V.F.4 Smart Energy Management of Multiple Fuel Cell Powered Applications*

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*Congressionally directed project

Objectives

- To demonstrate the most effective design and protection scheme of minigrid power systems for multiple fuel cell power plants.
- To define the most economical operational schedule for the multiple fuel cells in terms of electrical, thermal and hydrogen production.
- To lay the bases for generation of hydrogen using photoelectrochemical solar cells.
- To develop models for hydrogen production, purification, and storage systems.
- To demonstrate that smart energy management and control of fuel cell power sources when subjected to varying demands of electrical and thermal loads together with demand for hydrogen production.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section (3.4.4.2) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(G) Power Electronics.

Accomplishments

Task Number	Project Milestones
1	**Operational analysis of multiple FCPP based mini-grid system** • System design (3/15/06) • Representative residential load data collection (3/15/06) • Unmanaged short-term scheduling of FCPPs (4/15/06) • Thermal energy management based short term scheduling of FCPPs (4/30/06) • Hydrogen management based short term scheduling of FCPPs
2	**Production of hydrogen using photochemical (PEC) photocells** • Modeling and simulation • Investigation of nanostructured films for photooxidation of water • Development of smart materials for transparent conduction and corrosion resistance of photoelectrodes used in PEC cells
3	**Modeling of hydrogen production, purification, and storage** • Develop a working model of a methane reformer operating at full steady state capacity • Develop a model of hydrogen purification system • Develop a model of hydrogen compression system
4	**Smart energy management of FC application and energy conservation** • Energy conservation algorithm • Energy conservation hardware • Pilot program, test, and analysis
5	**Neighborhood level energy management** • Algorithm developed (Nik/BK) • Testing (Nik/BK) • Coordinate with electric cooperative industry
6	**Smart energy management and control for FC based small power application** • Select fuel cell in the range of 20-75 W • Buy FC 25-50 W (PEM or methanol)? • Secondary Storage (battery, supercapacitor) • Data collection • Maximize energy delivered to load • Experimental demo • Comparative analysis

Introduction

In this research project, the University of South Alabama research team has been investigating smart energy management and control of multiple fuel cell power sources when subjected to varying demands of electrical and thermal loads together with demands of hydrogen production. This research has focused on finding the optimal schedule of the multiple fuel cell power plants in terms of electric, thermal and hydrogen energy. The optimal schedule is expected to yield the lowest operating cost. Our team is also investigating the possibility of generating hydrogen using photoelectrochemical (PEC) solar cells through finding materials for efficient light harvesting photoanodes. The goal is to develop an efficient and cost-effective PEC solar cell system for direct electrolysis of water. In addition, models for hydrogen production, purification, and storage will be developed. The results obtained and the data collected will be then used to develop a smart energy management algorithm whose function is to maximize energy conservation within a managed set of appliances, thereby lowering operating and maintenance costs of the fuel cell power plant (FCPP), and allowing more hydrogen generation opportunities.

The Smart Energy Management and Control (SEMaC) software, developed earlier, controls electrical loads in an individual home to achieve load management objectives such that the total power consumption of a typical residential home remains below the available power generated from a fuel cell. In this project, the research team will leverage the SEMaC algorithm developed earlier to create a neighborhood level control system that incorporates efficient fuzzy logic control and historical load profile data.

Approach

- The University of South Alabama will design and evaluate the system, and calculate the operational costs of a multiple fuel cell based mini-grid system. The system design gives the layout of a primary and secondary distribution system of multiple fuel cells, including cable sizes, voltage drop, and system losses. In addition, a protection scheme for the fuel cell and the distribution system is introduced. The operational cost will include the estimation of the optimal operational cost of multiple fuel cells in terms of generating electrical, thermal, and hydrogen power.
- An important part of this research is the production of hydrogen using tandem photoelectrochemical (PEC) solar cells as electrolyzers. For this task, the University of South Alabama team is investigating the nanostructured films for photooxidation of water and developing smart materials for transparent conduction and corrosion resistance of photoelectrodes.
- To study the feasibility of producing, purifying, and storing hydrogen, a model including a methane reformer, hydrogen purification system, and hydrogen compression system is being developed.
- This research will accelerate the development of fuel cell applications for residential energy customers, will ensure load smoothing during peak demand periods, and will support the development of hydrogen use for energy supply systems.
- In addition, a smart energy management and control for low power fuel cell based application is under investigation.

Results

1. Operational Analysis of Multiple FCPP-Based Mini-Grid System

1.1 System Design

In this task a mini-grid consists of five neighborhoods. Each neighborhood contains a cluster of 10 identical single storied homes. Neighborhoods are fed from five proton exchange membrane (PEM) fuel cell power plants with a total capacity of 300 kW. The primary and secondary distribution system design is complete. Based on length and ampacity of the selected feeders, the over current protection devices at the sending and receiving ends are being designed. Surge protection for protecting FCPPs against lightning surge is being considered for installation at each FCPP.

1.2 Representative Residential Load Data Collection

Five domestic dwellings have been identified and preparations are currently being made to instrument these houses. Testing will be every 15 seconds for a period of 48 hours.

1.3 Unmanaged Short-Term Scheduling of FCPPs

The research group developed a mathematical model for economical short-term scheduling of multiple fuel cells. The model will be used to determine the optimal operation schedule for the FCPPs based on the available electrical and thermal load information. For this purpose:

- Data relating to the mini-grid load are being collected.
- Data for each FCPP for the purpose of development of economic model are being collected.

1.4 Thermal Energy Management Based Short Term Scheduling of FCPPs

A design for utilizing thermal energy from the fuel cell to reclaim hot water for domestic use has been developed. The hot water will be delivered to the homes at a temperature of approximately 65 to 70 degrees centigrade. During times of peak loading, the excess thermal energy from the natural gas reformer will be adequate to provide enough hot water for domestic use. During off-peak hours, two scenarios are currently being investigated: Storage of hot water in an insulated tank, and ramping the methane flow of the reformer to regulate the amount of thermal energy produced.

1.5 Hydrogen Management Based Short Term Scheduling of FCPPs

In order to guarantee a continued supply of hydrogen to the five FCPPs making up the generation system of the mini-grid it is envisioned that two methane reformers will feed two tanks located strategically along the hydrogen feeder system. Feeder lines to the five FCPPs will be connected to the feeder system. Hydrogen poses unique problems for storage and distribution. Being a gas with the lowest molecular weight of any gas it is capable of leaking at a faster rate than all other gases. Hydrogen leaks 2.8 faster than methane and 3.3 times faster than air. Since hydrogen is highly volatile, safety is paramount in the design of the hydrogen storage and distribution system. Also, there is the possibility of detonation when hydrogen is mixed with air. When ignited the flame produced is almost invisible. Hydrogen must not be allowed to concentrate in a confined space. Fortunately, when exposed to the atmosphere this gas disperses more rapidly than any other gas and in a practical storage and distribution system the concentration levels necessary for ignition or detonation are not likely to be reached.

It is advisable to use two methane reformers and two storage tanks will allow for the shut down of one tank and one reformer for maintenance purposes. Of course, each system must then be capable of supplying the peak and sustained energy requirements of the mini-grid for the period of the shutdown. Hence, the detailed sizing of the tanks and feeder lines will be dependent, not only on the shut down period, but also on the nature and types of loads, the scheduling strategy adopted and the energy management algorithm employed.

2. Production of Hydrogen Using PEC Photocells

This part of the project mainly focuses on the production of hydrogen using photoelectrochemical (PEC) solar cells as electrolyzers. The main thrust of this project is the simulation and modeling of materials suited for fabrication of efficient light harvesting photoanodes and investigation of naonostrucured thin films. The goal is to develop an efficient cost-effective PEC solar cell system for direct electrolysis of water.

We are currently investigating the application of nitride materials for bandgap engineering. Ab-initio calculations of nitrides of different semiconductors are also performed using the Vienna Ab-initio simulation package (VASP). Nitrides of III-V and IV-V materials are emerging as promising materials for photoelectrodes. Thin film development of different nitrides like InN, GaN etc. is in progress using pulse laser deposition system with the intent of using nitrides on photoelectrodes. We plan to use a combinatorial approach to change the bandgap of the nitrides. In particular, InN and Sn_xN_y had been found to have bandgaps suitable for efficient light absorption and their bandgap energies are close to water redox potential. These materials are more suitable for PEC hydrogen production due to their wide availability and low cost. The main challenges associated with the use of nitrides are the impurities inherent in p-type doping of InN and In-rich InGaN. One of the solutions for p-type doping of these nitrides may be Zn doping.

Accomplishments

- Basic understanding of photoelectrochemistry.
- Installation/access of VASP for theoretical calculations and simulations.
- Studied nitrides of semiconductors like InN, SnNx, GaN as promising materials for direct water splitting.
- Installed necessary equipments and accessories for film characterization and photocurrent measurement.

3. Modeling of Hydrogen Production, Purification and Storage

1.1 Develop a Working Model of a Methane Reformer Operating at Full Steady State Capacity

Data has been collected from a Plug Power GenSys 5 kW fuel cell system. A test plan for executing power profiles has been developed. Mass flow rates, system component temperatures, and reformat composition have been obtained from the reformer system and will be used to develop the models identified in Subtasks B and C.

1.2 Develop a Model of Hydrogen Purification System

Fuel cell data is being evaluated and will be used to develop an ASPEN model of a multi-stage pressure swing adsorption hydrogen purification system.

1.3 Develop a Model of Hydrogen Compression System

Fuel cell data is being evaluated and will be used to develop an ASPEN model of a metal hydride based compression process.

4. Smart Energy Management of Fuel Cell Application and Energy Conservation

4.1 Energy Conservation Algorithm

4.1.1 Conduct data collection to support algorithm development

This task is complete. Radiance designed and built a data acquisition system to collect flow, temperature, and power consumption from an electric hot water heater installed at the home of one of the developers. Data was collected at 5 second intervals, to form the initial training set of data for the neural network.

4.1.2 Energy Conservation Using Neural Network

Year three neural network algorithms have been adapted for an energy conservation focus for application on hot water heaters and HVAC systems.

4.2 Energy Conservation Hardware

Design completed. PC board layout completed – confirming layout before production begins. Bill of materials completed.

References

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