2006 HYDROGEN, FUEL CELLS INFRASTRUCTURE TECHNOLOGIES PROGRAM REVIEW

SMART ENERGY MANAGEMENT AND CONTROL OF FUEL CELL POWERED APPLICATIONS

BY

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FCP 42

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OBJECTIVES

- **Task I. Operational analysis of a multiple FCPP based mini-grid system**

- **Task II. Production of hydrogen using photo-electrochemical (PEC) solar cells**

- **Task III. Modeling of hydrogen production, purification, and storage**

- **Task IV. Smart Energy Management for Fuel Cell Applications and Energy Conservation**

- **Task V. Neighborhood Level Energy Management**

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BUDGET

- Phase I: $2m
- Phase II: $1m
- Phase III: $0.5m
- Phase IV: $1.0m

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TECHNICAL BARRIERS AND TARGETS

Under Distributed Generation Systems

- Mitigate technical, commercial and cost barriers to stationary fuel cells.
- Cost-effectively recover thermal energy to meet some or all of a building's heating/cooling requirements.
- Power systems for back-up or peak shaving applications for commercial/industrial operations.

Under Hydrogen Generation by Water Electrolysis Barriers

- Improved, lower -cost solar concentrator/collection technology, including materials, is needed.

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APPROACH

- **Number of mini-grids determined**
- **Fuel cell power plants selected**
- **Layout designed**
- **Modeling of hydrogen production, purification and storage in progress**
- **Management algorithms under development**
- **Neighborhood energy management algorithm under development**

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SAFETY

- **University of South Alabama Office of Research Compliance and Assurance inspects all laboratories annually**
- **Fuel Cell has extensive safety interlocks**
- **All electrical distribution panels have safety lockouts**

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PROJECT PHASES

- **Phase I: Laboratory House and SEMaC completed**
- **Phase II: Micro-grid, LEMSYS and MEMSYS developed for micro-grid community**
- **Phase III: Energy management and Control System developed for micro-grid connected neighborhoods**
- **Phase IV: Smart Energy Management and Control of Fuel Cell Powered Applications (In progress)**

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TECHNICAL ACCOMPLISHMENTS/PROGRESS

- **Micro-grid community layout completed**
- **Modeling of hydrogen production, purification and storage under development**
- **Energy management algorithms under development**

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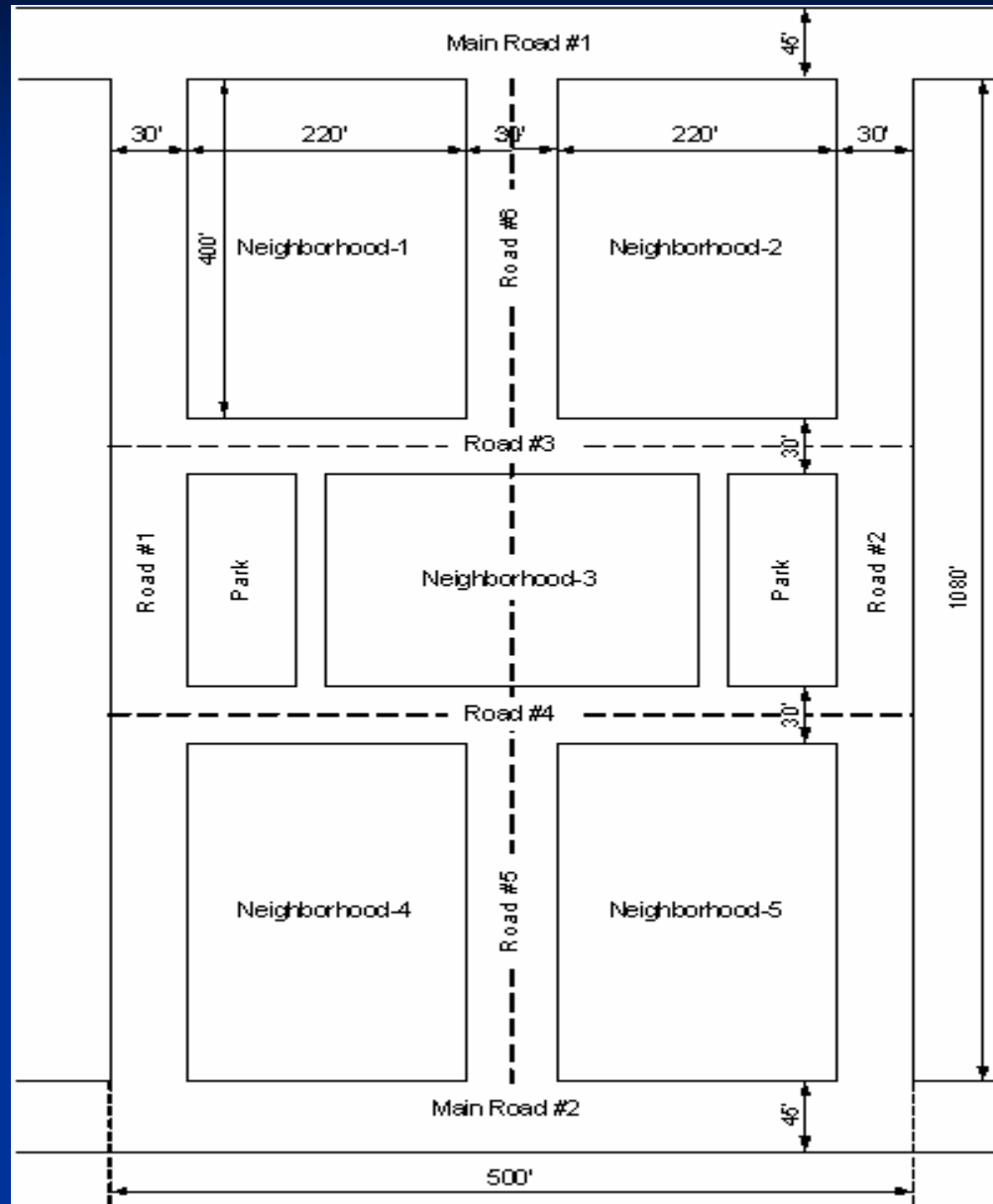
INTERACTIONS AND COLLABORATIONS

- **Teamed with Radiance Technologies, Inc. to develop SEMaC, MEMSYS and LEMSYS**
- **Made contact with other fuel cell research groups including CRN, Houston Area Research Center (HARC), and the Fuel Cell Testing Center (FCTC) in Johnstown, PA**

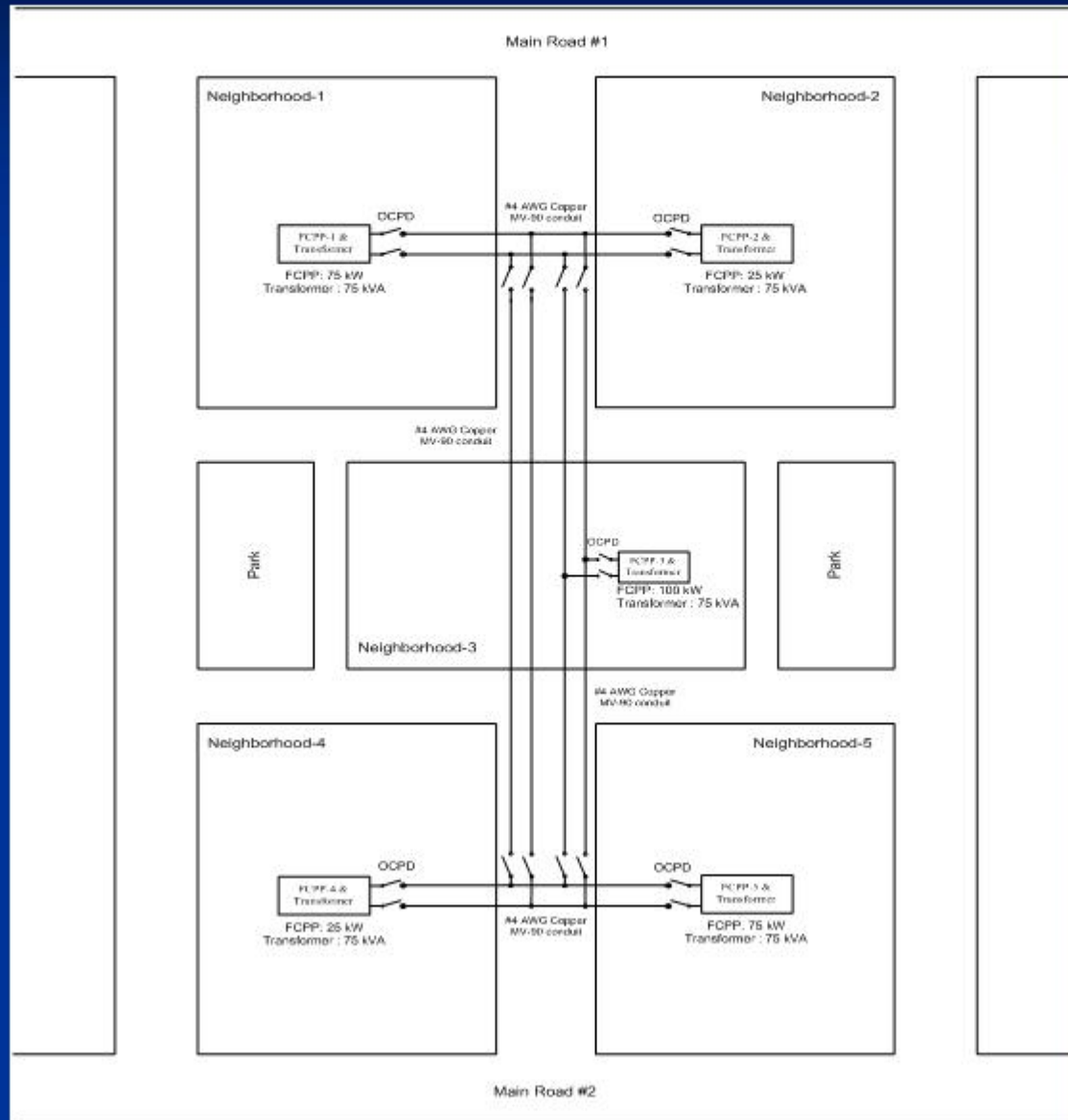# 2006 HYDROGEN, FUEL CELLS INFRASTRUCTURE TECHNOLOGIES PROGRAM REVIEW

FUTURE WORK (PHASE IV)

- Smart energy management and control systems for a mini-grid community

- Energy management algorithms for scheduling of Fuel Cell Power Plants

- Modeling of hydrogen production, purification and storage

- Test Hydrogen production using solar cells

TASK I: Mini-grid Community Layout

Single-phase mini-grid feeder system for multiple-unit configuration

Mini-grid System Protection Design

- **Based on length and amperage of the selected feeders, the over current protection devices at the sending and receiving ends are being designed.**

- **Surge protection for protecting fuel cell power plant (FCPP) against lightning surge are being considered for installation at each FCPP.**

Unmanaged Short Scheduling of the FCPP

- **Data relating to the mini-grid load are being collected**

- **Data for each FCPP for the purpose of development of an economic model are being collected.**

- **Based on the economics of the mini-grid system, a mathematical model is being developed**

- **The model will be used to determine scheduling of the FCPP which yields the minimum operational cost**

Thermal energy management based short term scheduling of the 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

  - Ramping the methane flow of the reformer to regulate the amount of thermal energy produced.

TASK II: Objective

Development of novel materials suitable for efficient light harvesting photo-anodes
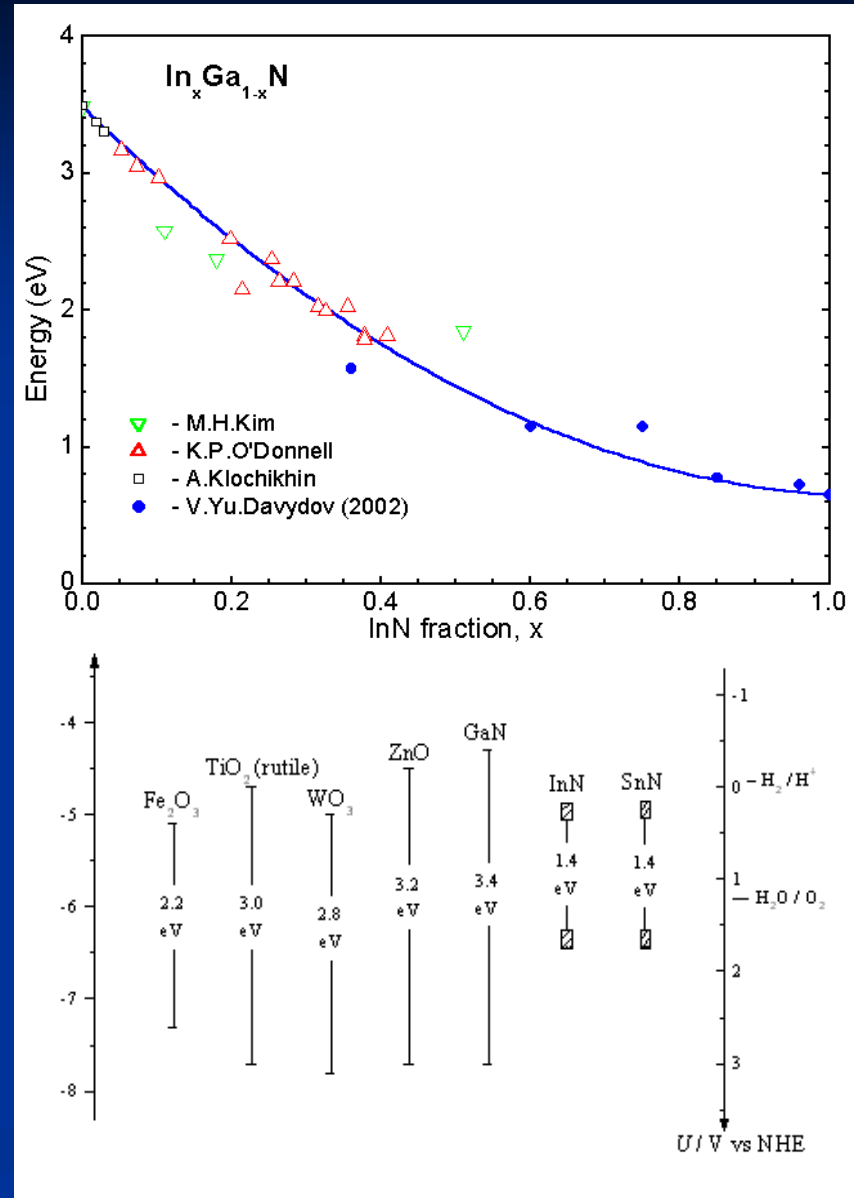
Approach

- **Developing Modeling the local density approximation for the band gap engineering of different nitride-based semiconductors using Vienna ab-initio simulation package (VASP)**
  - ➢ **Studying the effect of doping on band gap.**

- **Developing thin films of different nitrides like InN, SnN$_x$, GaN etc.**
  - ➢ **Utilizing pulsed laser deposition (PLD) in parallel with the Ab-initio calculations (PLD is an efficient and cost effective alternative for growing of thin films).**

- **Characterizing the thin films with the intent of optimization of efficient light harvesting photo-anodes.**

Nitrides of III-V and IV-V materials are emerging as promising materials for for photo-electrodes

➢Using a combinatorial approach to change the band gap of the nitrides

➢InN and Sn_xN_y have band gaps favorable for efficient light absorption

➢ Band energetics are very close to water redox potential

➢Uses widely-available and cost-effective materials

➢P-type doping of InN and In-rich InGaN are the main challenges

➢Zn may be the solution for p-type doping

Task II: Progress

- **Developed a basic understanding of photo-electrochemistry**

- **Utilizing VASP for theoretical calculations and simulations.**

- **Studied nitrides of semiconductors such as InN, SnN$_x$, GaN as promising materials for direct water splitting**

- **Installed necessary equipment and accessories for film characterization and photocurrent measurement.**

Task II: Future work

- **Perform density functional theory calculations of materials**
- **Thin film growth and characterization**
  - ➢ **Variation of growth conditions**
  - ➢ **Utilization of different substrates**
  - ➢ **Evaluation of different doping concentrations**
- **Optimization of thin films by band gap engineering.**
- **Photo-electrochemical measurements**

TASK III: Modeling of hydrogen production, purification, and storage

- Data has been collected from a Plug Power GenSys 5kW fuel cell system.

- A test plan for executing power profiles has been developed

- Mass flow rates, system component temperatures, and reformate composition have been obtained from the reformer system and will be used to develop a model of a methane reformer operating at full steady state capacity.

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

TASKS IV and TASK V: Smart energy management for fuel cell applications and energy conservation (Radiance)

- **Implemented fuzzy logic-based energy-management algorithms to better manage power demand around a threshold.**
  - **Results in a much smoother load management curve with no oscillations**
  - **Yields a higher performance, however**
  - **Difficult to implement due to large number of interdependent fuzzy rule sets**
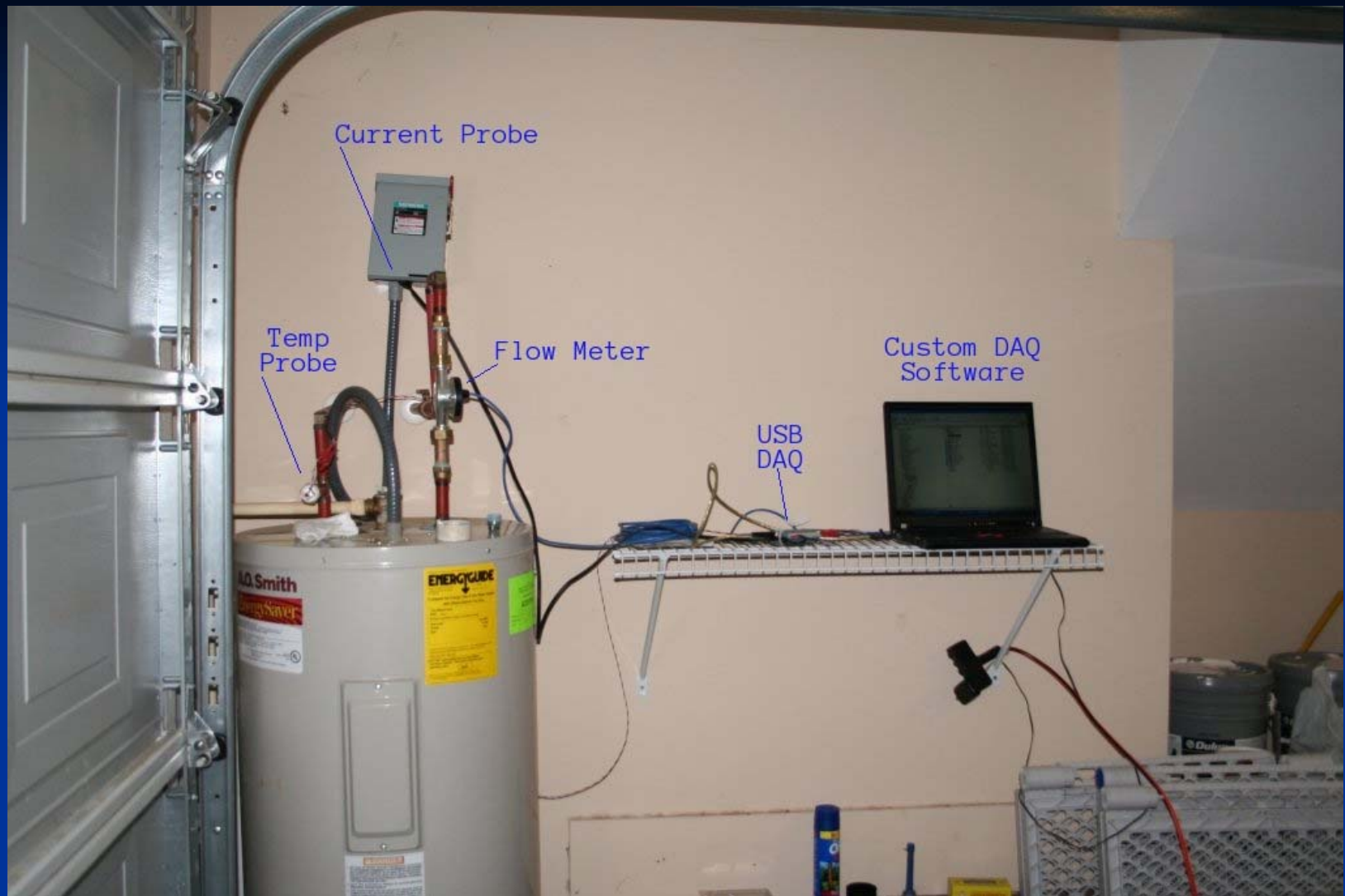
NEURAL NETWORK CONTROLLER (NNC)

Implemented a neural network-based algorithm that learns the patterns of hot water flow in a home, allowing control of power to the hot water heater when demand is low. The main features of NNC are:

- Accurate performance
- Algorithm trains slowly, but once trained, performs well
- Frequent retraining necessary due to changing usage patterns in home
- These issues are currently being addressed, with research focusing on adaptive-resonance neural networks that train continuously

TASK IV and V: Work in Progress

A similar neural network-based algorithm, to manage HVAC based on occupancy, is currently under development.
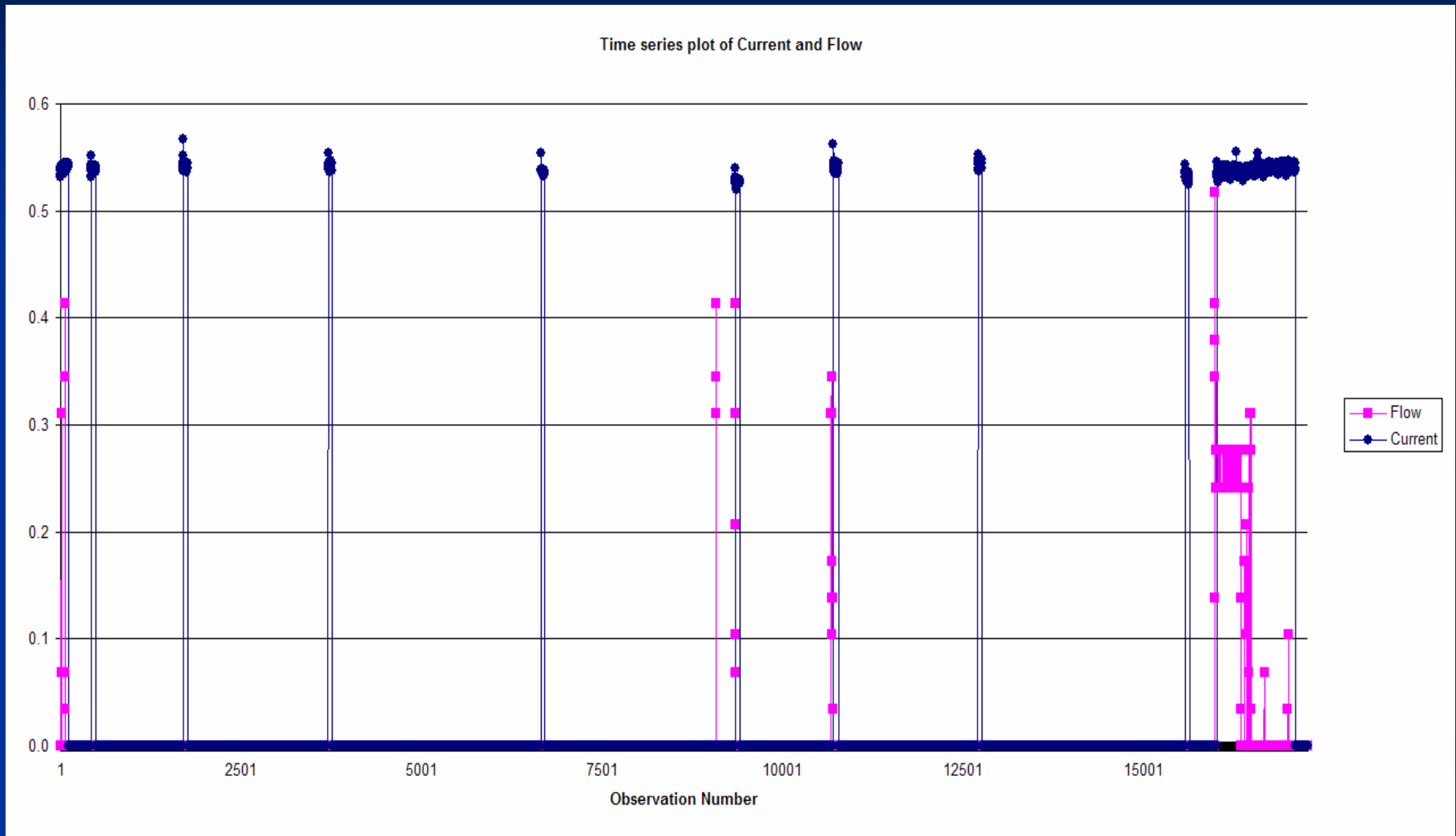
- An embedded hardware controller will replace the thermostat
- Both the hot water heater and the HVAC system, based on occupancy and demand, will be controlled

DAQ system developed to collect data from electric hot water heater installed in a home occupied by two adults.

Time-Series Plot of Current and Flow for Hot Water Heater

Initial data collection of hot water usage vs. power

Time series plot of Current and Flow

Journal Publications Resulting From This Project

- M. Uzunoglu and M. S. Alam, "Dynamic modeling, design and simulation of a combined PEM fuel cell and ultra-capacitor system for stand-alone residential applications," accepted for publication, *IEEE Transactions on Energy Conversion*, 2006.

- O. C. Onar, M. Uzunoglu and M. S. Alam, "Dynamic Modeling, Design and Simulation of a Wind/Fuel Cell/Ultra-capacitor Based Hybrid Power Generation System," accepted for publication, *Journal of Power Sources*, 2006.

- M. Y. El-Sharkh, M. Tanrioven, A. Rahman and M. S. Alam, "A Study of Cost-Optimized Operation of a Grid-Parallel PEM Fuel Cell Power Plant," accepted for publication, *IEEE Transactions on Power Systems*, 2006.

- M. Tanrioven and M. S. Alam, "Impact of Load Management on Reliability Assessment of Grid Independent PEM Fuel Cell Power Plants," accepted for publication, *Journal of Power Sources*, 2005.

- M. Tanrioven and M. S. Alam, "Reliability Modeling and Analysis of Stand Alone PEM Fuel Cell Power Plants," *Journal of Renewable Energy*, Vol. 31, p. 915-933, 2005.

- M. Tanrioven and M. S. Alam, "Modeling, Control and Power Quality Evaluation of a PEM Fuel Cell Based Power Supply System for Residential Use," accepted for publication, *IEEE Industry Applications Magazine*, Vol. 41, 2005.

- M. Y. El-Sharkh, M. Tanrioven, A. Rahman and M. S. Alam, "Impact of Hydrogen Production on Optimal Economical Operation of a Grid-parallel PEM Fuel Cell Power Plant," accepted for publication, *Journal of Power Sources*, Vol. 153, p. 136-144, 2005.

Journal Publications Resulting From This Project (Contd ...)

- M. Y. El-Sharkh, M. Tanrioven, A. Rahman, M. S. Alam, *"*Impact of Combined Wind Energy and Hydrogen Production on the Optimal Operation of a Fuel Cell Power Plant Based CHP System,"* accepted for publication, *IASME Transactions*, Vol. 2, 2005.

- M. Tanrioven and M. S. Alam, "Reliability Modeling and Evaluation of Grid-connected PEM Fuel Cell Power Plants Based on Markov Models," *Journal of Power Sources*, Vol. 142, p. 264-278, 2005.

- M. Y. El-Sharkh, A. Rahman and M. S. Alam, "Evolutionary Programming Based Methodology for Economical Output Power from PEM Fuel Cell for Micro-Grid Application," *Journal of Power Sources*, Vol. 139, p. 165-169, 2005.

- M. Y. El-Sharkh, A. Rahman, M. S. Alam, P. C. Byrne, A. A. Sakla and T. Thomas, "A Dynamic Model for Stand-alone PEM Fuel Cell Power Plant for Residential Applications," *Journal of Power Sources*, Vol. 138, p. 199-204, 2004.

- M. Y. El-Sharkh, A. Rahman, M. S. Alam, A. A. Sakla, P. C. Byrne and T. Thomas, "Analysis of Active and Reactive Power Control of a Stand-alone PEM Fuel Cell Power Plant," *IEEE Transactions on Power Systems*, Vol. 19, p. 2022-2028, 2004.

- M. Y. El-Sharkh, A. Rahman and M. S. Alam, "Neural Networks Based Control of Active and Reactive Power of a Stand-alone PEM Fuel Cell Power Plant," *Journal of Power Sources*, Vol. 135, p. 88-94, 2004.

Conference Publications Resulting From This Project

- M. Uzunoglu and M. S. Alam, "A Novel Wavelet based Load Sharing Algorithm for Fuel Cell and Ultra-Capacitor based Hybrid Vehicular Power System," to appear, *Proceedings of the IASTED International Conference on Power and Energy Systems*, Rhodes, Greece, 26-28 June 2006.

- M. Y. El-Sharkh, M. Tanrioven, A. Rahman, M. S. Alam, "Optimal Operation of a Wind and Fuel Cell Power Plant Based CHP System for Grid-Parallel Residential Micro-Grid," to appear, *Proceedings of the 2005 WSEAS Conference,* Vouliagmeni, Athens, Greece, 12-14 July 2005.

- M. S. Alam and M. Tanrioven, "Modeling and Fuzzy Logic Control of DC-DC Converter for Proton Exchange Membrane Fuel Cell," *Proceedings of the IASTED Conference on Modeling and Simulation*, Cancun, Mexico, p. 404-407, May 18-20, 2005.

- M. Tanrioven and M. S. Alam, "Modeling and Power Quality Evaluation of a PEM Fuel Cell Based Power System," *Proceedings of the IEEE Conference on Industry Applications*," Vol. 4, p. 2808-2814, Seattle, Washington, October 2004.