AC 2010-229: TEACHING RENEWABLE ENERGY THROUGH HANDS-ON PROJECT-BASED LEARNING FOR ENGINEERING TECHNOLOGY STUDENTS

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Teaching Renewable Energy through Hands-on Project-Based Learning for Engineering Technology Students

Abstract

Today we are facing an urgent need to prepare our undergraduate and graduate students with multidisciplinary skills to meet the challenges of the fast-growing energy economy. The objective of this paper is to explore the application of hands-on, project-based learning methods for teaching renewable energy courses to engineering technology students. Several renewable energy projects, including fuel cell, wind energy, and solar energy projects, were assigned to students who were interested in learning the new technologies. For the project assignments, the students were expected to conduct literature searches, to design experiments, to fabricate or request hardware, to test the devices, and to analyze the results. We demonstrated that hands-on teaching methods are effective for introducing various renewable energy concepts and practical skills to engineering technology students. Through working on the projects, students not only got a better understanding of the basic concepts of various types of renewable energy, but also were able to apply the concepts in the design of hardware and systems. Supervised by faculty with expertise in R&D of fuel cells, power electronics, solar energy, and thermal energy, the students were able to gain practical skills for fabricating and testing key materials, components, devices, and systems of various renewable energy technologies.

Introduction

Energy is becoming very important in the economic development of our society. The combination of the limited fossil fuel supply together with concerns about pollution and global warming has brought the development of clean and renewable energy to the forefront of future human endeavors. It has long been recognized that human activities impact many global problems that we face today, such as air and water pollution, global warming, the fuel shortage, etc., and if unchecked, these problems can bring disastrous outcomes to the earth and to all living creatures. In addition, the limited fossil fuel supply impacts the economy and national security and points to an urgent need to develop alternative renewable energy sources.

Engineers of the future will have to grapple with this energy problem for a long time to come, and it is important that universities and teachers prepare them for this task. Both graduate and undergraduate research, education, and community outreach in renewable energy will accompany the growth of research activities in this area. Current renewable energy courses emphasize instruction of principals (both qualitative and quantitative) and application of different renewable energy technologies. The students learn the fundamental and quantitative principles of the various renewable energy options, but they do not often get to practice using those skills in direct application to real-world problems. While it is essential to train students with solid analytical skills for how to design and apply different renewable energy technologies, it is also very important to train them with hands-on skills so they are able to design, fabricate, test, and manufacture key materials, components, devices, and systems of various renewable energy technologies.

The objective of this paper is to explore the application of hands-on, project-based learning methods for teaching renewable energy courses to engineering technology students. Several renewable energy projects, including fuel cells, wind energy, and solar energy projects, were assigned to students who were interested in learning the new technologies. In the project assignments, the students were expected to conduct literature searches, to design experiments, to fabricate or request hardware, to test the devices, and to analyze the results. Faculty with expertise in R&D of fuel cells, batteries, solar energy, thermal energy, circuit design, and power electronics supervised the engineering technology students working on the projects. The intended outcome was to prepare our students with the multidisciplinary skills needed to meet the challenges of the fast-growing energy economy.

Following are examples of some of the hands-on projects used to introduce renewable energy courses to engineering technology students. Although the objectives for each individual project were different, the presented examples share common practices, including:

(1) Students achieved a basic understanding of hardware or control systems by taking the courses related to the assigned projects or/and conducting literature searches.

(2) Students learned how to define specifications of hardware or control systems from the faculty members with expertise in the field.

(3) Students designed experiments to meet their project objectives.

(4) Students fabricated hardware or assembled test systems by working closely with their project advisors.

(5) Students analyzed the test results and prepared a final report to document their learning and findings.

Proton-Exchange Membrane Fuel Cells Project

Proton-exchange membrane H_2/O_2 fuel cells (PEMFCs) and direct methanol fuel cells (DMFCs) using a solid polymer, such as Nafion®, as an electrolyte have been the main focus for alternative power sources in many applications and are especially favorable for use in passenger vehicles[1]. However, hydrogen storage and high manufacturing costs are still barriers to overcome in order to commercialize PEMFC technology. DMFCs do not have the fuel storage problem, but do have the challenge of methanol crossover from the anode to the cathode through the membrane. Methanol crossover causes a poisoning of Pt-based catalysts in the cathode. To reduce the negative effects of crossover poisoning, methanol fuel has to be diluted in the DMFC, which reduces its energy density. To counter the crossover poisoning effects, the amount of Pt in the cathode has to be increased to improve the energy/power capacities of the DMFC, which then drives up its cost.

It was our objective to prepare our students with a good understanding for how various types of materials, such as polymers and nanomaterials, impact the performance, durability, and cost of PEMFCs. By taking the Engineering Materials course (MET 348) and conducting literature searches, students achieved this basic understanding of the PEMFC technology and learned how various materials affect the performance, durability and cost of PEMFCs. A literature summary report was assigned to the students and used to access how well the students understood the basic concepts of PEMFC technology.

After students learned what a PEMFC is, what the key components are in a PEMFC, what types of materials are used in the key components, and what challenges still remain to limit PEMFC applications, they were ready to form a team and to design experiments for how various types of materials affect the performance, durability, and cost of PEMFCs. Various teams focused on different components of the PEMFCs, e.g. one team studied how the amounts of catalyst loading on the anode and cathode affect the performance of PEMFCs, and another team investigated how the changes of material compositions of gas diffusion layers affect fuel cell performance.

Supervised by fuel cell researchers, students assembled and tested PEMFCs with designed features. Fig.1 shows key components in a typical PEMFC for the test. Fig. 2 shows the major equipment used by students to prepare key components for PEMFCs' assembly. The students recorded current/voltage curves under various fuel cell operation conditions, including various temperatures or H_2/O_2 back pressures. Each student had an active part in gathering materials, assembling, and eventually testing the fuel cells and then wrote an individual project report at the end of the semester.

In the final report, students commented that the projects were really great learning experiences. Throughout the semester, they learned about the procedures to prepare, fabricate, set up, and test PEMFCs. By tweaking several variables in designing the PEMFCs, they were able to improve PEMFC power capacity.

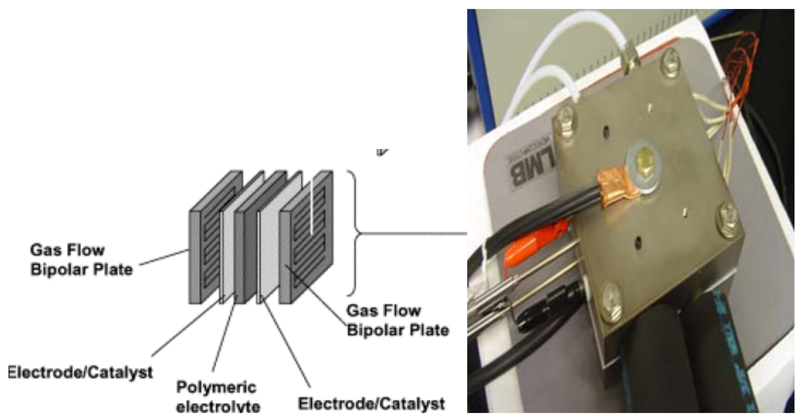

Figure 1. A typical PEMFC contains two bipolar plates with gas flow channels, catalytic layer for the anode, catalytic layer for the cathode and polymeric electrolyte (Nafion®) between two electrodes.

(a) **(b)**

(c) **(d)**

Figure 2. (a) Cole-Parmer 8890 was used to prepare inks for catalytic layers. (b) Carver Auto Series hot press auto "C" (model 3889) was used to prepare membrane electrode assemblies (MEAs). (c) VWR vacuum oven was used to dry the MEAs. (d) Fuel cell test system 850e, Scribner Associates (with Back Pressure module), was used to test PEMFCs.

Wind Power Systems Control Project

The main objective of this project is to educate undergraduate student researchers on developing a power system control technique for remote area application involving wind turbines. The power system including wind turbine has an uncertain source of power which depends on the speed of wind. To feed sensitive loads on a power system there are generally two approaches. One approach suggests grid connection wind turbines to have bidirectional power flows, and the other is to provide a short term backup unit like battery to feed the load when the wind speed is low. This project was also part of the course development on renewable energy generation and power plant design. The focus was on the design of power plants and their requirements for renewable energy systems. Because of more economic power generation in wind turbines compared to solar cells, research on wind power is of paramount importance.[2]

The project started by defining load power requirements such as AC/DC, Voltage, and frequency. A power system that includes wind turbine, power converters, and storage devices was developed and simulated. Hardware components including wind turbine-generator, power management system and battery controller were individually designed, tested and integrated to ensure seamless operation of the system components. Figure 3 shows the wind power generation system layout for telecommunication systems. Several predefined scenarios such as high wind speed and low wind speed, and days of autonomy were tested.

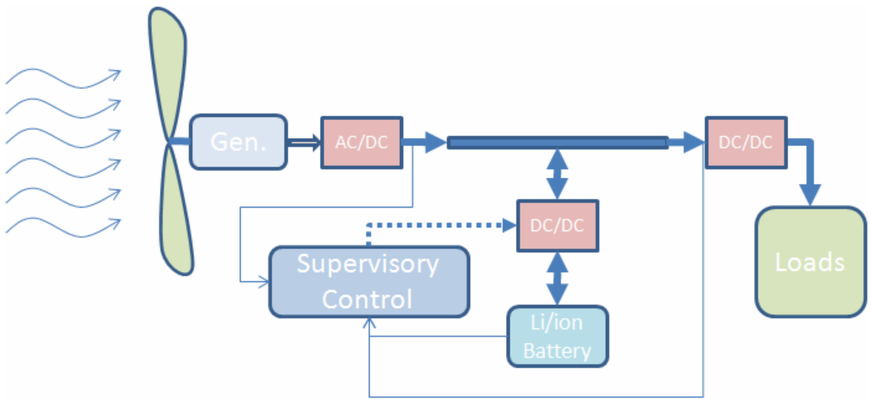

Figure 3. Wind power generation with battery pack in telecommunication towers.

The research was conducted to motivate undergraduate students towards a future in energy generation. They were selected from Multidisciplinary Undergraduate Research Initiative (MURI) teams. Students were introduced to the main ideas of renewable energy, energy harvesting, wind power system, wind turbines, supervisory controls, battery units, and power electronics.

Understanding advanced renewable energy systems is contingent upon mathematic and a systems engineering background. However, the basics of wind power systems can be covered at the high school level with hands on experience to encourage and attract students to STEM majors at the university level.

One of the main findings of the wind power system control project was a huge group of interested applicants for the project through MURI funding. Wind and other sources of energy are very popular among the current pool of university students. Advanced courses in this area will prepare and enable them for research at the graduate level. I received some positive responses in pursuing graduate studies on energy systems when I asked my undergraduate student researchers about their future plans and goals.

Solar Projects

One solar project involved the design of a solar thermal domestic hot water system with an option for radiant heating. The second project involved the design of a photovoltaic system that would provide the electrical power. Then the systems were combined, see Figure 4, to provide all the energy needs for an Eco Ready Shelter (an intermodal shipping container, sustainably converted into a dorm room). The class was initially setup to experience the full range of hands-on project based learning including: specification, design, fabrication, testing, documentation, and verification, but due to equipment delays and the iterative process of bring together multiple disciplines (ECET, MET, Art, CEMT, and IDT) the students focused on the first two items.

Informal interviews with experts were ongoing during the design process. Experts in green materials, solar technology, green roofs, various trades, etc. were helpful as sounding boards to the team's design ideas. The experts also included key university personnel that will serve to advance the concept on campus and to determine its eventual site.

The design of the solar hot water system and the photovoltaic system followed standard processes outlined in references[3-5] with two exceptions. Typically the first step in solar design is to identify and reduce loads due to the cost of installing solar equipment. The first design exception was to temporarily ignore load reduction and energy efficiency and to design a baseline system for an average American dorm student (i.e. one with no green philosophy, which is to say, no attempt to modify behavior or address their energy footprint). This was necessary because the project exists at multiple levels and with multiple disciplinary components. The primary project group consisted of volunteer students, professors, and industry professionals that operate outside of the standard class schedule. To include the project in the discipline specific classes, a scope of work had to be defined that was reasonable for a fifteen-week project. For the electrical and mechanical engineering technology students, that meant a solar thermal domestic hot water system for two adults living in the shipping container with an option for additional radiant heating for the first team's project and a solar photovoltaic system to provide power for all typical dorm room loads as well as the solar thermal system loads for the second team.

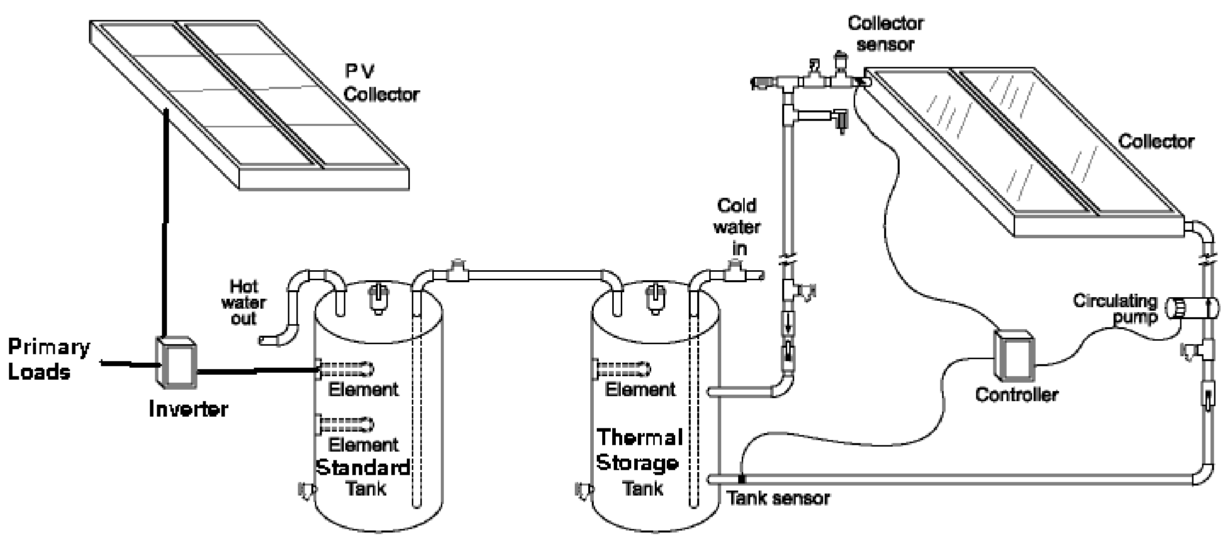

Figure 4. Combined PV energy generation and energy storage

The second exception relates to developing a novel way of combining the systems as shown in Figure 4, which we did not locate in the literature search, and which requires construction and testing in a future phase in order to complete the solar thermal design. In lieu of that data, the solar thermal system design consisted of one thirty-tube, evacuated tube heat pipe collector with an eighty-gallon thermal storage tank and a forty-gallon hot water tank. The hot water tank also included an auxiliary heating system that uses an eco-friendly ethanol fuel. The photovoltaic system was composed of twelve panels in a 2.2kW array with eight sealed, lead-acid batteries that could provide four days of energy storage. Depending on future decisions related to lighting, heating, electrical load reduction, thermal insulation levels, and the combined system performance, one or both system designs may be reduced in size (number of panels, thermal collector size, or thermal storage size).

Through this project, it was found that design is an iterative process, made more lengthy by including multiple personal/disciplinary perspectives, but with increased rewards for the educational process. Students developed a clearer picture of teamwork in this design process due to the interaction of multiple trades, professions, disciplines, and personalities in design charrettes for a project that started with a very broad scope.

Conclusions

Today we are facing an urgent need to prepare our undergraduate and graduate students with multidisciplinary skills to meet the challenges of the fast-growing energy economy. Through various project assignments, we demonstrated that hands-on teaching methods were effective approaches to introduce principles of various types of renewable energy to engineering technology students. Through working on the projects, students not only got a better understanding of the basic concepts of various types of renewable energy, but also were able to apply the concepts to the design of hardware and systems. Supervised by faculty with expertise in the R&D of fuel cells, power electronics, and solar and thermal energy, the students were able to gain practical skills for fabricating and testing key materials, components, devices, and systems of various renewable energy technologies while working on the assigned projects.

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