AC 2012-3693: EMBEDDING RENEWABLE ENERGY AND SUSTAINABILITY INTO THE ENGINEERING TECHNOLOGY CURRICULA

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Embedding Renewable Energy and Sustainability into the Engineering Technology Curricula

Abstract

The world demand for electricity is increasing and conventional energy resources are fast depleting, making the renewable energy based electricity the only alternative. Today the renewable energy is one of the most rapidly growing rapidly industry. Carbon tax, pollution reduction, and emissions trading legislation are paving the way for environmental accountability and sustainability in the industries. In the last decades there have also been not only significant advances in the renewable energy technologies, energy efficiency and sustainability, but also an increased demand for trained engineers and technicians in these areas. To maintain current living standards in developed countries and increase the quality of life in developing countries, sustainability and energy efficiency need to be at the core of all engineering activities. This requires the development of innovative curricula, new courses and laboratories to educate students to work in these rapidly developing industries. Teaching sustainability and alternative energy on today engineering curriculum has increasingly become an essential feature. Engineering education moves into the twenty first century charged with an environmental agenda to respond to wider changes in the society. However, the educators are regularly modifying curriculum content to embrace technological changes into the learning outcomes. In the modern world where everything changes at an extremely fast pace, keeping up to date with technology is not only desirable but necessary. On the other hand, the renewable energy and sustainability are highly interdisciplinary, crossing over between a numbers of research areas, making quite difficult to be covered in a single course. However, the renewable energy (RE) and sustainability field have strong potential for hands-on multi-disciplinary project-based learning. Renewable energy projects can easily 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 and sustainability into engineering and engineering technology curricula is the problem-oriented and project-based learning approach. In this paper, we are discussing a series of RE projects, included into our senior project design, power electronics and renewable energy courses. The project structure and outcomes, lesson learned and future improvements are discussed in details. Design and development of renewable energy and sustainability projects allow students to work on projects that can be relevant to current leading edge research and technology. The development, content and structure of an alternative energy course as part of this effort to embed renewable energy into our curriculum are also presented. The motivation for the course is outlined and a detailed description of the topics covered in the course is also given. The course and the projects are also part of the efforts of to establish a renewable energy and sustainability program at our university. The usefulness of this approach will be evaluated and feedback from other educators will be highly appreciated.

1. Introduction, Background and Motivation Rationale

Society is increasingly calling for professionals across government, industry, business and civil society to be able to problem-solve issues related to climate change and sustainable development as part of their work[1]. The Energy Information Administration predicts that U.S. energy consumption will increase at a rate of 1.1 percent annually, but that U.S. energy production will only increase at a rate of 0.9 percent annually, from now through 2030[1-3]. These projections are based in part on current usage of renewable energy sources. Motivated by these energy security requirements and the desire to create a sustainable and safe environment, there is a growing need to transition gradually from fossil fuels to emerging and renewable energy sources. To narrow the gap between consumption and production, additional usage of energy sources other than fossil fuels is required. Moving toward addressing energy needs of the future is supported by the U.S. Energy Policy Act of 2005, a long-term energy strategy that includes provisions for diversifying energy supplies, increasing residential and industrial energy efficiency and conservation, developing more efficient motor vehicles, improving the electric power infrastructure, and expanding reserve storage of petroleum[2].

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 renewable energy systems (RES) 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 RES 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 RES systems, evaluate their performance and impact on power systems to which they are connected[4, 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. This development and implementation of the technologies for the future energy supply in United States and abroad is also supported by the governments[1-3].

A key ingredient to addressing such issues is equipping professionals with emerging knowledge and skills to address energy challenges in all aspects of their work. Engineering and engineering technology programs must offer a relevant and validated curriculum that prepares students for post-graduation success[4,5, 7-9]. 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[6,7]. 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.

Undergraduate engineering or engineering technology curricula are facing a number of challenges including a rapid growth in what is perceived by the technical community to be a necessary foundation of knowledge, the realization that our workforce must be able to operate in a diverse global society and the recognition that the implementation of technology can have an enormous impact on the sustainability of our global resources. If our students are going to successfully function as professional engineers in the international corporate world of the 21st century, they must be equipped to be global engineers who are technically versatile (multi-disciplinary), able to solve problems from a systems-level perspective, effective communicators, function in diverse ethnic teams and demonstrate social responsibility. Accordingly, our undergraduate curricula must keep evolving in order to provide the proper learning environment for students to develop these characteristics. Due to the unprecedented growth of renewable energy technologies 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 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[16-18,20]. 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[20]. 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.

Equipping engineering students with the skills and knowledge required to be successful global engineers in the 21st century is one of the primary objectives of undergraduate educators. Enabling students to practice self-directed learning, to find solutions to design problems that are sustainable and to recognize that they are part of a global community are just of few of our educational goals. Self-directed learning can define an individual's ability to practice life-long learning. It places the responsibility on the individual to initiate and direct the learning process and can enable an individual to adapt to change. Project-based learning provides the contextual environment that makes learning exciting and relevant. It provides an opportunity for students to explore technical problems from a systems-level perspective and to develop an appreciation for the inter-connectedness of science and engineering principles. In engineering technology, the model of a tetrahedron is often invoked to illustrate the bottoms-up connectivity of the fundamental principles associated with processing, structure and properties, which must be optimized to reach a desired performance of any system. In addition, a top-down tetrahedron can be envisioned with the need for sustainability guiding the balance between economic, societal and environmental factors, which also influence the choice of the optimum design solution for a project. For students to fully explore this paradigm, it is imperative that project-based learning experiences be integrated throughout their undergraduate education.

Therefore the purpose of this paper is twofold: 1) to describe topical subjects and projects covered in this renewable energy course; and 2) to describe the projects involved in capstone senior design project and power electronics courses, in order to embed renewable energy technologies throughout the ET curricula. This article will also explore methodologies that we have adopted to implement project-based learning approach to embed renewable energy and sustainability through our ET curriculum. Significantly, our course evaluations indicate that students strongly feel that this is a better method for "learning" and believe that the projects provide a more realistic environment for applying the principles of engineering, science and mathematics towards solving practical problems. The renewable energy course outline and description may also be used as a starting point for other instructors considering offering a similar course. The course is primarily focus on the wind and solar energy, fuel cells and energy storage 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[19,20]. 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. The other aims of our paper are to share our experience on:

1. How and which is the best way to integrate renewable energy into engineering or engineering technology curricula?
2. What kind of knowledge we considered the most reasonable for a course on renewable energy? What kind of methodology we used during the course?
3. What are the advantages and constrains of project-based approach and how this approach can help to embed renewable energy into our curricula?

2. Course Synopsis and Content

The engineering elective course on renewable energy technology was offered in the spring quarter of 2008-2009 academic year. It is a three credit-hour course. The main course objective was to provide students an overall view of the renewable energy, and so, to go more deeply into different types of renewable energy was really delicate. This course is primarily focused on wind and solar electric power systems since they have shown a steady growth over the past decade and also projected a high growth in the future. To a lesser extent, this course also discusses other renewable resources and related technologies. A photovoltaic systems project was included to reinforce the renewable technology ideas and provide students with hands on experiences. Therefore, this course includes the following key areas of the renewable energy integration issues:

- Solar energy and photovoltaic power systems
- Wind energy and wind energy conversion systems
- Energy storage devices and fuel cells
- Power electronic interface and control systems
- Stand-alone and grid-connected renewable power systems

2.1 Course Objectives, Description, and Instructional Design

The course provides 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 extent to the other renewable energy systems, as wave energy, geothermal, etc. The students learn how the technologies work to provide electrical power today and they 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[16-24]. It also covers the modeling, analysis of major components of a DER system shown in Figure 1. The topics covered also include the need and the benefits of DER, energy storage devices, control and power electronic interfacing.

To develop learning in the cognitive and the affective domain was the main course objective for us. Usually when course objectives are drawing up only cognitive domain is take into consideration. Obviously, knowledge, skills, understanding and "know-how", are every relevant in order to create a good course. It is true that we must deliver information to students to be memorized, help them to develop skills in order to understand how a project could be done and finally check their results, but we can forget that learning in the "affective domain" is also important. In fact attitudes and values play as important a part as aspects of the cognitive domain. With reference to the objectives related to the cognitive domain we were aware of the main objective course. If we really want to show students their capability to develop a self learning process these kinds of objectives must lead them on the right track. The benefit of such broad coverage is to give the students a broad view of the various components of RES. 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 in a 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 sources. 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.

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.

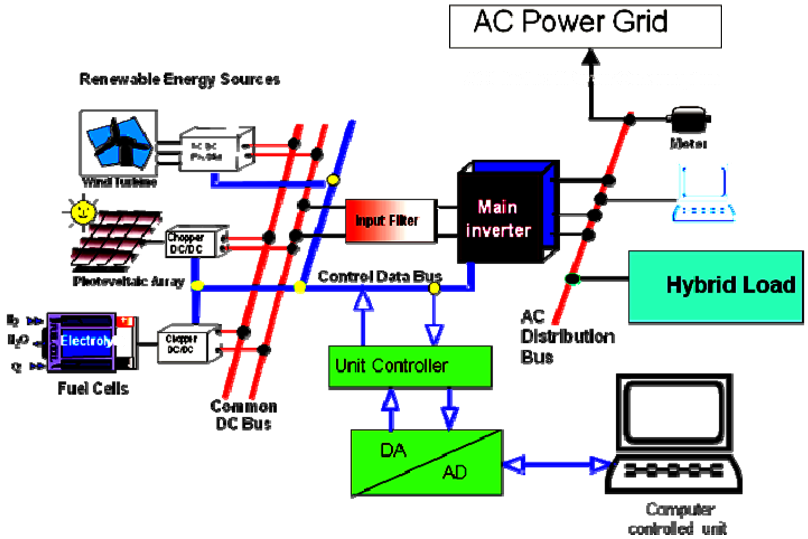

Figure 1 Block diagram of hybrid power (wind/PV/fuel cell) system [adapted from 20]

Since this course deals mainly with the analysis and the components of the wind and solar energy conversion systems, as well 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 skillful 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. Due to the diverse and intrinsic interdisciplinary subjects needed to be covered, the following reference texts are used and recommended to the students[16-20]. On completion of this course students should be able to explain: various types of renewable energy technologies, the environmental problems associated with renewable sources of energy, and how to consider the environment with regards to production, conversion and use of energy, source integration, power electronics and controls Students should also be able to describe: the energy efficiency concepts, the structure, operation and design of PV, WECS and hybrid power systems, the design and operation of an integrated renewable energy and energy storage system for remote areas, 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 a technical area by connecting the theory to practice facilitating an active learning process[10, 15, 18-22]. The educational strategy adopted at our school is focused on generating a well trained engineering force with a focus on renewable energy and its related aspects. This strategy aims to involve students at every level in research, design, controls and power electronics of various such RES systems. The 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 train and educate over 30 students a year in Power Electronics, and Renewable Energy Technology courses, 20 undergraduate students in senior design project course sequence 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.

2.3 Course Structure and Syllabus

The renewable energy technology course is divided into four major parts. Part I discusses the photovoltaic power systems, part II discusses wind power, part III focuses on energy storage devices and fuel cells, and part IV discusses power electronic interface, controls, stand-alone and grid-connected renewable energy systems. Due to the diverse topics that need to be covered in this course the following books were used as references (Patel, 2006; Masters, 2004; Ackermann, 2005; Messenger & Ventre, 2010). The course syllabus has two basic components:

1. Lecture and literature review
2. Project

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:

1. Basic principles of energy generation; Renewable energy development around the world and in USA
2. Introduction to renewable energy systems; Electric machines Basics; Electric machines for renewable
3. Solar energy fundamentals
4. Photovoltaic energy production; Photovoltaic systems
5. Wind energy resource characteristics
6. Wind energy conversion systems: aerodynamic and electric aspects
7. Wind energy modeling aspects
8. Fuel cell systems and energy storage devices
9. Other renewable energy sources
10. Distributed generation and power quality; Grid-integration of renewable energy sources

Lecture and literature review: Lectures were designed to serve two purposes. Firstly, provide students with broader background in renewable energy development and future trend. Secondly, provide students with technical tools to analyze and design renewable energy systems. To satisfy these purposes the topics listed above were covered. A project was incorporated to provide students with more insight to a renewable system design and integration issues. The project is described in the following section.

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

3.1 What is Project-based Learning (PBL)?

For an engineer in industry, a project is a sequence of tasks required to reach an objective. Typically, the objective is to design a device or process that has value to a customer (user). The project begins by defining a performance problem associated with an application and ends with a design solution. The problem drives the learning required to complete the project. Managing the project requires the engineer to demonstrate effective teamwork, clear communication and the ability to balance the social, economic and environmental impacts of the project. Project-based learning is based on the practice of solving problems. The concept of problem-based learning was first developed in the medical field in the mid-1950's. It has since been adopted in a variety of educational disciplines[11-14]. Traditionally, the educational process involves students first learning the fundamentals and then utilizing "total recall" to apply these facts to solve a problem; learning objectives are set by the instructor and principles are presented to the students through lectures. Assignments are given to reinforce the application of the concepts, but often students merely "learn" what is necessary to pass the test or "repeat-back" information to satisfy the instructor. In contrast, the PBL approach employs a problem as the driving force for learning the fundamental principles that are required to find a solution. Moreover, this approach provides a context that makes learning the fundamentals more relevant and, hence, results in better retention by students[11-13]. For clarity, we view problem-based learning as pertaining to the development of knowledge based on the fundamental principles of science and mathematics and project-based learning to include mastering the engineering skills required to implement a design solution.

So 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[18-22, 28, 29]. 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[25-27]. 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[11-14,30-34]. 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 one of the authors also proposed several senior design projects focusing on wind and solar/PV systems[31,32]. 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.

3.1.1 Implementing Project-based Learning

Each PBL experience begins with the students being introduced to a set of user defined performance requirements. It is imperative that a clear and concise design objective statement be formulated. From this statement a list of functional requirements can be derived and potential conceptual design solutions (how the requirements are achieved) are identified. Potential design solutions are analyzed from a systems level perspective, which explores the inter-relationships of components, including how they interact with each other and their operating environment. Next, a detailed design solution is developed and specifications are established that will enable the design to be fabricated and tested. A prototype of the design solution is built and tested to validate if it meet the original performance requirements. A project plan is developed to guide students through the process, support teamwork, focus communication and evaluate if the economic objectives of the project are being achieved. Throughout this process the students are challenged to learn how to work in teams and to practice systems level thinking when integrating technologies. Students are also challenged to recognize that their designs must both solve technical problems as well as make a contribution to society.

Teamwork: PBL activities can be individually oriented, requiring students to be self-directed, or they can be team-based requiring cooperative learning. It has been shown that team-based learning is a better method. The core disciplines necessary to build a learning organization are personal mastery, mental models, team learning, shared vision and systems thinking, while team learning can be defined as the process of aligning and developing the capacity of a team to create the results its members truly desire. It also builds on personal mastery, for talented teams are made up of talented individuals. Team learning is vital because teams, not individuals, are the fundamental learning unit in corporations today. Organizations cannot succeed unless team members can learn from each other. Teams transform their collective thinking; they learn to mobilize their energies and actions to achieve common goals and, thereby, draw forth an intelligence and ability greater than the sum of the individual members' talents.

Systems Thinking: Systems thinking emphasizes seeing the whole and establishing a framework for seeing inter-relationships rather than just individual components. It requires seeing patterns of change rather than static conditions and many have identified the need for taking this type of approach when developing design solutions. A systems approach to design involves learning that complex systems cannot be optimized by simply optimizing individual sub-systems; it requires an in-depth knowledge of how the sub-systems interact with each other[32-34]. It takes place after a conceptual design is established, but before the detailed design solution is completed. It requires students to evaluate the architecture of the design solution and explore the inter-relationships of its functional requirements and the operating environment.

3.2 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[6,7]. 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[30-32]. 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.

3.3 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.

1. **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.
2. **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.
3. **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.
4. **Reports and Presentations**: All teams must hand in a proposal, two term design reviews, and a final report. Various faculty and industry advisors review all these reports and the students are provided feedback on their projects and reports. All teams must also 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. The teams are judged on the projects' technical content and 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.

3.4 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[18-20, 30, 31]. 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[30,31]. 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.

3.5 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 week of 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 course challenging and interesting?
Q2	Have you learn more than 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 the 2009-2010 academic year respectively at the main campus of our university and 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 3.9/4.1/3.8 on 5.0 point ratings, for all academic years when the course was offered, compared with an average rating of 3.4 for the all courses and years 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 Sample of a Senior Design Project, System Design of a PV Power System Project

The multi-disciplinary team was tasked with designing, assembling, and testing a 500 W photovoltaic setup that they could simulate, assemble, and test in order to validate their simulation results. This gave the students an opportunity to reinforce the classroom lessons on solar energy and to apply it in a real-life situation using the same equipment as in large scale solar installations that are becoming more prevalent across the world. Students worked with suppliers and manufacturers to acquire equipment and testing supplies, troubleshoot devices, and to better understand how solar power is harnessed in large scale operations. The students came-up with testing scenarios to test different aspects of the system, and designed a system that could test many different variables including panel orientation, battery charging algorithm, and charge controller configuration. The team was given a maximum budget of $3,000 to spend on all aspects of the system which include the PV panels and necessary mounting, required power electronics, energy storage, and other miscellaneous components. Students were given approximately three weeks of classroom background on photovoltaic systems before being asked to purchase components. With that knowledge in hand, they were assigned components and asked to work together to design a system that will meet the required objectives.

Solar Panel: As mentioned above, the objective of the project was to design a system rated for 500 W. Since panels typically do not offer rated maximum power ratings higher than 250 W, the team decided on obtaining two panels. These panels would be mounted on custom stands that could be easily adjusted depending on the time of the year, the angle of the sun, and other variables. The panels needed to be weatherproof so they could withstand the elements of nature, and needed to have a plug-and-play interface for convenience. The test setup would consist of four-125 W PV solar panels with a nominal output voltage of 12 V, to allow for optimal testing versatility. They could be setup to outputs 12 V, 24 V, 36 V, or 48 V configurations.

Charge Controller: The reason for the need of a charge controller is because the solar panels alone cannot effectively or safely charge the batteries in the system. A component that regulates the proper charging of the batteries is critical to ensure safe battery charging that maximizes the life of the batteries and also controls the power flow. The charge controller is a component that goes inline between the solar panels and the battery bank. This unit takes the power generated from the panels and manipulates it to safely and efficiently charge the batteries. The charge method of most charge controllers is either a pulse-width-modulation (PWM), or maximum-power-point-tracking (MPPT) charging algorithm. When selecting a charge controller for a specific application, these are the two primary specifications to focus on. The controller has selectable operating voltages of 12 V, 24 V, and 48 V. The unit's rated current is 45 A, which far exceeds the requirements of the system, while also providing clearance for additions to the system in the future. This unit was selected over others because it incorporated PC connected monitoring and data logging capabilities, while also having a stand-alone logging feature. Another desirable feature of this controller was the option for adding a meter to the face of the controller..

Inverter: A power inverter is needed to convert DC power, either from the PV array or battery bank, into 120 VAC, 60 Hz power that can be used to supply most traditional household devices, or could potentially be connected to the grid if the inverter is grid-tie. When connected to the grid, a grid-tie inverter can send power from the renewable resource or from energy stored in the battery bank, back out to be used by other consumers. In large scale implementations, this has the potential to save or make money, and can cut down on the amount of electricity used from coal and other sources. A stand-alone, non-grid-tie inverter is simpler and is generally less expensive. The inverter can produce AC power which is less precise than the pure-sine wave that can be found from a typical wall outlet. The only condition is that the inverter output should be close enough to a sine wave to power its load. For the non-grid-tie setup this case, if the input cannot supply enough power demanded by the output, the output will not function. A grid-tie inverter must synchronize with the power on the grid. Any phase difference between the grid power and the inverter output results in a loss of power. Most grid-tied inverters also have one or more receptacles for local loads. With this, the inverter can power a load and send extra power back to the grid simultaneously, given that sufficient power is being input. If the load is drawing more than the input can supply, the inverter can actually draw power off the grid.

Batteries: There are many different options for energy storage of renewable energy systems on the market today, each with their own advantages and disadvantages. Options for energy storage include batteries, flywheels, compressed air, superconducting magnet, and ultra-capacitors. Batteries are generally the most practical form of energy storage for the project due to their size to weight ratio and their cost. This is the most commonly used energy storage device and has a charging and discharging efficiency of 80% to 90%. Batteries can be broken into two categories:

primary batteries and secondary batteries. The most popular primary-style of batteries is zinc-carbon batteries and alkaline batteries. The most popular secondary-styles of batteries have a chemical composition of lead acid, nickel-cadmium, nickel-metal hydride, lithium-ion, or lithium-polymer. When selecting a battery for renewable energy systems, the overall load must be known and the amount of time the batteries must support the system must be known. From there, the size of the batteries can be determined. When selecting the battery capacity for a system, it is important to analyze the load that will be applied to the system. For this project there was no specified load, as many different loads were to be tested. The load would also be interchanged depending if a gird-tie inverter or a non-grid-tie inverter was being used.

6 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. Semester/quarter long projects integrated within the course allow students not only to learn the material on renewable energy, but also to live it. This is very crucial in particular to renewable-energy-based engineering given its historic past and it's promising future. The course provided theoretical background on renewable energy integration and also the opportunity to apply learned principles on a small scale project. Students realized the practical challenges in integration issues and gained insight to tackle these issues in the future, while allowing them to use problem solving skills learned in other disciplines. The key elements to success were the interdisciplinary nature of the projects, the team work effort and the faculty advising and mentoring during completion of the projects. The lessons learned from this type of projects lead us to believe that they are very attractive and favorable for students, leading to an increased students' interest in this field. Finally, they may represent one of the ways to enhance engineering education in our college.

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