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Hydrogen System Engineering (Power Parks)

Quarterly Report

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The Department of Energy's Hydrogen, Fuel Cells, Infrastructure and Technology program's Technology Validation activity is demonstrating hydrogen production systems. In addition to demonstrating the technologies, the projects provide data on the efficiency and economics of hydrogen production. The data collected from a facility are evaluated for comparison to targets established in the multi-year program plan [1]. The objective of this project is to provide consistent analysis of the hydrogen systems being demonstrated. To perform the analysis, we have developed a library of components in the Simulink [2] language that are assembled into system models. While we continued to survey and analyze operation data at DOE demonstrations (APS, DTE, HNEI), we added a new focus last year on the "Hydrogen from the Sun" project located in Brescia, Italy, in support of the International Energy Agency Hydrogen Implementing Agreement Task 18: Integrated Systems.

Analysis of Italian Hydrogen Demonstration

The "Hydrogen from the Sun" project, developed in conjunction with the EU and a private investor, is modeled to provide an economic, thermodynamic, electrical and control system analysis. This project is important to the DOE in supporting IEA Task 18 commitments and meeting Plan targets with further technical data.

The H_2 house is intended to operate independent from the electrical grid during times of emergency. Power for the private residence is managed by the energy management system and supplied by a 5 kW polymer electrolyte membrane fuel cell (PEMFC), a 3000 Ah battery and the photovoltaic (PV) panels. The PV panels supply 11 kW at peak solar incidence; this is connected through a DC-to-DC converter and bus bar system to the 6.7 kW alkaline very-high-pressure electrolyzer, which produces 1 Nm^3/hr of hydrogen at 200 bar. This flowrate of H2 is equivalent to fuel energy rate of approximately 3kW, using the lower heating value (LHV) of H_2. Conditions on the power management system are: the electrolyzer can only operate when the solar power is greater than 6.7 kW and the fuel cell can only operate when hydrogen is present. When there is no hydrogen present the load must be taken by the batteries, the fuel cell or a combination of both to maintain power (Figure 1).

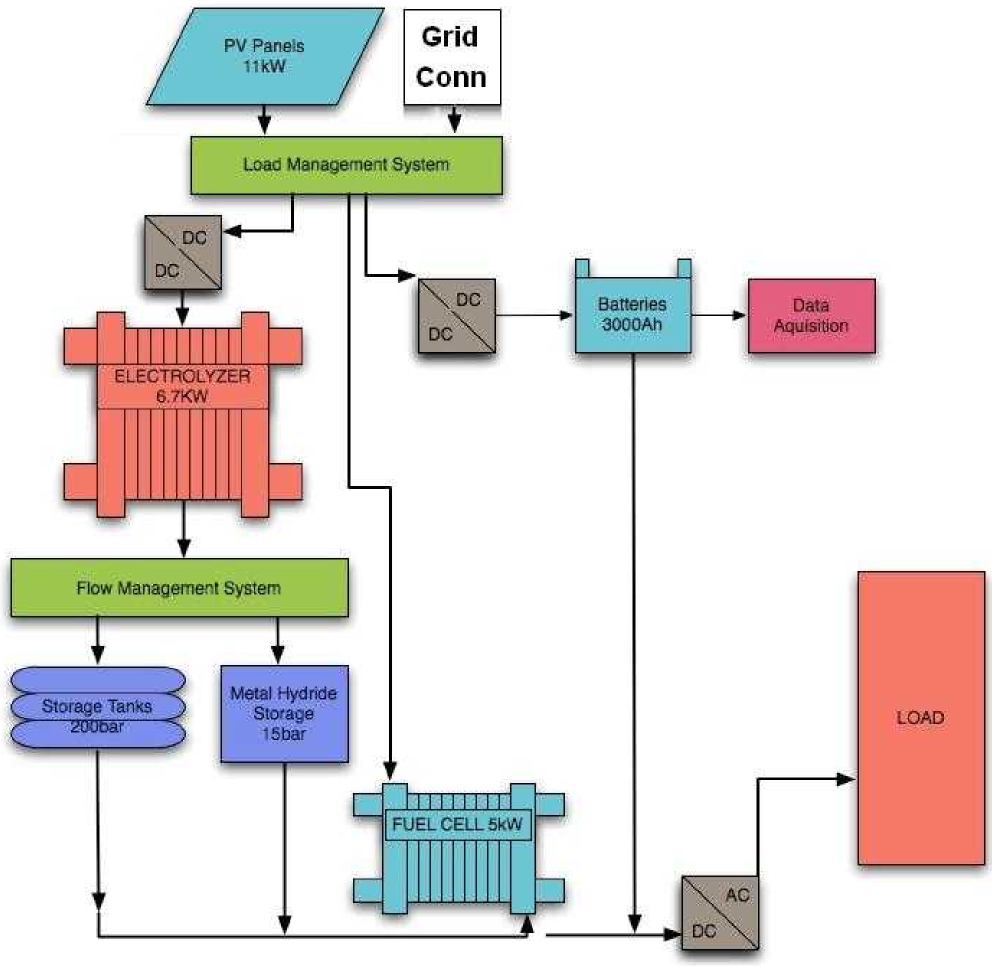

Figure 1: The Italian "Hydrogen from the Sun" schematic

Control Strategy Development

The control strategy for the hydrogen and energy flow within the Italian house system has been developed further using the fuzzy logic control system package within Simulink. The stochastic nature of the solar energy collection is handled by this system that provides continuous control conditions, instead of direct digital control, where boundaries are rigidly fixed. For example, if the PV supplied is just above 6.7 kW for 10 s, it is not practical to pulse the electrolyzer system. Using fuzzy logic, the control system will disconnect the electrolyzer until the PV output is sufficient for operation. The smoother system response is defined through a control surface (Figure 2) and the system response's from Simulink are illustrated (Figure 3,Figure 4).

The conditions to be satisfied include selecting the metal hydride as the primary hydrogen storage and source, and monitoring the state of charge of each hydrogen storage system, drawing information from both the hydrogen being produced by the electrolyzer and the hydrogen being used by the fuel cell (Figure 4). This is interlinked with the energy flow control system, which maintains the house power requirement at a set point, drawing from either the fuel cell/battery combination, or the grid connection (Figure 3). This inter-linkage also creates a safety condition to keep the fuel cell offline if no hydrogen is available from either storage device.

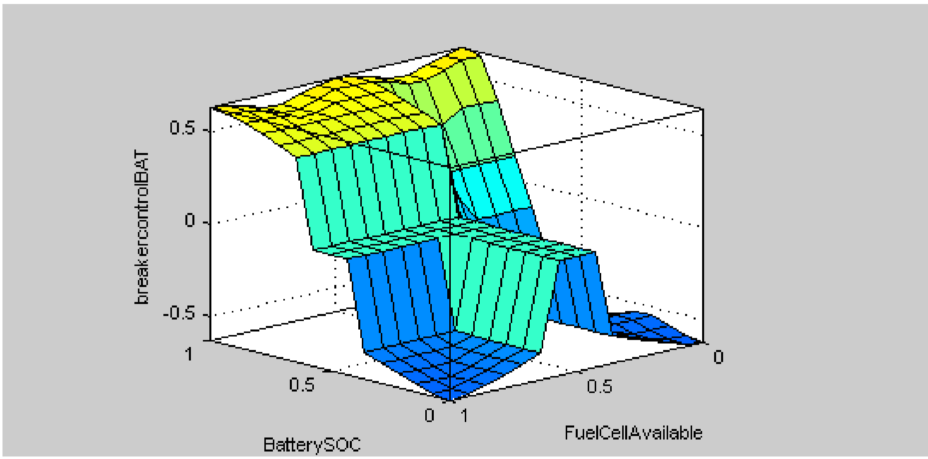

Figure 2: Simulink fuzzy logic control surface developed for the electrical circuit breaker controls, allowing the different power sources to be switch in and out smoothly

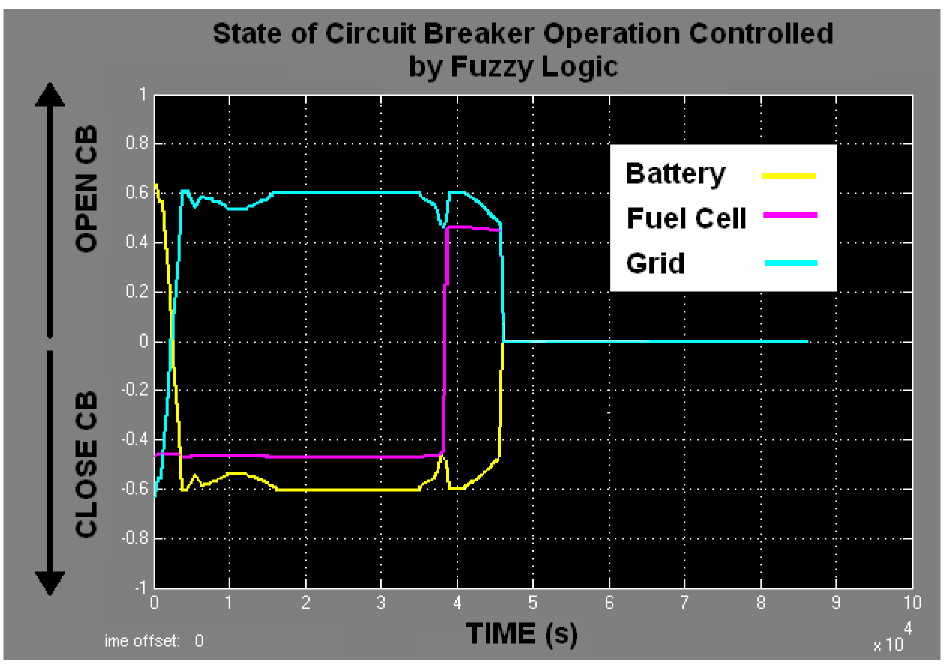

Figure 3: Circuit breaker operation profile for the battery, fuel cell and grid, a positive number indicates the breaker is open, and the signal crossing into the negative on the y-axis indicates the breaker is closed and the power source is by-passed

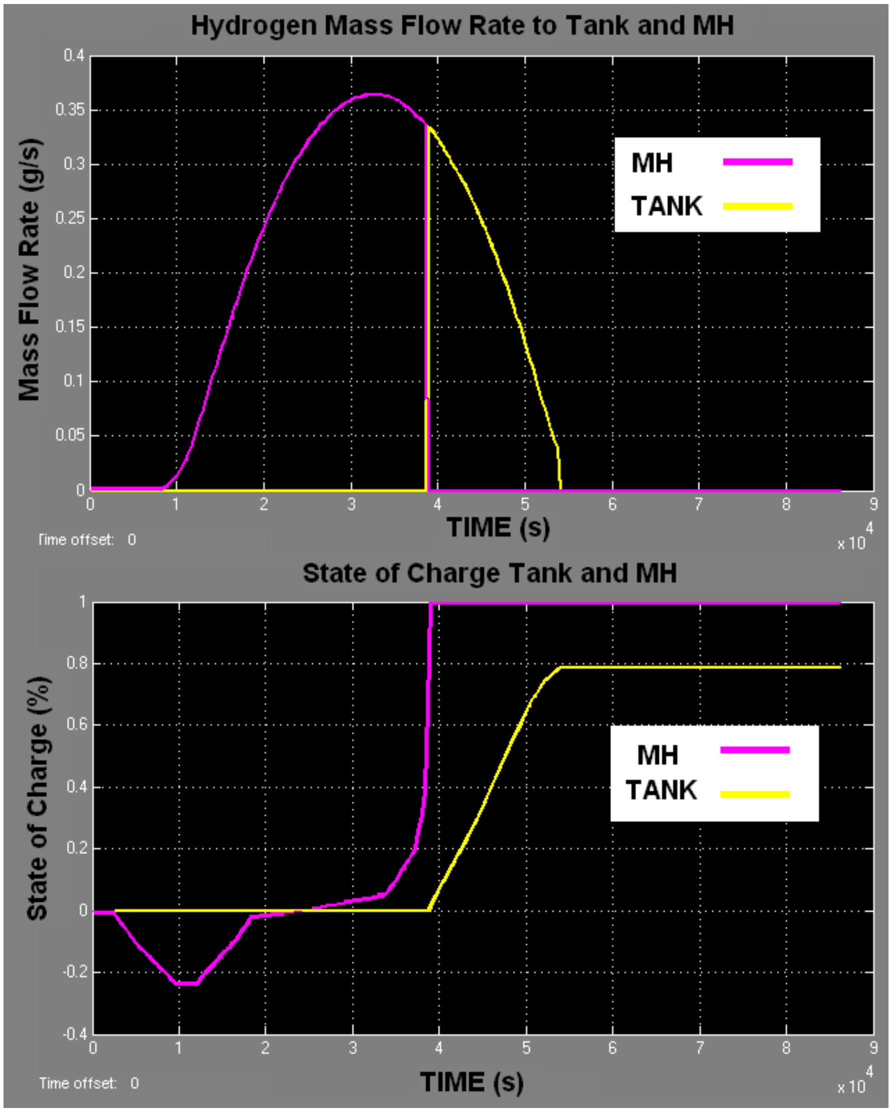

Figure 4: Hydrogen mass flow rate and storage state of charge over the period of a day. The period of electrolyzer operation, shows the switch from when the state of charge of the metal hydride (MH) is 100% to filling the tanks.

Electrical Integration of the System

The load profile of the house must be simulated to represent an average day. A common load profile for a residential load in a warm climate is within the range of 1 to 7 kW [3]. The analysis of this system must take into account the load profile and, as an electric system, was modeled using SimPowerSystems. This also allowed the integration of circuit breaker models for switching in and out the different power sources from the control system. Heat is provided for this house using a biomass system and is therefore independent of heating load.

Preliminary Economic Analysis

The economic analysis of the cost-of-hydrogen produced from the integrated house depends on the capital cost, operation and maintenance cost, and the cost of electricity needed when the fuel cell/battery is not available. The cost of the electricity is based on the cost of residential electricity in Italy [4], not taking into account the profit from selling the PV generated electricity back to the grid, a process to be integrated into the model and also the development in the future. The other economic analysis parameters use the default values consistent with the H2A methodology [5].

The site does not contain a hydrogen refueling station, and therefore the electrolyzer and hydrogen storage tanks were sized to supply the fuel cell load only, and did not account for the metal hydride storage. In further analysis after the Spring 2007 site visit, the cost of H_2 had been reduced to 8 $/kg, when the actual system operational data had been obtained, further research indicated the cost of electricity per kWh double that of the US at 72 €/MWh [4], converted using the exchange rate [6] of 1.42 €/USD to 51 $/MWh or 0.05 $/kWh. This caused the electricity component of the cost of H_2 to increase from approximately 5 $/kg to 6.64 $/kg. This results in a higher cost overall for the hydrogen of 9.36 $/kg (Table 1). The economic analysis of the H_2 production used the steady-operation efficiency for the electrolyzer and assumed that the unit would operate using the off-peak energy rate of 5 cents/kWh in Italy. One of the site owners objectives was to demonstrate effectively the use of a metal hydride storage system, purchased from Treibacher AG. This storage component was not specifically sized as it is an "off-the-shelf" component.
The electrolyzer system efficiency is predicted to be 55%, during full operation to 45% at marginal operation. This change is due to the electrolyzer producing its optimal amount of H_2 at maximum power, and the efficiency reduces when the minimum amount of power is available. The efficiency is defined as the H_2 flowrate times the LHV divided by the power supplied to the electrolyzer, including the stack and balance-of-plant.

	H_2 Cost ($/kg)
Capital	2.37
Electricity Cost	6.64
O & M	0.34
Net H2 Cost	9.36

Table 1: Breakdown of cost of Hydrogen during the simulation

Possible decreases in the cost of hydrogen could be obtained by operating the control system differently to allow the maximum level of hydrogen to be stored. Minimizing grid operation activities would also streamline this. Using this hydrogen system as the main power source for the site would reduce the energy costs significantly, as the electricity costs are the dominant factor in the overall cost of hydrogen. Currently the system is to be used as a back-up power facility, but switching these roles will provide the most economic power supply to the domestic load.

Future Activities

The first measurement data from the site is to be provided at the Autumn IEA Task 18 meeting, which will allow the model to be further validated and the economic analysis to be developed further. The model will be integrated to include the balancing of the solar power with the grid connection and the supply of power back to the electrical distribution grid, which will change the economic parameters.

References

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