Advanced Electrical Energy Education
- Internet, Industrial Alliance, and Software

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Abstract: Electrical Energy Education is an important part of the electrical engineering curriculum. Traditionally, the contents include power generation, power distribution, and electrical machinery. However, issues related to advanced electrical energy education should be addressed due to following reasons. 1. Rapid progresses have been made in the research and development. New energy systems such as fuel cell power generation units are being tested and installed. 2. The Internet has provided abundant resource materials and up-to-date information around the world, and is a useful tool for the instructions in the classrooms and for the research in the laboratories. 3. The U.S. electrical utility industry is going through a "deregulation" process. Decentralized power generation modes may be preferred in the future. 4. Energy industry wants to establish closer relation with us to conduct joint R&D and to train next generation engineers. 5. Newly developed software packages for energy applications are much suitable for teaching and research. 6. There is an increased pressure on the electrical energy producers to increase efficiency and reduce emission. The electrical energy education is becoming an interdiscipline topic. In this paper, two new courses will be presented. The first course is entitled "Advanced Electrical Energy Systems". The teaching contents of this course are based on the author's R&D materials collected in the past several years. The students were from electrical engineering and mechanical engineering on campus, and a utility company (through a distance learning method). The second course is an industrial design course, with three requirements: 1. Student team work; 2. Industrial co-advisor and co-examiners; 3. EPRI software package and Internet. The feedback from participants of those two course were very positive. In summary, Advanced Electrical Energy Education rely on the Internet, alliance with the industry, and software.

Key words: electric energy, fuel cell, new course, internet resource, industrial alliance

1. Introduction

There are many areas in an electrical engineering curriculum, including communication, control, computer, and power. Usually, contents of power education are selected from the following four topics: power generation, power distribution, electrical machinery, and power electronics [1-4]. Depending on a particular curriculum structure, some of the contents may be required and others may be technical electives. New courses and/or contents may be added to a curriculum when there are new developments in the field of electrical power engineering. Furthermore, such teaching may be expanded into electrical energy, which deals with energy conversion, generation, systems, consumption, and environmental impact.

There are many reasons to add the advanced electrical energy systems in the electrical engineering curriculum. Firstly, rapid progresses have been made in the research and development (R&D) of advanced electrical energy systems. New energy systems such as fuel cell power generation units are being tested and installed. The concept and practice of the new systems are quite different from that of the traditional systems. Engineering students should have some knowledge about the newly emerging energy systems. Secondly, the Internet has provided abundant resource materials and up-to-date information around the world. The speed of information flow is so fast that we can use the Internet as a useful tool for the instructions in the classrooms and for the research in the laboratories. Thirdly, the U.S. electrical utility industry is going through a "deregulation" process. In the future, there may be several separated entities dealing with electrical power: generation, transmission, and delivery. If the centralized power generation mode can not meet the requirement in a dynamic market, some of the decentralized power generation modes may be preferred in the future. Future engineering practice may be different from the traditional practice. The implication for engineering education is that we need to prepare our students for the change. Fourthly, energy industry wants to establish closer relation with us to conduct joint R&D and to train next generation engineers. Such relation is beneficial to both industrial and academic sides, and most importantly, is beneficial to the students. Fifthly, newly developed software packages for energy applications are much suitable for teaching and research. The software installation and usage are no longer taking much of the valuable time away from the teachers and students. Those packages are indeed user friendly and can yield numerical and graphical results to enhance the teaching process. Sixthly, there is an increased pressure on the electrical energy producers to increase efficiency and reduce emission. Energy system design and evaluation have become more complicated than before, which require better communications among all kinds of engineers including electrical, mechanical, chemical, and/or environmental engineers. Thus, the electrical energy education is becoming an interdiscipline topic.

In this paper, two new courses will be presented. The first course is entitled "Advanced Electrical Energy Systems". The teaching contents of this course are based on the author's R&D materials collected in the past several years. The students were from electrical engineering and mechanical engineering on campus, and a utility company (through a distance learning method). The second course is an industrial design course, with three requirements: 1. Student team work; 2. Industrial co-advisor and co-examiners; 3. EPRI software package and Internet.

2. Advanced Electrical Energy Systems

2.1. Description

This course is a technical elective course. Its objective is to provide students in electrical engineering and other engineering disciplines with the knowledge of advanced electrical energy systems. The prerequisite of the course is the electrical circuit or the introduction to electrical engineering. The teaching contents include: fundamentals of electrical energy systems; development of electrical energy systems; advanced power generation systems such as fuel cells, turbine engines, and solar cells; advanced energy storage systems such as SMES (superconductive magnetic energy storage), battery/capacitor storage; advanced power conditioning units such as UPS (uninterrupted power supply). As an example, the contents related to fuel cells are described in the following subsection. Even though it is difficult to find a text book suitable for the course contents, many reference books are available [5-7].

2.2. Example-fuel cells

A fuel cell is a device that directly converts the chemical energy of reactants into D.C. electricity without combustion. The reaction is an electrochemical process, and requires two types of reactants: fuel and oxidant. The reactants are usually stored outside the reaction areas, and will be supplied to the reaction areas when power production is required. The fuel is typically hydrogen, and the oxidant can be atmospheric oxygen. There are three essential parts in the reaction areas: fuel electrode or anode, oxidant electrode or cathode, and ion-conducting electrolyte. Both anode and cathode are porous, and allow reactant gases to flow. The electrolyte is usually dense, and does not allow any cross flow between two electrodes. The molar ratio between the reactants is that two hydrogen molecules correspond to one oxygen molecule. As an example, in the anode area, two hydrogen molecules split into four positive hydrogen ions and four electrons. The positive ions move through the electrolyte and reach the cathode. At the same time, the electrons first flow to a load outside of the fuel cell, and then to the cathode where one oxygen molecule combines with four hydrogen ions and four electrons. Besides the electricity produced, two water molecules form. Theoretically, the D.C. voltage produced by a fuel cell is 1.229 volts. The current density of the fuel cell stack is determined by the equivalent impedance of electrodes and electrolyte, which in turn is determined by their effective surface areas, volumes, and electrochemical properties. To construct an actual fuel cell power generator, one needs to assemble multi-unit-cells into a stack, connecting the cells in series and/or parallel configurations to meet the voltage and current requirements. Furthermore, an inverter is needed to convert the D.C. into A.C. if desired.

Hydrogen can be obtained in gas or liquid form. Currently, the infrastructures for hydrogen storage and transportation are very limited. A common approach is to extract hydrogen from hydrocarbon sources such as natural gas, methane, methanol, and ammonia. Depending on the electrolyte materials and the electrochemical reaction temperature, such extraction may or may not take place inside of the fuel cells. If not, a fuel processor is needed to produce hydrogen which is then fed into the fuel cells.

Fuel cells have advantages of high efficiency, low noise, and minimal environment impact. In a stationary power application, fuel cell power generators can be located very close to the point of use, which is convenient, safe, and easy control. An example of such application is a fuel cell power generator installed at a waste bio-mass treatment facility where methane from the bio-mass is utilized as the fuel. In a transportation application, fuel cells can be installed in buses and cars, which can be electrical vehicles with or without hybridization of combustion engines.

There are several energy loss mechanisms in a fuel cell, including activation polarization loss, concentration polarization loss, and ohmic polarization loss. The activation polarization loss is caused by low ionic charge transfer reaction. The concentration polarization loss is due to low concentration of electro-active particles near the interface between an electrode and an electrolyte. The ohmic polarization loss is due to the resistive loss in the cell.

According to the electrolyte materials utilized, fuel cells can be classified into several categories: phosphoric acid, molten carbonate, solid oxide, proton exchange membrane (PEM), and alkaline. The alkaline fuel cells have been utilized in space programs for several decades, with efficiency of approximately seventy percent. Due to the cost, the alkaline fuel cells' applications in commercial sectors are limited. Phosphoric acid fuel cell technology is relatively mature, with approximately one hundred unit installed world wide. The power rating of the commercial units is typically 200 KW or larger. The operational temperature is about 200 C. Efficiency is forty percent or larger. When the hot water steam from the cells is utilized for co-generation, the efficiency can reach eight percent or larger. PEM fuel cells are under intensive development and testing worldwide. The operational temperature is approximately 80 C. A typical power range is between 3 and 10 KW. Such power level is suitable for most automotive and residential applications. The power density of PEM is relatively high. Molten Carbonate fuel cells operate at a temperature around 650 C. There are few units installed and tested in U.S., with power lever larger than 200 KW. Solid oxide fuel cells have potentials to be economical, with operation temperatures around 800-1,000 C. A few units have been tested, with power levels in the hundred kilowatts range. Ideally, fuel processing can take place inside of the solid oxide fuel cells, thus eliminating the need for a separate fuel processor.

2.2 The role of internet

Because of the rapid progresses in fuel cell development and testing, one needs to use internet to get the latest information. There are many sites related to the fuel cells, some are educational and others are commercial. Examples of the sites are from U.S. Department of Energy, an alliance called "fuel cell 2000", ONSI-International Fuel Cells, Ballard, Plug Power, and Fuel Cell Energy.

The classroom setting was in a video conference room, with internet connections and video projections. The instructor utilized up-to-date information in the classroom teaching, and students utilized internet to enhance their project presentations. For example, one could link to an educational site where a video animation is stored. By playing the animation, students could see the hydrogen flow, oxygen flow, chemical reaction, and electrons' motion. Such teaching was very effective.

3. Industrial alliance

During the teaching and research of the advanced electrical energy, alliances with the industry were established. Such alliances were motivated from both sides. The electrical energy industry wants to collaborate with us in order to conduct R&D. (Due to the restructuring of the industry, more R&D activities are being carried out by outsiders.) The industry also wants to help the training of the next generation electrical engineers. On the other hand, we need the industrial sponsorships. Working with the industry gives our students experiences in the actual industrial settings.

An example of the alliances is an industrial design course. In a particular design project, three students formed a team to work on problems related to the real products of a power company located approximately 70 kilometer away from the school. There were two advisors. Besides the author, another advisor was a manager from that company. In the first semester, we identified the problems and proposed several solutions. The relationship between voltage and current for each of the products was non-linear. At the beginning of the second semester, students worked on modeling, mathematical calculations, and software simulations. Once the theoretical prediction was obtained, experiments were conducted at the industrial site. There was close agreement between the theory and experiment. The final report was presented in front of engineers and managers of the company, the chairman and faculty of electrical engineering, and student peers.

4. Software

Due to the complicity of the electrical energy problems, such as nonlinear relationships, computer software should be utilized to aid the problem solving. For example, the industrial design course discussed above required a software package. Through intensive computer experimentation, it was found that a newly developed EPRI software package was much suitable for our teaching and learning purposes. The software was called Tflash, and was user friendly. Another well known package was identified as cumbersome.

Currently, we are evaluating other kinds of software packages. For electromagnetic problems in the energy devices, we have evaluated Maxwell 2D and 3D by Ansoft. Static and nearly static problems can be adequately solved by the software. In comparison to an old electromagnetic software package, the Maxwell package is much suitable.

5. Conclusion

In conclusion, Advanced Electrical Energy Education is important. Due to the fast progresses in research, development, and testing, one needs to add new course and/or materials so that the students can gain the new knowledge. To enhance the educational process, the Internet can be utilized as a resource center. Utility deregulation will create more job opportunities for our students in the electrical energy field, and we should prepare the students for the immediate future demands. To establish alliances with energy industry is beneficial to both academia and industry. Newly developed software packages for energy applications are user friendly. The responses from the students and other participants of those two courses are very position. Advanced Electrical Energy Education rely on the Internet, alliance with the industry, and software.

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