Embedding Renewable Energy into the Engineering Technology Curricula

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Abstract

The demand for electrical power is increasing and the conventional energy resources are fast depleting, making the exploitation of renewable energy sources for electricity generation the only alternative. Interest in the production of electricity from renewable energy sources is rapidly increasing. Carbon tax, pollution reduction, and emissions trading legislation are paving the way for environmental accountability and sustainability in the industries. In the last two decades there have been significant advances in the renewable energy technologies, as well as increased demands for engineers and technicians trained in these areas. These require the development of innovative curricula, new courses and laboratories to educate students to work in this rapidly developing industry, or to help professionals become acquainted with these new technologies. However, the pace of change in education curriculum is growing exponentially due to legislative changes, financial or administrative constraints. Engineering education moves into the twenty first century charged with an environmental agenda due to response to wider changes in the society. Educators are regularly modifying curriculum content to embrace technological changes in the learning outcomes. In modern world where everything changes at an extremely fast pace keeping up to date with technology is not only desirable but necessary. The renewable energy is highly interdisciplinary and crosses over between a numbers ofresearch areas, making it quite difficult to be covered in a single course.However, the renewable energy technologies have strong potential for hands-on multi-disciplinary project-based learning. In particular, projects within sustainable engineering and renewable energy technologies can readily involve electrical, mechanical, computer, civil, and chemical engineering aspects while still being accessible to undergraduate students.A natural and efficient way of teaching and embedding renewable energy technologies into curriculum is the problem-oriented and project-based learning approach. In this paper, we are discussing a series of renewable energy projects, included for over a three-year period into the senior project design, power electronics and renewable energy technology courses. Theoutcomes and observations are discussed in details, as well as the lessons learned and the future improvements.Design, development and build renewable energy projectsallow students to work on projects that can be relevant to current leading edge research and technology. The paper also presents the development of an interdisciplinary course on alternative energy as part of this effort to include renewable energy and sustainability into our curriculum. The motivation for the course is outlined and detailed description of the topics covered in the course and the course outcomes are given. The course and the projects are also part of the efforts of to establish a renewable energyconcentration at our university.

1. Introduction

Climate change, green house gases, high oil price, limited world oil reserves are driving the increasing search for new alternative and green energy resources. These environmental concerns and the ever-increasing needs for electrical power generation and steady progress in power deregulation have created increased interest in environmentally conscious distributed generation. Of particular interest are alternative energy distributed generation (AEDG) systems such as wind, photovoltaic (PV), and fuel cell (FC) power generation with near zero pollutant emissions. These generation devices can be used in stand-alone configuration or be connected to the electric grid. Given the rapid progress in AEDG development and utilization, there will be a great need for trained professionals with adequate knowledge in this area to be able to plan, design and operate AEDG systems, evaluate their performance, and evaluate their impact on power systems to which they are connected[2,5]. On the other hand, electric power systems, transmission and distribution systems are undergoing rapid changes due to deregulation, the penetration of dispersed and distributed energy resources (DER), renewable energy generation and power electronics technologies, and the adoption of efficient computation, communications and control mechanisms. Renewable energy is becoming an important and economical source of energy for electricity generation, with a total of 9.33% according to the US Energy Information Administration in its 2003 Annual Energy Review. The bulk of the renewable electric energy comes from hydro, about 7.33%. Emerging renewable energies, such as wind, solar and geothermal account for the remaining 2%. However, it is interesting to mention that wind and solar energy are the fastest growing energy source, with grew more than five-fold in the past decade. Due to the rapid development of the technologies of the renewable energy becomes more and more important. This development and implementation of the technologies for the future energy supply in United States and abroad is also supported by the governments[2,5,].

Engineering and engineering technology programs must offer a relevant and validated curriculum that prepares students for post-graduation success[3,4]. Courses that cover traditional subject matter in mathematics, the sciences, materials, engineering economics and related topics provide the foundation of knowledge upon which specific skill sets are added depending on emphasis. However, it is critical for engineering/technology to transition from theoretical work in the classroom and experiential learning with applications of technology and design. The main objective of senior design courses in engineering and engineering technology curricula is to bridge the gap between theory and real world practice. Accordingly, the proposed senior projects should include elements of both credible analysis and experimental proofing such as design and implementation as discussed in ABET criteria[1].Additionally, the senior design courses can serve as an excellent culminating experience in the program of study when it focuses on research and design projects that have practical value to consumers or to industrial customers.

Due to this unprecedented growth in the use of renewable energy for electricity generation and in the interest of keeping students abreast of the current scientific and technological developments and trends, we believed that it was important and timely to develop an upper-level undergraduate course on renewable energy. There also is a well-documented demand and need in offering program study, courses and training in the areas of renewable energy and power systems[6-10,].This course focuses on wind energy conversion, solar/PV and fuel cell systems, and the impacts of the intermittency of renewable energy on power systems[10]. We also strongly believe that renewable energy topics must be included when it is appropriate into other courses in our program, especially as projects, an essential aspect of the engineering education.

Therefore the purpose of this paper is to describe topical subjects and projects covered in this renewable energy course, involved in our capstone senior design project. The renewable energy course outline may also be used as a starting point for other instructors considering offering a similar course. This course is primarily focus on the wind and solar energy sources, and to a lesser extent on the other renewable energy sources and related technologies. One the other hand, the senior design project course is a 3-term core course usually taken by the students during their terminal year in the ET program. The lessons learned are presented and the ways to improve project management are discussed. Our senior design project course is a 3-term core course sequence usually taken by the students during their terminal year. This paper describes the content and motivation of the renewable energy course and the issues related to the inclusion of the renewable energy projects into senior design and power electronics courses. These projects were first offered in the Senior Project Design course sequence during the 2009-2010, and 2010-2011 academic years[10]. The Senior Project Design courses are intended to stimulate the problem-solving capabilities of the students. The topics for the projects are suggested by the author.

2. Description of the Renewable Energy Course, Course Syllabus and Content

2.1 Course Objectives, Description, and Instructional Design

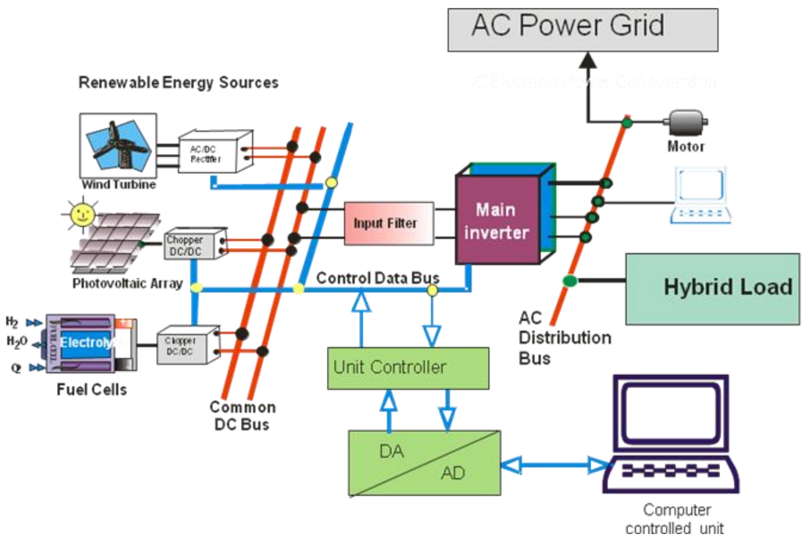

Figure 1 Block diagram of hybrid power (wind/PV/fuel cell) system [adapted from Reference 7]

The course will provide an introduction to the renewable/alternative energy systems with an emphasis on those utilizing solar and wind technologies, storage energy systems and to a lesser extend to the other renewable energy systems, as wave energy, geothermal, etc. The students will learn how the technologies work to provide electrical power today and will get a glimpse of the capabilities foreseen for the future and a few of the basic research needs. The course provides an introduction to energy systems and renewable energy resources, with a scientific examination of the energy field and an emphasis on alternate energy sources and their technology and the most common applications. This course covers the principles of energy conversion in the three distinct areas of wind, solar/PV, and fuel cell power generation, system planning and design[6-10,19]. It also covers the modeling, analysis of major components of an AEDG system shown in Figure1. The topics covered also include the need and the benefits of AEDG, energy storage devices, control and power electronic interfacing. The benefit of such broad coverage is to give the students a broad view of the various components of AEDG.Each student picks one area to explore further by studying and presenting one or two research paper(s) to the class as well as doing a project developing a written report and presenting the results of their work to the entire class.

Due to the time constrains, our university is a quarter-based institution course materials are divided in ten modules. Each module is self-contained and is covering the basic and essential knowledge of the topics. The modules are divided into three parts: ***basic principles, system***

technology, and experimental aspects of the topics. The imparted knowledge is divided into two parts: the first part is the basic knowledge, and the second part is the deepened knowledge, additional contents of teaching, and references. Modules are ended with a multiple-choice quiz, covering theoretical aspects of the topic. After completing the quiz students get access, through the course management system to download the unit homework. The instructional design illustrates how to better present the concepts, convey the objectives of the course ina pedagogical way and appropriate it to suit the targeted audience. Interactive tutorials support both instructor lead and self-paced learning. This course is designed to introduce the students to the principles, characteristics, power conditioning aspects of major renewable energy technologies. The students will also explore the use of electrical equipment required for power transmission and conditioning, and understand their workings and principles. It provides students with knowledge so they are able to design, analyze, and implement small-scale standalone and grid connected renewable or hybrid energy systems. During the second part of the quarter the students are required to design, via a project a hybrid power systems, integrating wind, PV and energy storage systems to provide power for a specific load. The project is handled by a team of 3 to 4 students. The project is part of the final grade of the students, and is complementary to the final exam. The students are free to make the team based on their preferences and mutual interests. They are required to make a 10-min presentation on the project topic during the final exam week of the quarter. The outline of the course includes (ten 3-hour lectures/units):

1. Basic principles of energy generation
2. Introduction to renewable energy systems
3. Electric machines Basics; Electric machines for renewable
4. Solar energy fundamentals
5. Photovoltaic energy production; Photovoltaic systems
6. Wind energy resource characteristics
7. Wind energy conversion systems: aerodynamic and electric aspects
8. Wind energy modeling aspects
9. Fuel cell systems
10. Distributed generation and power quality

This course supports the achievement of the following outcomes: a) an appropriate mastery of the knowledge, techniques, skills and modern tools of their disciplines; and b) an ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering and technology. Our upper-level undergraduate course on renewable energy and power systems was first offered in spring 2009 quarter. It is a three credit-hour course. The course primarily focuses on wind energy, solar/PV, and fuel cell generation, and to a lesser extent on other renewable energy sources and related technologies. Wind and solar energy make up about 75% of the course since wind and solar energy represent the fastest growing areas of renewable energy in the past decades. The teaching modules of this course consist of the following topics each of them presenting a special type of renewable energy and dispersed generations.

Since this course deals mainly with the analysis and the components of the wind and solar energy conversion systems, as well as the analysis of integration and interconnection to the power system grid, the desired prerequisites include a course in energy conversion, electric machines and co-requisites a course in power electronics and power system analysis. Students are expected to be well around in general renewable energy issues and energy conversion technologies. They are expected to be particularly skilful in analyzing and solving wind and solar power systems and related problems. Exam combined with a presentation represents the significant part of the student grade and is used to assess the student course understanding. The renewable energy course is divided into ten modules. Each module can be completed within three to five 50-minute lecture sessions. Due to the diverse and intrinsic interdisciplinary subjects needed to be covered, the following reference texts are used and recommended to the students[11-14].

On completion of this course students should be able to explain: various types of non-renewable technologies, various types of renewable energy technologies, the environmental problems associated with non-renewable and renewable sources of energy, and how to consider the environment with regards to production, conversion and use of energy, how solar cells work and how they are manufactured, the most common applications of solar energy, the future of renewable sources of energy, Students should also be able to describe: the design and operation of a small hybrid system, an integrated renewable energy and energy storage system for remote areas, the concept of energy efficiency and energy conservation, the structure, operation and design of PV, WECS and hybrid power systems, the structure, operation and design of a PV or WECS system, the environmental impacts associated with the energy production, the use and disposal of PV modules or a component of a wind energy conversion system.

2.2 Activities for Hands-on Laboratory Experience

It is well known that good laboratory experiences increase the interest of students in an area by connecting the theory to practice facilitating an active learning process[18-22]. An interesting strategy have been developing at school of technology of our university to have a well trained engineering force with a focus on renewable energy and its related aspects, specifically by involving the design, controls and power electronics of such systems. The main objective of this strategy is essentially to prepare the best engineering technology workforce to satisfy the required energy needs of a country or a region without sacrifice its future sustainability. The presented laboratory experiences have a potential to reach over 50 students a year in Power Electronics, and Renewable Energy Technology basic undergraduate course, 20 undergraduate students in advance courses in addition to those doing undergraduate research. This experience have a tremendous impact in the large amount of ET students that graduate every year from concentrations related to electrical engineering technology (EET) and the future planned renewable energy concentration. The laboratory exercises include:

1. Solar cells and panels, PV systems – MATALB simulation and experimental test
2. Control of single-phase grid converter used for PV residential applications
3. Control of three-phase grid converter used for Wind Energy Conversion Systems
4. Battery tests.

3. Power Electronics and Senior Design Project Courses: Increased Renewable Energy Content

A natural and efficient way of teaching core engineering courses is the problem-oriented and project-based learning approach. Students are often unaccustomed to assimilating material from many courses at one time, thereby making it difficult for them to simultaneously bring together the circuit, signal and system analysis, electro magnetics and control which are required to fully describe the operation of a power electronic converter. In problem- and project-based learning (PBL), learning is encouraged by a problem and students learn topics when they need them during problem solving. In Project-Based learning, students also manage resources and time for project execution and work in teams[18,20-22]. Both Problem- and Project-Based Learning have been applied in many fields of engineering. Motivated by the PBL teaching and learning approaches, for the last three years our focus shifted towards incorporating renewable energy concepts in our senior design project and power electronics courses in order to make them more attractive to the students. To enhance the hands-on experience this course was restructured as a project based course. Students are required to analyze, design, simulate or built a completely functional system, as an end-of-term project, selected from a list proposed by the instructor. The goal of the design project is to explore and enhance students understanding of the fundamental power conversion principles, power circuit simulation capability and hands-on demonstration of circuit prototyping. The course project is worth 20% of the course grade. Students are required to present their project output in a poster session arranged for a technical audience. They are also required to summarize the results of the design in a short report by the end of the course.

Power electronics is the enabling technology for the efficient generation, transmission, distribution and management of electrical energy[15-18]. Teaching power electronics is a challenging task since the field is quite broad and requires significant knowledge in multiple areas of electrical and computer engineering. The job of a course provider is often made more difficult due to the theoretical analysis of topics, such as magnetic characteristics, analog electronics, and compensator design, are particularly hard to comprehend without experimental observations. Thus, an effective power electronics course should ideally contain hands-on design and experimental work, as well as projects in addition to the study of theory and simulations [2-9]. Motivated by these facts in the 2008-2009 academic year, we started to propose a few mini projects related to the renewable energy. While beginning with the 2009-2010 academic the author also proposed several senior design projects focusing on wind and solar/PV systems. From this perspective, these approaches of restructuring the power electronics course and adding renewable energy projects to the senior project design courses are of critical importance in solidifying the fundamentals of power electronics and renewable energy into the curriculum and creating the foundation for the planned renewable energy concentration.

3.1 Capstone Project Design Course Sequence

MET 421/422/423 (Senior Project Design) is a sequence of three-quarter capstone project design courses required for all the BSET majors. The course focuses on planning, development, and implementation of an engineering design project, which includes formal report writing, project documentation, group presentations, and project demonstrations. The goal of these courses is to demonstrate the ability to manage a major project involving the design and implementation of products with a mixture of electrical and mechanical elements as a member of a product development team. In these project-based courses, the students are expected to effectively manage their time and team efforts to produce a finished product in three ten-week quarters. No textbook is required. Progress and formal reports, and oral presentations constitute integral components of this course sequence. Before beginning the projects, student teams are provided adequate training in project formulation and resource analysis, performance goals and team expectations, public presentations of project work, and individual project supervision[19].

ABET defines Engineering Design as: "The process of devising a system, component, or process to meet the desired needs[1]. It is a decision making process, in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet stated objective[1]. Among the fundamental elements of the design process are: the establishment of the objectives and criteria, synthesis, analysis, construction, testing and evaluation"[1]. In our senior design classes we have placed this definition at the core of our courses. First we focus on objectives and ask the student to write a short proposal stating these objectives, principles, and the decisive factors to reach the stated goals. These projects involved elements of structural design, wind and solar energy resource assessment, electrical, electronics and computer engineering system design. The second step is conceptualization and laying down how to achieve the stated objectives[18,19]. At this junction the students are encouraged to draw a block diagram showing different components of the system they want to design. A set of questions are posed to students to further understand the task at hand. These are typical questions:

- What are the inputs to the system and, what are their characteristics and magnitudes?
- Do the inputs require conditioning?
- What is the medium through which inputs are interfaced to the system under consideration?
- Do the inputs dictate to the system to be designed how to behave, or just activates the system?
- What is the voltage, current and power requirements for the load?
- Is it a single output or multi-output system?
- Are there feedback loops in the system?
- Do the loads require separate power supplies?

Once the students compile the answers to these questions, they are directed to perform system analysis, design, component purchase and fabrication, building and testing of the prototype, as well as the overall design improvements.

3.2 MET421/422/423 Courses Structure and Organization

From the very beginning, this course sequence was organized following the ABET guideline for capstone and/or senior project design courses. The senior design class is organized in a very structured form.

Teams: All students have to work in teams of three or four. We consider this to be the optimum team size. A team of two may result in distress in cases where one of the students was not able to do his or her share of the work, while for teams larger than four may have difficulties to choose projects which were challenging enough for such a big group of students and still could be finished within three-quarter time frame.

Self and Peer Review: A very simple self and peer review system has been introduced. The students must evaluate their own and their team members' performance on a scale of 5. The main challenges we faced were that we never had anything similar to this and were inexperienced in how to adequately give feedback to the students.

Industrial Advisors: Some of the department's advisory board members are also serving as industry advisors for the senior design class. They are reviewing reports, listen to presentations and give feedback on those and are also serving as judges for the Senior Design presentations.

Reports: All teams must hand in a proposal, two midterm design reviews, and final report. Various faculty and industry advisors review all these reports and the students are provided feedback on their projects as well as on their report writing.

Presentations: All teams must present their proposals and first quarter design review. On the Friday before Final Exam week, in the Spring quarter all teams show their prototypes. The audience for these presentations is the class, faculty members and some of the industry advisors. They also prepare a professional poster to display with their projects. Some of the faculty and industry members also serve as judges. The teams are judged on the projects' technical content. The individual students are judged on their presentation style. These ratings have a two-fold purpose: they will be used as a part of the students' final grades and for a ranking of projects and teams. The winning team receives an award and members' names will be engraved on a plaque.

3.3 Increased Renewable Energy Content of the Senior Project Design

For the last two years, our focus shifted towards incorporating renewable energy topics in our senior project design courses[9,18,19]. In the first quarter in the project design course sequence we assigned to our students the project topics related to renewable energy, power systems or other engineering topics. These projects are a good example of multi-disciplinary cooperation of different engineering disciplines as well as providing valuable hands-on experience to the students. In addition to providing useful lessons in teamwork and project management, the project will provide a working demonstration of a wind and solar energy system[18,19]. For the last two years our focus shifted towards incorporating renewable energy concepts in our senior design courses. Two examples of senior projects are presented in the following subsections of this paper. During the first month of the fall quarter section of the course, each team is given partial specifications for the project. Each team demonstrates the finished project to the entire class and then a written report summarizing the project is handed in as part of the senior project design course. This process synthesizes all of the basic materials in the core courses and can also be used as part of the requirements of the senior project requirements for each student. Examples of the renewable energy senior design projects included in this course are:

1. Power Conditioning Units for PV-Powered Water Pumping
2. Control and Power Electronics of a Small Wind Power for Battery Charging
3. Fuel Cell Based Domestic Power Supply
4. Savonius Micro-Wind Turbine for Remote Applications
5. Modeling and Simulation of a High Performance Wind-Electric Battery Charger System
6. High Efficiency Charger for Photovoltaic Power Systems
7. Indoor Solar Harvesting Energy for Sensor Network

The design also includes test models of the prototypes, which can be tested and operated. The nest sections will discuss two of the project listed above.

3.4 Power Electronics Course Design Projects

To enhance the hands-on experience this course was restructured as a project based course. Students are required to analyze, design, simulate or built a completely functional system, as an end-of-term project, selected from a list proposed by the instructor. The goal of the design project is to explore and enhance students understanding of the fundamental power conversion principles, power circuit simulation capability and hands-on demonstration of circuit prototyping. The course project is worth 15% of the course grade. Students are required to present their project output in a poster session arranged for a technical audience. They are also required to summarize the results of the design in a short report by the end of the course. During the second weekof the quarter, each student team (three to four individuals) is given partial specifications for a renewable energy conversion power electronics application. The team builds it initially with the function module and/or using circuit simulation packages. Each team demonstrates the finished project to the entire class. A short written report summarizing the project is also required as part of the design project. This process synthesizes all of the basic material in the power electronics course and can also be used as part of the requirements of the senior project requirements for each student. Examples of end of term design projects included in this course are:

1. Analysis and Design of Single-Phase PV Inverters
2. PV Maximum-Power-Point-Tracking Controller
3. Line-Commuted Inverter
4. Design a Soft-Starter for an WT Induction Generator
5. Parallel Inverter System for Large Load
6. Fuel Cell Inverter Based

4. Student Assessment

Table 1 Questionnaire for the evaluation of the Project-based Power Electronics course

Q1	Are the courses challenging and interesting?
Q2	Have you learnt more than what you expected with the course?
Q3	Is the team project useful to you?
Q5	What was the level of “hands-on” feeling experienced the laboratory exercises?
Q6	Please, provide an overall evaluation of the course

The Power Electronics and Senior Project Design courses, using the new teaching and learning approach was first time offered in theFall 2008 quarter, and 2009-2010 academic year respectively at the main campus of our university. It was offered in Winter 2009 quarter at one of the partner college. At the end of each quarter, all students have been requested to answer (with a five point scale: 1-very poor, 2-poor, 3-satisactory, 4-good and 5-very good) an anonymous questionnaire as shown in Table 1. According to the results, the new project-based approach of power electronics and the received a 3.9/5.0 rating, comparing with an average rating of 3.4/5.0 for the all courses at our program. The results from the students’ feedback have been extremely positive with the regard to the renewable energy-related projects and the experiments provided during the laboratory sessions. The majority of students felt that such projects enhanced their understanding of the theoretical materials and made the course more interesting.

5. Conclusions and Future Work

The design experience develops the students' lifelong learning skills, self-evaluations, self-discovery, and peer instruction in the design's creation, critique, and justification. Students learn to understand the manufacturer data sheets, application notes, and technical manuals and component specifications. The experience of teamwork, prototype design and test, which would be difficult to complete individually, gives the students a sense of satisfaction and accomplishment that is often lacking in many engineering courses, not including projects. Furthermore, the design experience motivates student learning and develops skills required in industry. The students were able to make satisfactory estimations and calculations of these projects. Their results reflect that they have understood well all the basic ingredients of the modeling techniques and design of the renewable energy systems. They were also very pleased with the approach used to teach them. Our experience with the incorporation of renewable energy topics in the senior project design courses demonstrated that the abstract knowledge acquired by the students during their first three years of studies was put into practice. The students in these projects gained extensive knowledge of electronics and mechanical components and their characteristics, environmental and structural constraints, separating different aspects of the project, such as generator or converter type, its parameters and characteristics, and what are the final outputs and its relationship to the load, etc. They learned, during the three-quarter senior design project course sequence with increased renewable energy to identify a problem, conduct research on a particular project, and compare their finding with other similar projects.

The key element to the success was the interdisciplinary team work and the efforts of the faculty to continually instruct the students on the completion of their projects. The lessons learned from this type of projects lead us to believe that they are very attractive and favorable for students. Finally, they may represent one of the ways to enhance engineering education in our college.

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