2006-2251: ADDING A HANDS-ON LABORATORY EXPERIENCE TO THE FRESHMAN ENGINEERING PROGRAMMING CLASS AT CLARKSON UNIVERSITY

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Adding a Hands-On Laboratory Experience to the Freshman Engineering Programming Class at Clarkson University

Abstract

Clarkson University received a grant from the National Science Foundation to effect curriculum reform by adding more hands-on experiences in engineering classes. The first class for attempted reform was the freshman engineering class ES100, *Introduction to Engineering Use of Computers,* a second-semester freshman year course taken by approximately 350 students; nearly all engineering majors.

One of the desired changes to the course was to incorporate laboratory experiments that could be performed by the students to further pique their interest in engineering and to generate real-world data sets for processing, analysis and reporting. The experimental system developed was designed around an alternative energy system, i.e., a fuel cell apparatus. This setup included a solar panel, an electrolyzer, two gas holding tanks, two fuel cells and a variety of load devices, e.g., thermoelectric cells, small motors, etc. Details of the experimental setups and the logistics to incorporate these into the class are presented.

Background

In 2003, Clarkson University received a grant from the National Science Foundation entitled "Hands-On Learning in Engineering". The major goal of this project was to increase the number and quality of hands-on experiences in engineering classes. The first class for attempted reform was the freshman engineering class ES100, *Introduction to Engineering Use of Computers.* ES100 is a second-semester freshman year course taken by approximately 350 students; nearly all are engineering majors.

Prior to the Spring of the 2004-2005 academic year, ES100 was handled independently by each of four engineering departments, each with their own instructor, teaching solely to their own majors, using their own, independent syllabus and typically, taught in a lecture hall format. There was no coordination between sections, no required standardization of computer languages or tools and no shared vision for the outcomes of the course. None of the sections included any laboratory experience outside of computer lab.

The reform of this class involved all four engineering departments and was actively supported by the administration of the Coulter School of Engineering. Two teams of faculty and graduate students were formed: one to work on the overall curriculum issues and one to develop multi-disciplinary laboratory experiments. The lecture portion of the course now emphasizes the use of MATLAB software to model and analyze simple systems. All sections are coordinated and involve instruction in a computer classroom with emphasis on hands-on exercises. Another of the desired changes to the course was to incorporate laboratory experiments that could be performed by the students to further pique their interest in engineering and to generate real-world data sets for processing, analysis and reporting.

A team of faculty and graduate students were tasked with designing a multidisciplinary experiment that would include aspects of each area of engineering involved. It was required that the system utilize a computer-based data acquisition system and be controlled using LabVIEW® software in order to provide the students with exposure to these tools and technology to provide a foundation for higher-level classes where these are used.

It was desired that the experiments involve a system that could be tested in component parts and as a whole to emphasize breaking down a complex problem into its component parts for better overall understanding. In addition to these requirements, and the need for the experiments to be interesting to freshman students, the experiments needed to be economical, rugged, reliable and straight-forward as well.

Overview of the Experiment

The experimental system developed was designed around an alternative energy system, i.e., a fuel cell apparatus. This setup included a solar panel, an electrolyzer, two gas holding tanks, two fuel cells and a variety of load devices, e.g., thermoelectric cells, small motors, etc. (figure 1) The laboratory experiments were broken into four parts: solar panels, electrolyzers, fuel cells, and then a complete system including loads. Each of the first three laboratory experiments was designed to measure the operating characteristics of one of the fundamental components in the system. Once the behavior of each component was understood, the overall system was examined for a given load.

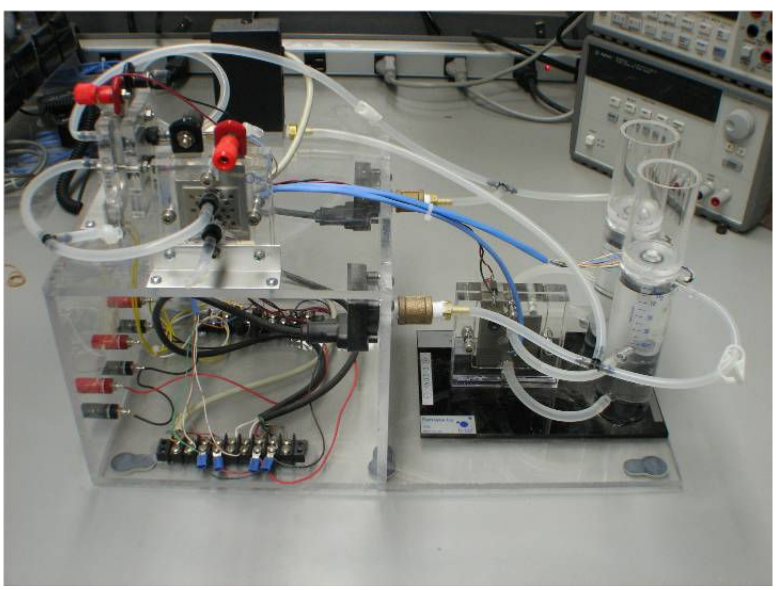

Figure 1. Alternative Energy System Experimental Setup

For example, during the electrolyzer experiment, students used LabVIEW® to record voltage and current waveforms applied to the electrolyzer. Using these data and information gathered from visual inspection of the gas holding tanks and time, students learned how much hydrogen gas the electrolyzer could produce based on its power input and its efficiency. They also investigated the chemical reaction of water and how it applied to the electrolyzer. A thermocouple was embedded in the electrolyzer to monitor temperature as the reaction took place.

General Description of the Hands-on Lab Experience:

The ES100 laboratory constitutes 30% of a student's final ES100 grade based on four experiment-based projects. Students work together on project teams of up to four students throughout the laboratory portion of the course. For each laboratory project, there are four areas of responsibility that can be summarized as follows:

1. Wiring: One team member has primary responsibility for wiring the required circuit components as indicated in the laboratory procedure.
2. Measurements: One team member has primary responsibility for performing and recording all measurements indicated in the laboratory procedure using the provided LabVIEW virtual instruments.
3. Data Analysis: One team member has primary responsibility for importing the collected data into MATLAB and performing all of the data analysis/visualization associated with laboratory experiment in MATLAB. Hard copy listings of any MATLAB code developed to support the lab should be included in the lab report.
4. Report: One team member has primary responsibility for writing the laboratory report which will summarize all measurements and answer all questions posed in the laboratory procedure.

An important aspect of the hands-on learning process is that each team member is given an opportunity to perform each role at least once during the course of the semester. To accomplish this, individual responsibilities *rotate* among the team members throughout the four lab projects. It is emphasized to the students that, even though one student has the principal responsibility for a task, the work is expected to be shared and understood by all group members.

Lab Project 1: Solar Panel Experiment

A solar cell, or photovoltaic cell, is a semiconductor device consisting of a large area p-n junction diode that, in the presence of light, is capable of generating usable electrical energy. This form of energy conversion (called the photovoltaic effect) was discovered in 1839 by French experimental physicist Alexandre-Edmond Becquerel. The field of research related to solar cells is known as photovoltaics.

Solar cells have many applications. They are particularly well suited to and historically used in situations where electrical power from the grid is unavailable, e.g., remote power systems, Earth orbiting satellites, handheld calculators, remote radiotelephones and water pumping applications. Solar cells, in the form of modules or solar panels on building roofs, are often connected to the power grid through an inverter in a “net metering” arrangement (where an alternative energy system owner receives retail credit for at least a portion of the renewable electricity that they generate).

The developed experiment investigates the conversion of photonic energy to electrical energy using commercially available poly-crystalline solar cells and is designed to investigate the relationship between voltage, current and power output for a solar panel given changes in light intensity and angle of incidence (figure 2). Students use a custom LabVIEW virtual instrument to acquire experimental data (figure 3) and the MATLAB programming environment to perform the data analysis and visualization necessary to document their experimental results in a written report.

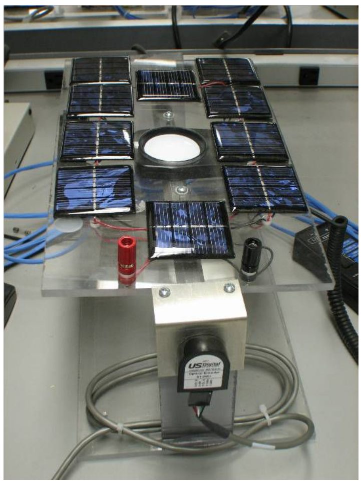

Figure 2. Solar Panel Experimental Configuration

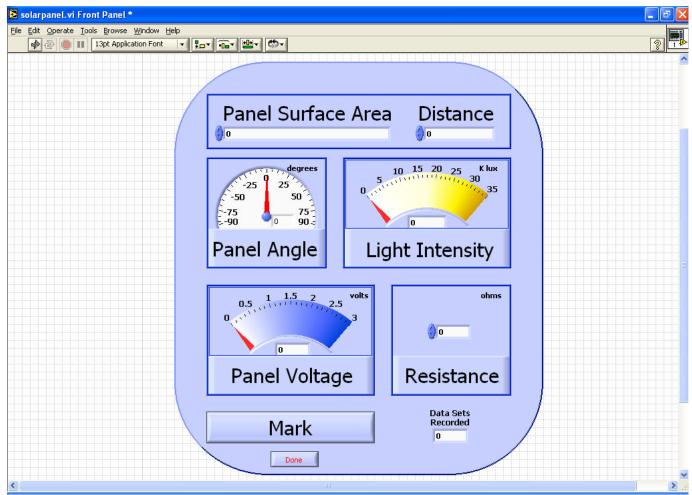

Figure 3. LabView Virtual Instrument Interface

Lab Project 2: Electrolyzer Experiment

In chemistry and manufacturing, electrolysis is a method of separating bonded elements and compounds by passing an electric current through them. An electrolyzer is a device that performs electrolysis, e.g., for water we have $2H_2O_{(L)} \rightarrow 2H_{2(G)} + O_{2(G)}$.. Within the electrolyzer an electrical potential (voltage) is applied across a pair of conductors immersed in the water. The negatively charged conductor is called the cathode and the positively charged conductor is called the anode. Each conductor attracts the ions of the opposite charge. Positively charged ions (cations) move towards the cathode while negatively charged ions (anions) move to the anode. The energy required to separate the ions and increase their concentration at the electrodes is provided by an electrical power supply that maintains a potential difference (voltage) across the electrodes. At the electrodes, electrons are absorbed or released by the ions, forming concentrations of the desired elements or compounds. For example, when water is electrolyzed, hydrogen gas (H_2) will form at the cathode and oxygen gas (O_2) will form at the anode. This phenomenon was first discovered by William Nicholson, an English chemist, in 1800.

In the developed experiment an electrolyzer takes water from two storage tanks, splits water molecules into hydrogen and oxygen gas using an electric current, and returns the gases to the storage tanks. The setup is used to investigate the conversion of electrical energy to chemical potential energy. Effects studied include the relationship between voltage and current in an electrolyzer, e.g., decomposition voltage, the difference between the theoretical and experimental volume of gases produced, and the effect of changing the electrical potential (voltage) on electrolyzer performance. Students use a custom LabVIEW virtual instrument to acquire experimental data and the MATLAB programming environment to perform the data analysis and visualization necessary to document their experimental results in a written report.

Lab Project 3: Fuel Cell Experiment

This experiment investigates the conversion of potential energy, stored chemically as hydrogen and oxygen gas, to electrical energy using a device called a proton-exchange or Polymer Electrolyte Membrane (PEM) fuel cell. A PEM fuel cell produces electricity by reacting hydrogen and oxygen gas together to form water, i.e., $2H_{2(G)} + O_{2(G)} \rightarrow 2H_2O_{(L)}$. In this type of fuel cell, hydrogen is split into protons at the anode, which in practice is a thin layer of catalyst on the surface of a polymer membrane. These hydrogen ions travel across the membrane to the cathode (which is similar to the anode layer) where they combine with oxygen and electrons that have traveled to the cathode from the anode via an external electrical "load" circuit. The fuel cell's only by-products are heat and water when it is fueled using pure hydrogen gas (produced by electrolysis). In order to function properly, the membrane must be a special material capable of conducting hydrogen ions (protons) but not water molecules or electrons as this would "short circuit" the fuel cell.

The developed experiment investigates the relationship between voltage, current and power output for a PEM fuel cell, the effect that an electrical load (resistance) has on the average fuel cell voltage, current, power and hydrogen consumption rate, and the energy efficiency of the fuel cell. Students use a custom LabVIEW virtual instrument to acquire experimental data and the MATLAB programming environment to perform the data analysis and visualization necessary to document their experimental results in a written report.

Lab Project 4: Applications of Renewable Energy Systems

This experiment investigates several practical applications of renewable energy systems that involve the conversion of electrical energy to other forms of energy used to accomplish practical tasks. Three real-world applications (involving different forms of energy) are studied: (1) drinking water storage using a submersible pump (mechanical energy) (figure 4), (2) heating or cooling a space using a thermoelectric cooler (thermal energy) (figure 5), and (3) lighting a room using a cluster of white light emitting diodes (photonic energy) (figure 6).

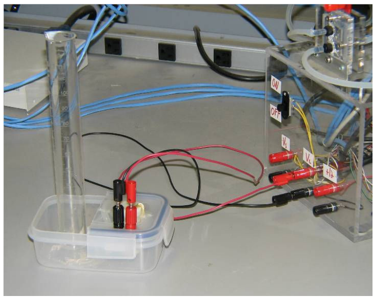
Figure 4. Mechanical Energy Demonstration

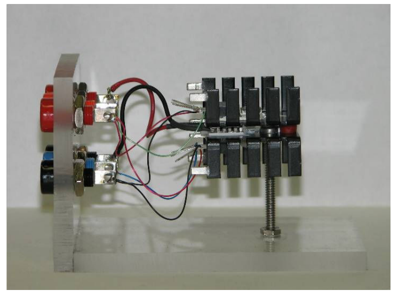
Figure 5. Thermal Energy Demonstration

Figure 6. Photonic Energy Demonstration

For each of these applications, an experimental setup has been developed that is fully instrumented and compatible with the first three laboratory setups. This arrangement allows students to study the flow of renewable energy from its primary source (light converted to electrical energy via a solar cell), to a storage medium (hydrogen gas via water electrolysis), to electrical generation (via a hydrogen-based PEM fuel cell), to a variety of practical user "loads," so that that can characterize the efficiency of the overall process.

Ultimately, students are asked to consider how the renewable energy systems studied could be applied to develop real-world products that better serve the needs of humanity. As in the prior laboratory experiments, students use custom LabVIEW virtual instruments to acquire experimental data and the MATLAB programming environment to perform the data analysis and visualization necessary to document their experimental results and justifying their product design concepts based on the observed experimental data in a written report.

Physical Description of the Lab Stations

There are eight lab stations consisting of an IBM Intellistation M Pro computer with a National Instruments data acquisition card. Each station is equipped with an Agilent 344014A 6 ½ digit multimeter and an Agilent E3631A Triple Output DC Power Supply as well as an auxiliary power supply and an Elenco Resistor Substitute Box to facilitate the aforementioned energy system experiments. (figure __)

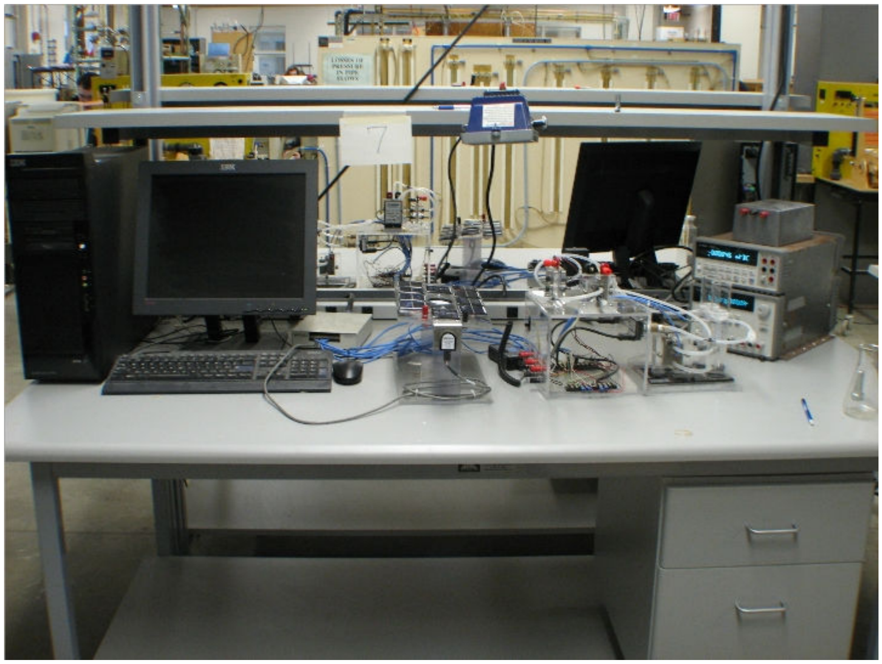

Figure 7. Student Lab Station

Conclusion

The class of 350 students was broken up into twelve (12) sections. The laboratory experiments were performed by teams of, typically, four students who were required to run the experiment, download the data files to be processed and analyzed in MATLAB and to submit a written report. Students were required to evaluate their own, as well as their fellow students', performance.

The four laboratory experiments described in this paper: solar panels, electrolyzers, fuel cells, and then a complete system including loads, are presently in their second year of student use. Students are gaining experience using computerized data acquisition systems, LabView virtual instrument experimental control and data acquisition and data analysis and processing using MATLAB.

The response of the students has been very positive; many have stated that the use of "real" data makes the programming concepts taught in lecture much more meaningful to them. For many of these students, this experience involves the most intensive teamwork they have had to deal with in their educational experience. They learn both the positive aspects of teamwork as well as the liabilities. A student survey has been developed to gauge student opinions on all aspects of the course, including the lab experiences. Adequate data for preliminary analysis of student attitudes should be available at the end of the Spring 2006 semester. One of the key outcome indicators will be feedback from instructors of subsequent courses where the skills and knowledge learned here should have a major impact on future student performance.

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