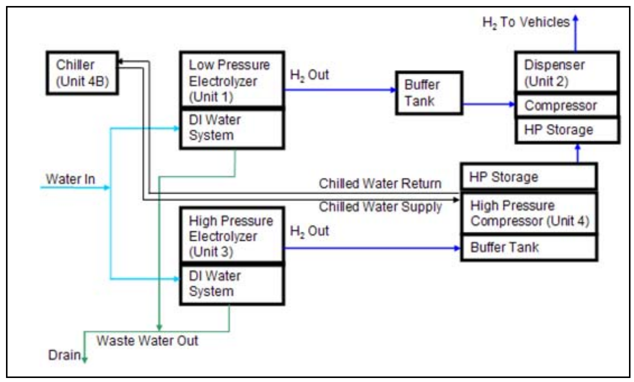

Fig. 2: Water and Hydrogen Flow through the HFS.

3. SOLAR PV ARRAY

The system is powered by a grid connected solar PV array which is made up of four single-axis tilted trackers rated at 4.2 kW DC each, for a total system output of 16.8 kW DC (14 kW AC). The trackers shown in Figure 3 are tilted at 30º, and follow the sun throughout the day, which allows a 27.5 percent increase in power output over fixed photovoltaic panels with the same tilt.

The system is connected to the grid through a net metering agreement with Nevada Power Company. Excess power produced by the solar PV array goes to the grid when the system is not generating hydrogen, and grid power goes into the HFS when the electrolyzer is generating hydrogen on cloudy days or at night.

Fig. 3: Solar PV Array.

The electricity flow through the system is shown in Figure 4. Output from the solar PV array is combined, inverted, and transformed before being provided to the HFS equipment. Power not required from the equipment is sent through the net meter and into the grid.

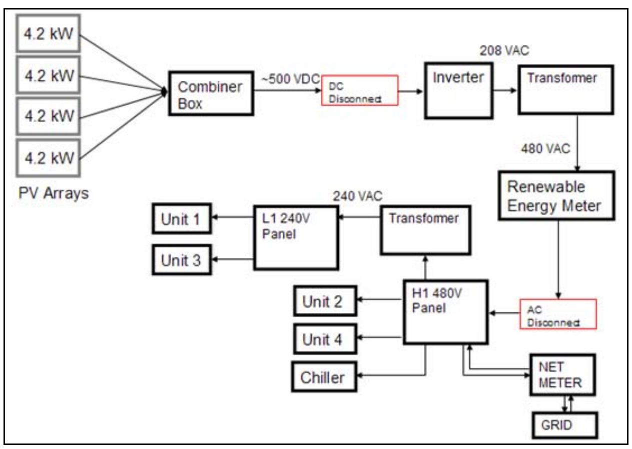

Fig. 4: Electricity Flow through the HFS.

4. DATA ACQUISITION SYSTEM

To monitor weather conditions and equipment performance at the station, the data acquisition system shown in Figure 5 was installed. A Campbell Scientific model CR10X data logger recorded data and was connected to a modem for remote monitoring. A data collection program was created to automatically download and plot data.

Fig. 5: Data Acquisition Equipment.

To measure the efficiency of the solar PV array, a LI-COR LI200X pyranometer was installed directly on the frame of one tracking unit (Figure 6). Therefore, it is able to measure the incoming radiation incident on the panels. Additionally, wind speed, temperature, and relative humidity are recorded. Power output and usage is measured with WattNodes from Continental Control Systems. This allows measurement of not only the power into or out of each component of the system, but also the power flow into and out of the utility grid.

Fig. 6: Placement of the Pyranometer on the Tracker.

5. RESULTS

The HFS operated steadily with negligible maintenance, and a small amount of hydrogen was used from May through September of 2007. Starting in October, the station began the upgrading process to Phase III. Figure 7 shows the net power flow from the station for a sample day when the station was generating hydrogen.

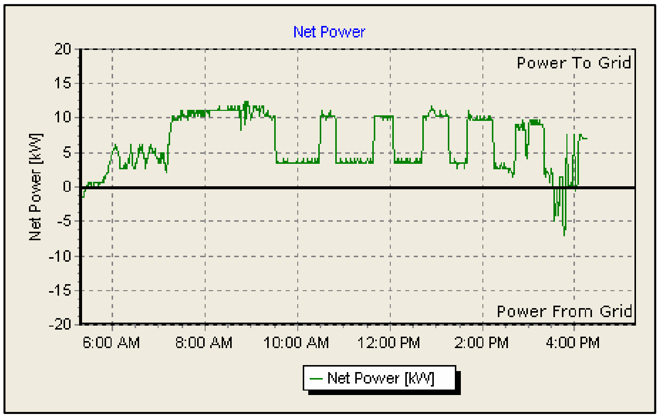

Fig. 7: Net Power to the Grid for a Sample Day.

The power flux of the station for the month of May 2007 is shown in Figure 8. It is noted that during the days with hydrogen generation, for example May 10th and 11th, the solar PV array output matches the power requirement of the HFS equipment. Similar plots exist for the months of June – September. These results show that the solar PV array provides sufficient power output for the current hydrogen demand at the station.

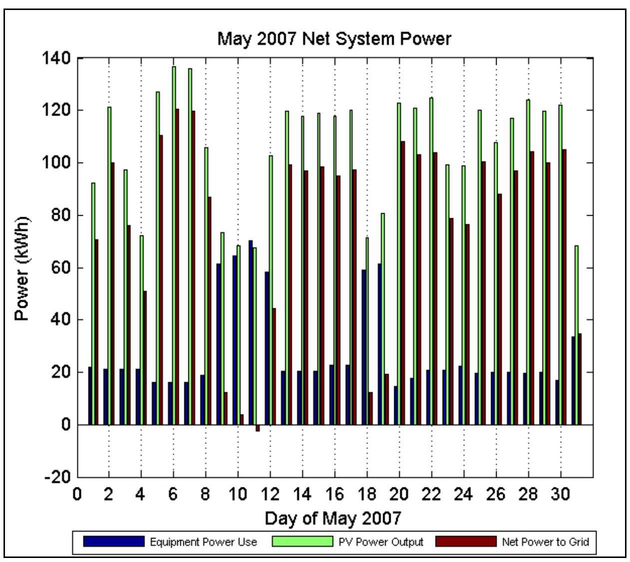

Fig. 4: Power Plot for May 2007.

Since the electrolyzer produces approximately 0.092 kg of hydrogen per hour, and requires about 10 kWh to do so (including compression), the total possible solar hydrogen production could be calculated. To fill the vehicles converted to use this station, it takes approximately 0.4 kg of hydrogen, at 350 barg (5076 psig) per tank. Therefore, the number of possible vehicle fills was found to be just over 500. Over the course of five months, this is enough to fill both the fuel cell vehicle (two tanks) and the IC engine vehicle (one tank) each day. Once vehicle performance testing is completed, the distance each vehicle can travel with each fill will determine if the station is capable of handling the hydrogen demand solely with solar power. The five month performance of the station is shown in Table 2.

TABLE 2: FIVE MONTH HFS PERFORMANCE

PV System Efficiency	9.85 %
Total PV Energy	18.64 MWh
Possible Solar PV Hydrogen Production	~201 kg
Tanks Filled on Vehicle	~500

6. CONCLUSION

In this paper, five months worth of power output and possible hydrogen production were presented. This demonstration project is a model of one way to generate hydrogen from renewable energy. Since the only inputs are water and electricity, the station has the potential to be a stand-alone or grid-tied system. The data collected at the station will give valuable information on the conversion of electricity to hydrogen storage. Additionally, the testing of hydrogen vehicles at the same site will allow for optimal sizing and usability of such a station to be determined.

7. ACKNOWLEDGMENTS

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