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Development of a Fuel Cell Teaching Laboratory as the Focus of a Multi-Disciplinary Engineering Design Class

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Abstract

Fuel cell technology, and the use of hydrogen as fuel are important elements of long-term energy planning. The impact of fuel cell technology on greenhouse gases and the need for a decreasing reliance on fossil fuels is quite evident. Consequently, a significant amount of governmental and industrial resources have been invested on developing Proton Exchange Membrane fuel cells (PEMFC) as well as other hydrogen fueled systems, as "cleaner" more efficient alternatives.

The multi-dimensional coupling of PEMFC electrochemistry to reactant flow temperature and moisture conditions, to electric load, to supply pressure and back pressure, to membrane design and instantaneous conditions requires a system approach to design and analysis. The understanding of the overall system requires the involvement of specialists in electrochemistry, fluid dynamics, heat transfer, system analysis and control, fuzzy logic and load management. This can be only achieved by assembling a genuine multi-disciplinary team dedicated to understanding the coupling mechanisms between their area of specialty and communicating with specialists in other areas.

Under a grant from the National Science Foundation, FAU's College of Engineering has developed a Fuel Cell Teaching Laboratory designed to initiate learning and communication activities for students from electrical, mechanical, and other disciplines, to enhance the inter-disciplinary needs of the fuel cell community. This paper describes the development of this laboratory, the organization of the associated class, and the experience gained thus far.

Keywords

PEM, Fuel Cells, Teaching, Laboratory, Multi-disciplinary

I. Introduction

The multi-disciplinary and the inter-disciplinary aspects of fuel cells make them ideal teaching tools. Design and analysis of fuel cells involve the understanding of electrochemistry, thermodynamics, fluid flow and heat transfer, system dynamics, electronics and controls on both theoretical and experimental levels. Mechanical, electrical, material science and computer science students can all work together in a unified approach to modeling, simulation, and testing of fuel cells. The College of Engineering at FAU has for several years supported a multi-disciplinary approach to engineering education. The senior year set of two design courses involve students from all engineering departments working together in design and fabrication of student projects.
The concept of using fuel cells as the center of a cooperative course between electrical and mechanical engineering grew out of a cooperation between respective faculty members of these two departments. The tools needed for analysis, simulation, and testing of fuel cells are common to both departments and include: system modeling and tools as such as Matlab's Simulink^R, an extensive data acquisition system and the utilization of National Instrument's Labview^R hardware and software. These common threads between the students from mechanical and electrical engineering departments were used to form a cohesive class of multi-disciplinary individuals working on a common project. The Fuel Cell Laboratory in the mechanical engineering department equipped with a Teledyne Energy Systems experimental PEM stack, and recent acquisition of two Ballard NEXA^R 1.2 kW fuel cell test stations is the primary experimental focus of the course. The computer laboratory in the electrical engineering department is the focal point for the modeling and simulation of the fuel cell system.

General View of the Fuel Cell Laboratory

II. Organization

The class is organized in two distinct parallel tracts. For Track A, one day a week he students are introduced to theoretical principles of fuel cell sub-systems. For Track B, on the second meeting each week, the students are introduced to modeling principles and conduct in-class exercises with Simulink^R and Labview^R software packages. The first four lectures of Track A cover electrochemistry and the fabrication techniques that allow PEM (Proton Exchange Membranes) to operate. Two other lectures of Track A cover general fuel cell information including overall efficiency, packaging methods and stack assembly, comparison with other energy conversion methods limited by Carnot efficiency.

The first six weeks in Track B are designed to improve the students' skills in modeling and instrumentation. Using the software packages, the students are given three modeling exercises and three virtual instrument exercises. The modeling projects deal with basic aspects of electrochemical reactions and Nernst equation, heat and fluid flow, system assembly, and implementation of basic controls. The instrumentation exercises include building basic virtual instruments for measuring techniques using Labview^R software's exclusive method of building VI (Virtual Instruments) to achieve specific tasks, such as measure temperature, pressure, power, or actuate specific controls such as turning on a fan or a pump, or closing and opening solenoid valves. Some of the experiments envisioned at this time are described below.

All these building blocks are used in the next six weeks to model actual fuel cells, and conduct experiments that involve operating fuel cells systems. To achieve the goals for a complete multi-disciplinary experience for the students, they are organized in teams of three to four. Each team is given two specific tasks: One is to choose a topic within the general fuel cell technology field, conduct a full literature search on the topic, expand on they learn and present a Powerpoint presentation to the class. The Second is to work together on a full power-up, full load management control run, and system shot-down experimental operation of a PEM 1.2 kW fuel cell. Either Labview or a proprietary data acquisition and control software exclusive to each fuel cell package is used for these experiments.

III. Project Details

While the flexibility of the PEMFC design makes it an ideal candidate for use in a variety of applications, several areas within the technology need to be advanced to make them a practical and cost effective solution. Issues associated with water management, membrane longevity and cost, need to be addressed in order for the PEMFC to be seriously considered as a viable alternative to present day carnot-cycle/heat engines. As a result, a great deal of effort within the fuel cell community is centered on improving membrane and electrode materials, developing methods for managing product water levels and implementing novel manufacturing techniques to reduce cost .

In addition, issues regarding storage, transportation and distribution, and point of use sale protocols involve hydrogen safety and production, regulatory agencies both at the state and federal levels involved in safety (OSHA) and transportation (DOT) rule making authority need to be involved. The student projects span the entire spectrum of these issues and allow the training of rounded individuals that have to design, build, deliver, and regulate every aspect of fuel cell utilization.

IV. Experimental Projects

The Fuel Cell Laboratory at consists of a prototype test station fully outfitted with extensive data acquisition systems, a single stack 250-watt test fixture incorporating Teledyne Energy Systems prototype, two (2) 1.2 kW Nexa^R systems from Ballard, and numerous small scale fuel cell stacks, photovoltaic powered electrolysers, and numerous balance-of-system components.

(1)Labview and data acquisition introduction

This experiment will expose the student to Labview and basic concepts associated with data acquisition. The student will be "walked" through a simple Labview based DAQ program to become familiarized with the software environment and operation of the test station. This will provide the student with a better understanding of how subsequent experiments will be performed.

(2) Effect of current density on cell voltage

This experiment will expose the student to how a fuel cell's performance is linked to current density. Polarization curves (cell voltage vs. Amp/cm^2) will be generated at various pressures and the results analyzed to provide reasons behind observed performance variations.

(3) Effect of reactant gas stoichiometric flow rates on fuel cell performance

To demonstrate the effect reactant gas flow delivery has on performance, the student will test the fuel cell, operating at a fixed current density, under various stoichiometric rates. Results will then be plotted with respect to cell voltage and conclusions made.

(4) Effect of fuel cell operating temperature on performance

To provide a first-hand understanding of how operating temperature effects fuel cell performance, the student will begin by theoretically determining the effect various temperatures have on performance, and then test the fuel cell at the specific conditions. The student will then compare theoretical and experimental results.

(5) Effect of fuel cell operating pressure on performance

To gain an appreciation of the role operating pressure has on fuel cell performance, the student will begin by theoretically determining the effect various pressures have on performance, and then test the fuel cell at the specific conditions. The student will then compare theoretical and experimental results.

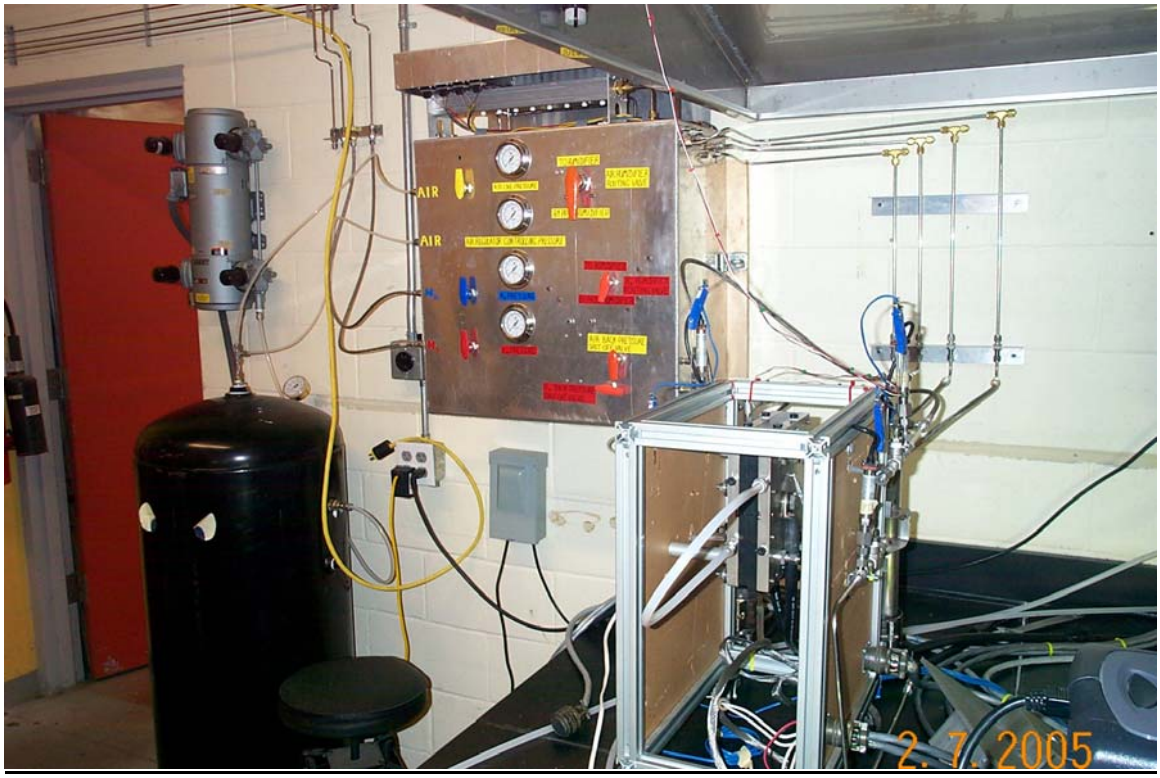
(6) Effect of cathode and anode gas humidification on fuel cell performance

This experiment, will allow the student to obtain a first hand understanding of the role humidification has on fuel cell stability. The student will be asked to generate a simple software model to determine the amount of water necessary to properly humidify at different fuel cell operating temperatures and pressures. These conditions will then be simulated on the test station and the resulting fuel cell performance evaluated.

(7) Fuel cell heat generation as a function of cell voltage

In this experiment, the student will learn about how cell voltage relates to fuel cell thermal efficiency and heat generation. Students will generate simple software models to predict heat generated with respect to cell voltage and then verify results with laboratory testing.

(8) System design and verification project



Teledyne Single Stack Test Set-up

The first part of the project will entail the student designing a system for providing power to a particular application. The student will be required to generate a system model, which will take into account power conversion efficiencies, required fuel cell power, expected fuel cell stack voltage range, heat removal requirements, reactant delivery requirements, gas storage requirements and fuel-to-net output system efficiency. The application, e.g. electric fan, resistive heater or water pump, will be of the students choosing and approved by the course instructor. The second part will consist of the experimental phase in which the system will be assemble and tested in conjunction with the fuel cell to attain data for comparing to model results.

The remainder of the class focuses on the PEM fuel cell, its fundamental operation, basic design, components, operating conditions, performance, applications and prevalent system designs. The fundamentals of electrochemical and thermodynamic processes associated with PEMFC are addressed, as well as a review of basic designs and components used. Major components such as membranes, electrodes, catalysts, gas diffusion layers, collector plates, bus-plates and endplates is covered to provide a fundamental knowledge of present materials. A substantial time is spent reviewing operating conditions and their effects on fuel cell performance. Effects of operating pressure, temperature, reactant gas humidification, product-water management and heat removal is also discussed. Commonly used methods for identifying causes of maladies and appropriate remedies are also examined. Considerations necessary for the implementation as well as sizing of a fuel cell stack to a particular application are discussed. This will also consist of a review of electrical design considerations necessary to meet both DC and AC power requirements. An overview associated with the connection of fuel cell stacks in series, in parallel or in conjunction with batteries is provided. Three main system configurations are discussed, pure hydrogen/oxygen, pure hydrogen/air and reformate/air. Both advantages and shortcomings are addressed and areas of improvement reviewed.

V. Achievements and Conclusions

Student reaction thus far has been exceptionally gratifying. There is a sense in the classroom that this is a real opportunity for learning. The chemistry between the students and the teachers reveals the special bond that develops when a group of interested students and teachers come together for a common goal. While projects and lab assignments are graded, it is clear that most of the students are not in this class are not attending merely for a grade. One of the most interesting observations in this class is that when learning is task oriented, much better results are achieved. This is particularly evident in the students' attitude toward modeling and instrumentation software packages. Because the students are aware that they will use the software in the upcoming experiments involving the fuel cells with their specific lab assignments, there is improved attendance, retention, and nearly 100% compliance with assignment goals. As compared with the authors' experience in for example Experimental Methodology which also uses the Labview packages but for generic experiments, there appears to be a better response in the goal oriented furl cell class.

In summary, the Fuel Cell Course has proven to be a tremendous tool in multi-disciplinary learning, in the teaching of modeling and instrumentation software, covering the fundamentals of fuel cell technology, and hands on training of students with PEM fuel cells.

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