2006 HYDROGEN, FUEL CELLS INFRASTRUCTURE TECHNOLOGIES PROGRAM REVIEW

SMART ENERGY MANAGEMENT AND CONTROL OF FUEL CELL POWERED APPLICATIONS

BY

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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

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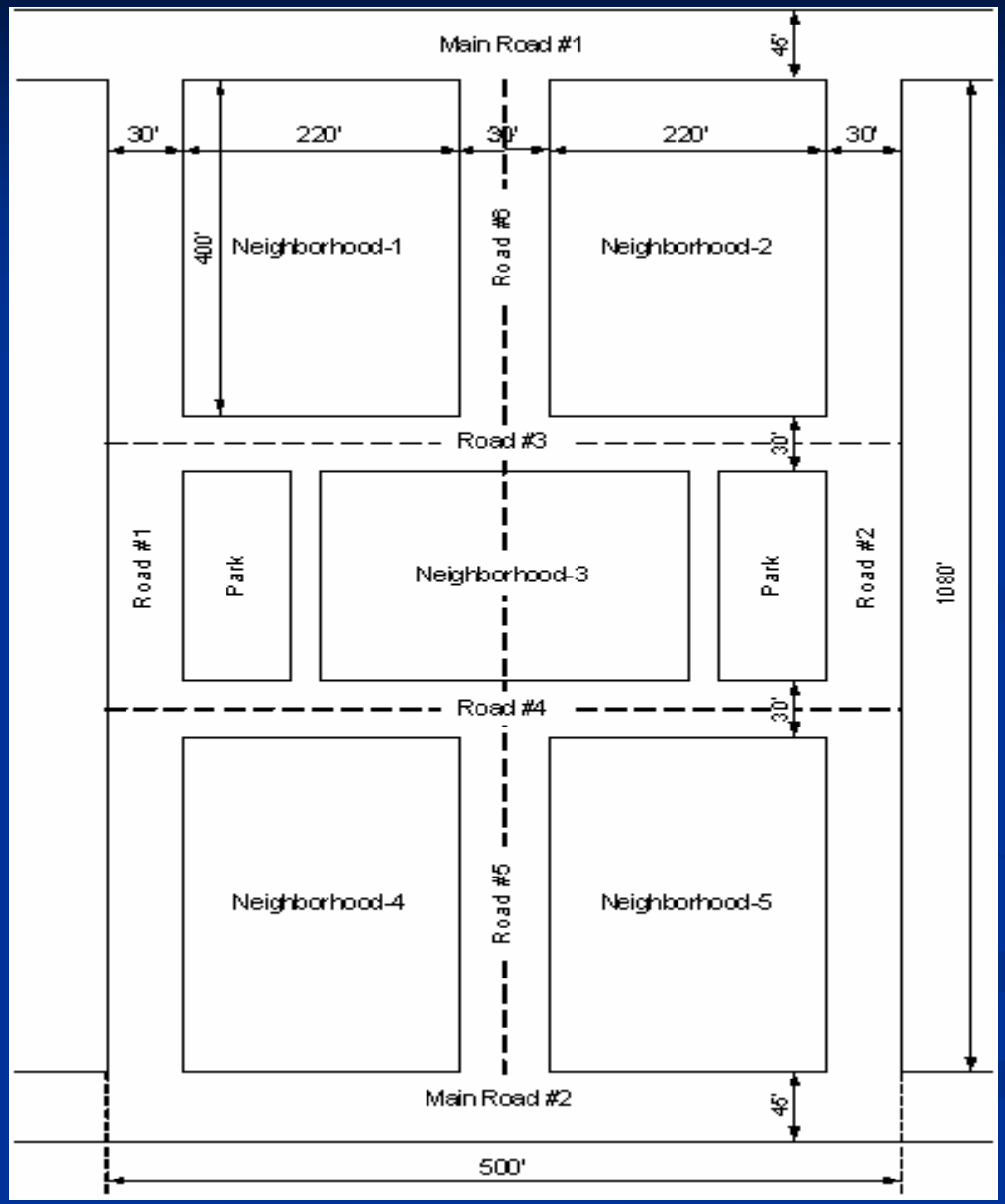
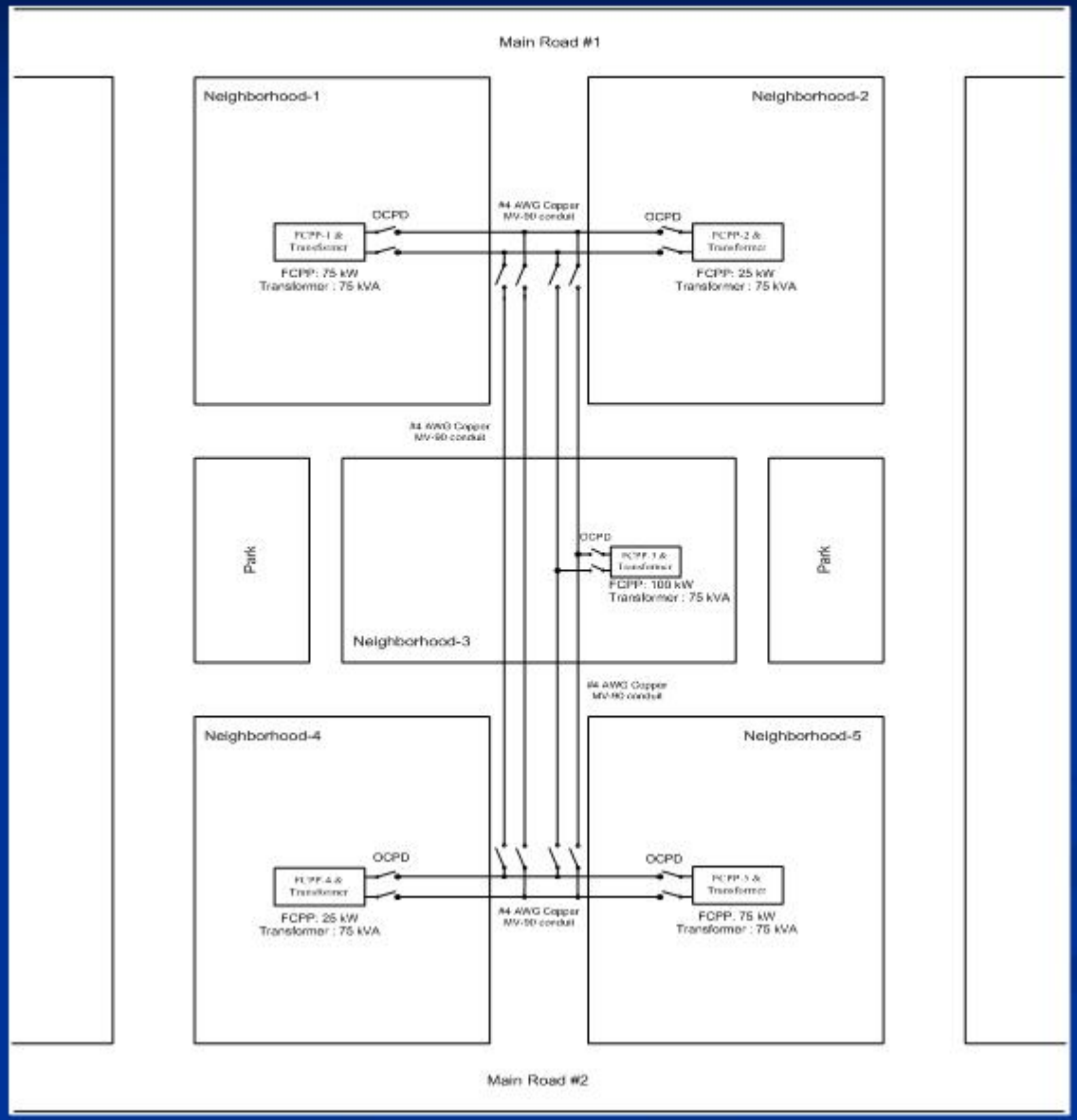
FUTURE WORK (PHASE IV)

- 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

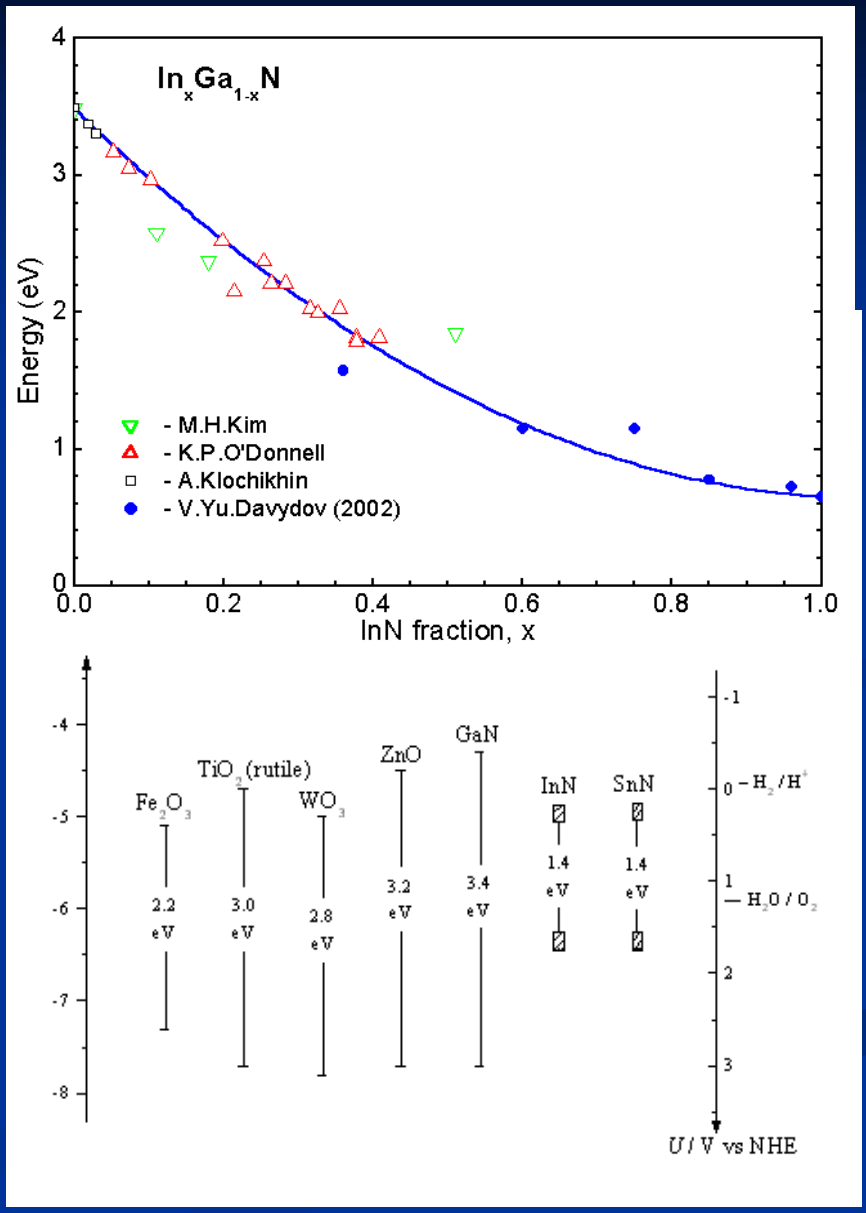
Approach

- **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.**

Approach: Nitrides Materials Summary

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



Torbjorn et al. (Solar Energy Materials & Solar Cells 73 (2002) 377–389

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)

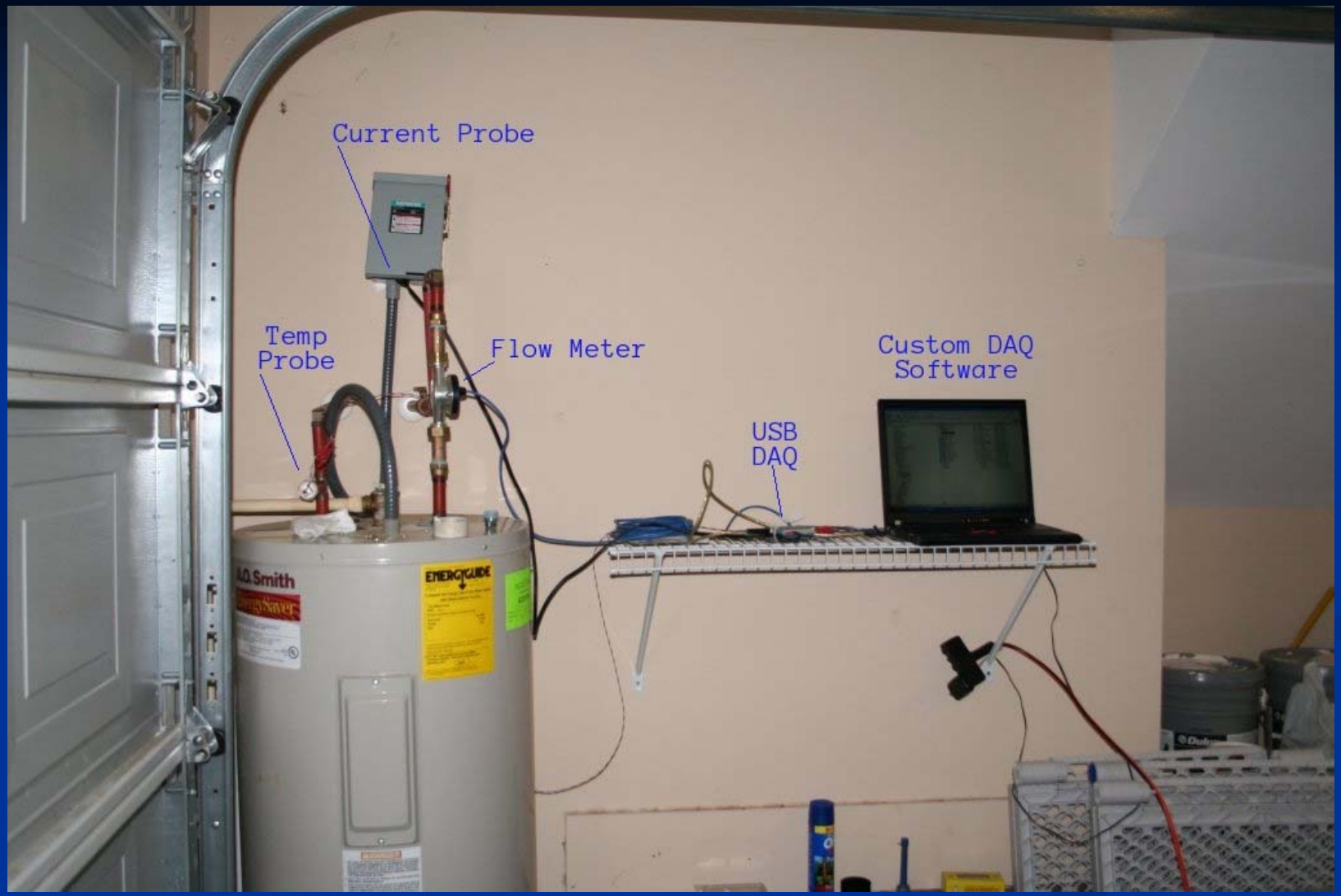
Implemented a neural network-based algorithm that learns the patterns of hot water flow in a home, allowing control of power to the hot water heater when demand is low. The main features of NNC are:

- 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.

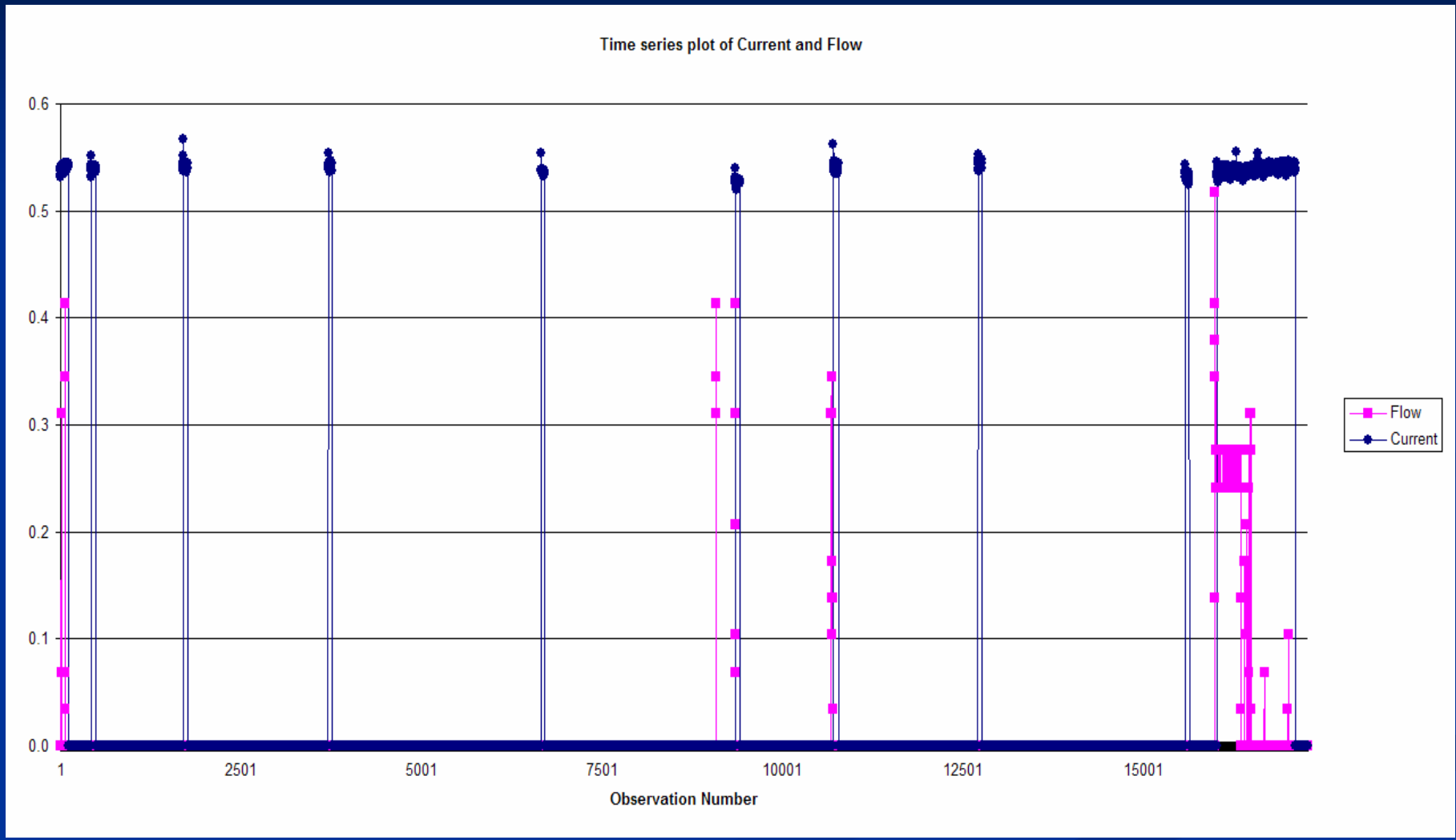
- **An embedded hardware controller will replace the thermostat**
- **Both the hot water heater and the HVAC system, based on occupancy and demand, will be controlled**



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



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.**