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US/UK Hydrogen Technology Scholarship to Sandia National Laboratories

Emma M. Stewart

1 Introduction

This report describes the 1 year US/UK Hydrogen Technology Scholarship undertaken by Emma M. Stewart, a second year PhD Student from the University of Strathclyde in Glasgow, Scotland. The scholarship was awarded to attend Sandia National Laboratories/California (SNL), specifically to be in involved in the Hydrogen Program in the Combustion Research Facility (CRF), as a visiting research scholar between January 2006 and January 2007. The report introduces a project undertaken to analyze a hydrogen technology development and provides conclusions on the successful collaboration.

2 Sandia National Laboratories/California: The Combustion Research Facility

The CRF is a Department of Energy, Office of Science user facility. It houses researchers who conduct research into the use and control of combustion processes. It was established in the 1970s in response to the growing energy crisis in the US. The energy crisis led a drive into reducing dependence in the US on foreign oil imports – an issue being highlighted again by the current energy crisis. Sandia's hydrogen program is involved in various research and development areas including hydrogen storage in complex metal hydrides, material development for hydrogen separation, advanced materials for fuel cell membranes, modeling of fuel cell systems, new materials for the improvement of electrolysis, production of hydrogen from renewable energy, nuclear energy and fossil fuels, systems integration of hydrogen technologies subsystems, systems modeling for analysis of alternative hydrogen futures, hydrogen fuelled internal combustion reciprocating engines, advanced combustion capabilities for hydrogen and hydrogen-blended hydrocarbon fuels in gas turbines, development of science based codes and standards to ensure hydrogen safety and sensors. The work conducted towards this

Hydrogen Technology scholarship was in the area of the validation of hydrogen technology [1].

3 Technology Validation

Technology validation is designed to address challenges being faced in the commercialization of fuel cells. The validation procedure is used to confirm that hydrogen technologies and their accompanying structures can meet the system performance and operation targets within the specified scenarios and time scales. The Hydrogen, Fuel Cells and Infrastructure technologies program is supported by the Department of Energy Office of Energy Efficiency and Renewable Energy. [**Error! Reference source not found.**]

3.1 Analysis of Hydrogen Demonstration Systems

Hydrogen demonstration systems, sometimes known as hydrogen power parks, are in development and analysis throughout the world. Two examples are the DTE Hydrogen Energy Park in Detroit, USA and the Hydrogen and Renewables' Integration (HARI) project in the UK. The term power park is used when a development uses hydrogen technology and also meets a local load at the site. The technology is used in different ways; a typical development could power an electrolyzer with either renewable energy or a grid source, producing hydrogen to be used for either a vehicle demonstration program or a stationary fuel cell unit. This section introduces a power park project in Europe which is in the early stages of operation and analyzed during the scholarship period at SNL.

3.1.1 Analysis methodology

The general method is to gather operational data from the demonstration systems and compare to simulations using analysis tools.

The main technical and quantifiable parameters considered in the demonstration system evaluation are: energy efficiency (%), system availability (hours/day), emissions (grams/day), costs ($/kg and kWh).

All of these parameters are dependent on the system design and operation, which makes the evaluation complex. The general evaluation methodology adopted can be summarized as follows [**Error! Reference source not found.**]:

- Obtain system design and operational data from existing demonstration plants
- Verify models based on data obtained from physical installations
- Model physical system based on common system simulation and modeling tools
- Identify and improve shortcomings in data and models
- Evaluate overall system performance using calibrated models
- Recommend alternative designs and/or operation for demonstration

The model is built using the Matlab/Simulink platform. H_2Lib is a flexible modeling tool created at Sandia National Laboratories, which extends the existing Simulink library to include a customized library of hydrogen system components [3]. The hydrogen models are based on fundamental physics and chemistry and can be adjusted to represent the specialized or individual system components. Models that handle gas/liquid mixtures use the Chemkin package [5] to provide thermodynamic properties.

The components included in the package are:

- Electrolyzer - balances mass and energy
- PEM fuel cell - uses experimental data for the polarization curve
- Compressor – multi-stage with inter-cooling, isentropic efficiency
- High pressure storage vessel – uses the real gas equation of state [6]
- Photo-voltaic solar collector – solar incidence with location and time of day
- Chiller – pump work and refrigeration cycle with coefficient of performance
- Economic analysis modules

3.2 IEA Task 18: Integrated Hydrogen Systems

The International Energy Agency (IEA) Hydrogen Program has similar objectives to the aforementioned international projects. They state their objectives as based on;

- Technology: promoting the acceptance as hydrogen as an energy carrier
- Energy security: contributing to global energy security
- Environmental: exploiting the environmental benefits of hydrogen
- Economic: development of cost effective hydrogen energy systems that can compete in global markets
- Market: identification and overcoming of barriers for hydrogen penetration into the market
- Deployment: promotion of the deployment of hydrogen technologies
- Outreach: advertise hydrogen benefits

The Hydrogen Implementing Agreement (HIA) splits into topical Annexes. Annex 18 is focused on the evaluation of integrated systems. The overall goal in this task is to provide information about hydrogen integration into society around the world. Annex 18 has three subtasks. Subtask A provides data and analysis to the hydrogen community regarding the developing use of hydrogen in the form of inventory databases summaries. Subtask B uses modeling and analysis tools to evaluate hydrogen demonstration projects, or to guide their design and assessment, and to validate models and assumptions. Subtask C regards synthesis and learning; members bring together the lessons learned from case studies and projects, and perform trend analysis based on exploration of hydrogen work from earlier dates to the present. Focusing on Subtask B, the general method adopted for all the projects analyzed is the gathering of technical and operational data from various stationary hydrogen energy demonstration systems with the Annex 18 member group, and design simulations using different analysis tools such as TRNSYS and Simulink, and then to verify and improve the models and assumptions used in the modeling tools, and/or to investigate alternative designs. In Annex 18 modeling tools are used to help guide, assess, and evaluate the overall design and performance of a variety of integrated hydrogen demonstration projects [7].

3.3 The Italian House Simulation

The second project introduced in this section is the Italian Hydrogen House, being analyzed at SNL under the IEA Task 18 project once again. The "Hydrogen from the Sun" demonstration project is located in Brunate, Italy and is being supported by the Catholic University of the Sacred Heart (Brescia, Italy), the European Science Foundation (ESF) and the residence owner.

The overall goal of this solar/hydrogen energy system analysis is to study technical design and control issues related to an integrated PV/H_2-system installed at a domestic house located in Northern Italy. The main components of the hydrogen system are:

1. Pressurized alkaline water electrolyzer – Gruppo Sapio Hargassner(1 Nm^3/h)
2. Hydrogen storage - (90 Nm^3 in gas cylinders and 30 Nm^3 in MH-storage - Treibacher Industrie AG)
3. 5 kW PEM fuel cell – Arcotronics Penta PEM
4. Solterra Solar Panels

The electrolyzer is connected indirectly to the PV-systems through a separate 48 V DC bus bar, because of the many different voltages of the various PV-systems already installed. The simulation tools will be used to optimize the overall energy management system (i.e., power flow from PV to load, batteries, and electrolyzer). The modeling tools developed will also be used to find optimal methods for hydrogen discharge from the MH-system using excess heat from the PEM fuel cell and/or solar domestic hot water (from solar collectors). The main outcome of this project will be a conclusion on the feasibility of operating a domestic solar/hydrogen system that only makes use of solar energy (PV and solar thermal) and domestic utilities (e.g. tap water) in order to cover the electricity demand throughout the year, including winter months.

The aim of this house, with regards to load management, is to operate independently from the electrical grid network. There are various elements to the house operation. The photovoltaic 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 hydrogen at a rate of 1 Nm^3/hr at 200 bar. Therefore only the electrolyzer can operate and provide hydrogen to the storage system when the solar power is greater than 6.7 kW. The load management system also controls the flow of the photo-voltaic power such that when the electrolyzer is not in operation the power can be transferred from the PV directly to the load. The hydrogen produced by the electrolyzer is controlled by the flow management system. The control strategy is based upon the desire that the metal hydride (MH) storage is the primary storage mechanism (and the pressurized tanks secondary, i.e. when hydrogen is produced it is stored first in the MH and second in the tanks. When hydrogen is required by the fuel cell it is transferred first from the MH and second from the tanks again. The load, which is a private residence, is managed by the load management system, and is supplied by a 5kW PEMFC, a 3000Ah lead acid battery and the PV when the electrolyzer is off (Figure 1) [9].

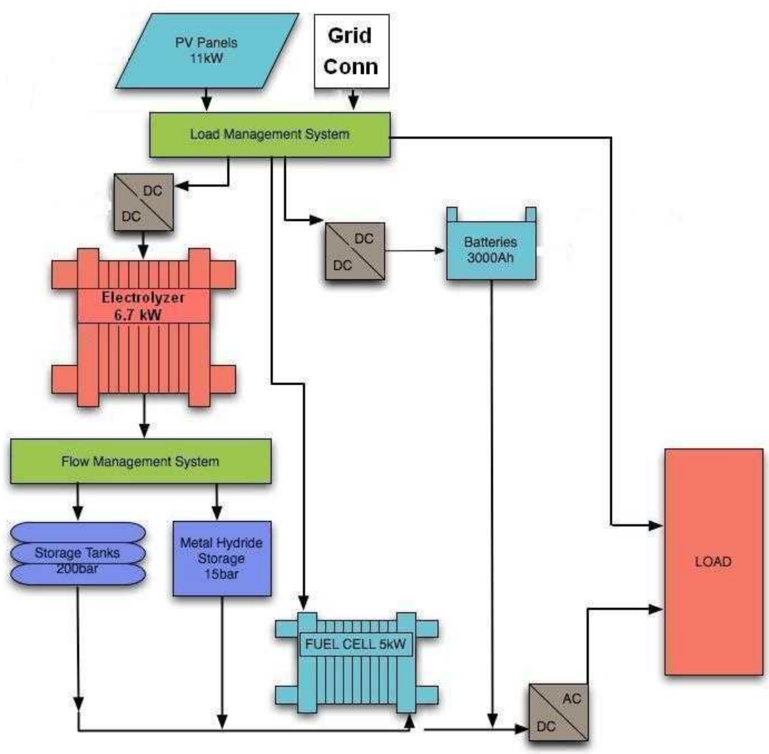

Figure 1: Technical schematic of the components involved in the hydrogen house

1.1.1. Site development – safety/planning issues

The planning phase of this project overcame safety and construction issues. There was a lack of regulations within the region, with regards to hydrogen storage and power, Approval was sought from the Fire Brigade of the Province of Como. Problems were experienced due to another private residence 28 meters from the hydrogen storage facility. After discussions between developers and safety officials it was decided that the 15-meter limit established for similar types of facilities would be respected in this case. The H_2 pipeline from the storage facility to the 5kW fuel cell (located underground) was constructed of zinc coated steel material. The hydrogen cabin was constructed, with approval from the fire brigade, with steel supporting pillars, fireproof sheet roofing and a boundary wall. Within the cabin, separating walls were used for each section and metallic grid walls for safety and security.

1.1.2. Analysis for the prediction of hydrogen cost and electricity cost

The model predicts the cost of hydrogen (COH) from this electrolyzer system will be 8 $/kg and the electricity will be approximately 0.56 $/kWh (Table 1). Economically, this system is not designed for commercial hydrogen production and is using a small electrolyzer (6.7kW) in comparison with commercial sizes of at least 200kW. The capital cost of the electrolyzer was scaled using the DTE data with production rate to 0.6 power. The O & M costs were estimated at 2% of the capital cost.

Contribution	**COH ($/kg-$H_2$)**
Capital	2.37
Feedstock	5.32
O & M	0.34
TOTAL	**8.03**

Table 1: Separation of hydrogen overall cost per kg into components

Without operational data the economic results cannot be verified, but the preliminary analysis has shown that the cost of H_2 is consistent with the other demonstration systems investigated in Annex 18 and the DOE Hydrogen Power Parks Project.

4 Conference Presentations

The following events were attended to present work completed during the scholarship period.

- NHA 2006, Long Beach, CA, USA
- NHA 2007, San Antonio, TX, USA
- IEA Annex 18, Fall Meeting 2006, Glasgow, Scotland
- IEA Annex 18, Spring Meeting 2007, Brunate, Italy
- DOE Annual Merit Review 2007, Washington DC, USA

5 Summary of achievements

Firstly the work that was completed here was both interesting and useful. It provided a basis for the PhD work which is being continued into my final years of research and also provided a strong direction, which it has now taken. The international collaboration allowed me to obtain a much wider view of the hydrogen world and form contacts and receive information which would not have been possible in the academic environment. The international collaboration was ongoing throughout, with work being undertaken for the International Energy Agency and specifically for an Italian project. The technology validation work completed allows me firstly to improve my knowledge in an area of science I had not touched on through my undergraduate degree and initial years of study. The hydrogen demonstration program research can move PhD work into applied programs, allowing the theoretical knowledge to be applied and grow into a much more useful field.

6 Conclusions

The EPSRC Scholarship has allowed me to develop my research interests to a wider extent than was possible in an academic environment. The University of Strathclyde in allowing me to take part in this Scholarship throughout my PhD study has widened my knowledge of hydrogen technology through the research undertaken at Sandia, travelling to conferences to present papers and being able to represent Sandia and Strathclyde University throughout the world. I was able to give feedback and engage in discussion with my supervisors, Prof. Jim McDonald, Dr Andrew Cruden and Dr Graham Ault through conference calls and study visits and this has given me a huge opportunity to develop my area of research and experience in this subject.

The support received from the Hydrogen Program and Sandia National Laboratories, specifically Dr Jay Keller and Dr Andy Lutz, was far beyond my expectations and gave me the confidence and ability to take my work to a much higher level than I had anticipated. The experience at SNL changed the direction of my work and moved it to a much more focused and applied area, and their continued support will help drive it to an extremely successful conclusion. Although the administrative and immigration processes are often bewildering and lengthy, I felt I had the support from my mentors here and also the administrative staff strived to make this as easy and smooth as possible. Overall I feel that my experience through this scholarship was 100% successful and I hope my collaboration with Sandia and Strathclyde can continue in the same direction.

7 References

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