AC 2011-400: RENEWABLE ENERGY BASED CAPSTONE SENIOR DESIGN PROJECTS FOR AN UNDERGRADUATE ENGINEERING TECHNOLOGY CURRICULUM

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Renewable Energy Based Capstone Senior Design Projects for an Undergraduate Engineering Technology Curriculum

Abstract

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 university educators. Enabling students to practice self-directed learning, to find solutions to design problems that are sustainable, and helping them to recognize that they are part of a global community are just a few of our educational goals. A major program objective of an engineering technology (ET) program is to prepare graduates to be technically competent and productive in industry once employed. The skills acquired in school can lead them to a very successful and rewarding career. One way the engineering technology program can prepare graduates with the necessary design skills is through the senior capstone design course. It provides an opportunity for students to explore technical problems from a system-level perspective and to develop an appreciation for the inter-connectedness of science and engineering principles. Our senior design project course sequence consists of three courses taken in the final year by all engineering and engineering technology students in our university. They are intended to bridge the gap between theory and real world practice. Accordingly, the proposed senior projects should include both credible analysis and experimental proofs such as the designs and implementations discussed in the ABET criteria. Additionally, the senior project design can serve as an excellent culminating point in the program of study where it will focus on projects that have practical value to either consumers or to industry. The topic of alternative energy is not only relevant to a multitude of issues today it is also an effective vehicle for developing instruction that applies across a variety of disciplines and academic standards. Since many of the issues associated with alternative energy are open-ended, alternative energy also lends itself to project-based and problem-based instruction. The ET programs at our university have been recently updated to include a strong renewable energy component. Since Spring 2009 quarter, the author has begun to offer an introductory course focused on renewable energy technology. The course has proven to be very successfully with an enrollment of about 40 students. The results of the introduction of the renewable energy topics in our capstone senior project design course are discussed in this paper. These projects are a good example of the multidisciplinary 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 projects will provide a working demonstration of the wind and solar energy conversion systems.

Introduction

Global environmental concerns, the ever-increasing need for electrical power generation, and steady progress in power deregulation have created increased interest in environmentally conscious distributed power generation. Of particular interest are alternative energy distributed generation (AEDG) systems such as wind, solar/photovoltaic (PV), and fuel cell (FC) power generation devices with zero (or near zero) emission of greenhouse and hazardous gases[1,2, 4]. These generation devices can be used in stand-alone configuration or be connected to the power network for grid reinforcement. 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, and perform analytic evaluation of their impact on power systems to which they are connected[4, 5]. On the other hand, electric power systems, electric 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. Due to this monumental 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[21], we believed that it was important and timely to develop upper-level undergraduate courses on renewable energy systems and to include renewable energy projects in power electronics and senior project design courses in our ET program. There is a well-documented demand and need in offering program study, courses and training in the areas of renewable energy[21-23]. Future engineers must be taught to be creative, flexible and imaginative. There should be meticulous attention given to team work and on the challenges of sustainable development, including cultural, economic, environment and social imperatives. Future engineering curriculum should be built around developing and increasing skills and technical knowledge. The topic of alternative energy is not only relevant to a multitude of issues today, it is also an effective vehicle for developing instruction that applies across a variety of content disciplines and academic standards. Since many of the issues associated with alternative energy are open-ended, alternative energy also lends itself to a project-based and problem-based instruction.

Engineering and engineering technology programs must offer a relevant and validated curriculum that prepares students for post-graduation success. Courses that cover traditional subject matter in mathematics, the sciences, engineering economics and other related topics provide the foundation of knowledge upon which specific skill sets are added. However, it is critical for engineering/technology to transition from theoretical work in the classroom towards 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 academic theory and real world practice. Accordingly, the proposed senior projects should include elements of both credible analysis and experimental proofing as discussed in ABET criteria[5]. The senior design project 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 industry. For the ET program at our university, the senior design course is a year-long educational journey (three quarters) that takes an idea generated by a student or an industrial sponsor and culminates in a product or project. This course is an excellent capstone experience, which requires both teamwork and individual skills in solving a modern industrial problem[6-9]. Senior design projects seminars in fall and spring quarters bring the students, faculty, and industrial partners together to see the student's results and to give them the additional experience of public presentation of their work.

The purpose of this paper is to describe the renewable energy projects involved in our capstone senior design project. 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 usually taken by the students during their terminal year in the ET program. This paper describes the content and motivation of the renewable energy course, our senior design course sequence, the issues related to the inclusion of the renewable energy projects in senior design courses and two of the projects in which this approach was put into practice. These projects were offered in the course of the Senior Project Design during the 2009-2010 academic year. 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 faculty of our department or are proposed by the students themselves.

Motivation and Content of the Renewable Energy Technology Course

Our upper-level undergraduate course on renewable energy and power systems was offered for the first time in the Spring 2009 quarter. The course primarily focuses on wind power systems, solar/photovoltaic energy generation and fuel cells. To a lesser extend it focuses on other renewable energy sources and related technologies. This course is meant to enable the students to apply their basic science knowledge. Wind and solar energy and wind and solar power systems make up about 70% of the course since wind and solar energy represent the fastest growing areas of renewable energy in the past decade. The renewable energy course and power system is divided into ten modules, each of them presenting a special type of renewable energy and dispersed generations. Due to the diverse and interdisciplinary subjects needed to be covered, the following reference texts are used and recommended to the students[6-11]. Based on these and additional references the following course syllabus was developed. The outline of the course includes (ten 3-hour lectures):

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

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 have a good grasp of general renewable energy issues, electric machines and energy conversion technologies. They are expected to be particularly skilful in analyzing and solving wind and solar power systems and related problems.

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. Weekly progress reports, design notebooks, 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.

ABET defines Engineering Design as: "The process of devising a system, component, or process to meet the desired needs. 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. Among the fundamental elements of the design process are: the establishment of the objectives and criteria, synthesis, analysis, construction, testing and evaluation"[5]. In our senior design classes we have placed this definition at the core of our courses. First we focus on objectives and criteria 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, as well as the electrical, electronics and computer engineering system design. The second step is conceptualization and laying down the foundation for how to achieve the stated objectives[12-14,16,17]. 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:

1. What are the inputs to the system and, what are their characteristics and magnitudes?
2. Do the inputs require conditioning?
3. What is the medium through which inputs are interfaced to the system under consideration?
4. Do the inputs dictate to the system to be designed how to behave, or just activates the system?
5. What is the voltage, current and power requirements for the load?

6. Is it a single output or multi-output system?
7. Are there feedback loops in the system?
8. 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.

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[5,15].

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/teams. The winning team receives a small prize and team members' names will be engraved on plaques to be displayed in the department.

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[21-26]. 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[18-20]. 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. Analysis and Design of Single-Phase PV Inverters
2. Power Conditioning Units for PV Water Pumping
3. PV Maximum-Power-Point-Tracking Controller
4. Line-Commuted Inverter
5. Design a Soft-Starter for an WT Induction Generator
6. Control and Power Electronics of a Small Wind Power for Battery Charging
7. Parallel Inverter System for Large Load
8. Fuel Cell Based Domestic Power Supply
9. Modeling and Simulation of a High Performance Wind-Electric Battery Charger System
10. High Efficiency Charger for Photovoltaic Power Systems

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.

Modeling and Simulation of a High Performance Wind-Electric Battery Charging System

The major goal of this project is to design, model and analysis of a wind energy based battery charger. The system development, analysis and the system performance are part of the project, while the improvements that can be achieved by altering the system configuration to better match the load to the wind turbine are taken into consideration during to initial project stages. By understanding the basic characteristics of the components many of the performance limitations of the system can be remedied and the optimization of the system can be explored. The approach considered is to insert a load controller between the generator and the load. Different types of controllers were investigated, during this project including a power converter and a capacitor-compensated system.

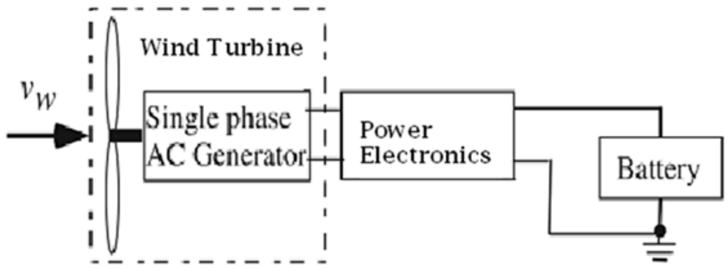

Figure 1: Physical Diagram of the Wind-Turbine-Battery System

The physical diagram of the system under investigation can be shown in Figure 1. The three-phase alternator is connected to a three-phase rectifier, the output of which is connected to a battery bank. In the conventional system, there is no active control used to adjust the energy produced by the wind turbine; therefore, the power flow to battery is dictated solely by the wind speed and the passive interaction of the various system components. The benefits of this project include but are not limited to:

- Cost effective Power Generation in remote areas
- Upgradeable parts ensure the possibility of ongoing student involvement
- Clean, renewable energy source
- Can operate in stand-alone application or can be attached to any power grid with minimal modifications.

The features of this project will include: a) Power generated in DC mode or at a 3-phase, 60 Hz output; b) Modular design for easy upgrades; c) Places to install both a commercial and hand-made generator; d) Hinged 30 foot or shorter tower for easy installation; and e) Low power loss from generation to transmission.

High Efficiency Charger for Photovoltaic Power Systems

This solar energy system is a good choice for a renewable energy topic and can be used in many electrical applications. Currently solar power is extensively used in stand-alone power systems. The conversion efficiency of PV cells is defined as the ratio between the electrical power output and the solar power impinging the cell. The efficiency of the PV cells generally is less than 30%. This means that when a cell is illuminated, it will generally convert less than 30% of the irradiance into electricity. The continuing effort to produce more efficient and low cost PV cells has resulted in different types of PV technologies [4]. Major types of PV cells are single-crystalline silicon, polycrystalline, semi-crystalline, thin films and amorphous silicon.

Main advantages of photovoltaic power are: (1) short lead time to design, (2) highly modular, (3) static structure, no moving parts, hence, no noise, (4) high power capability per unit of weight, (5) longer life with little maintenance due to no moving parts, (6) highly mobile and portable because of light weight. In this project a 12V, 10W industrial grade solar panel is used as the main solar panel[17-20].The output current is rated at 0.60 A. Depending on the light conditions, the solar panel outputs 2.5 Ah to 4 Ah a day. Due to its small dimension and light weight, it can be moved very easily. Furthermore, it is waterproof and easy to install. To improve the system performance, a controller is added between the PV panel and the battery (Figure 2).

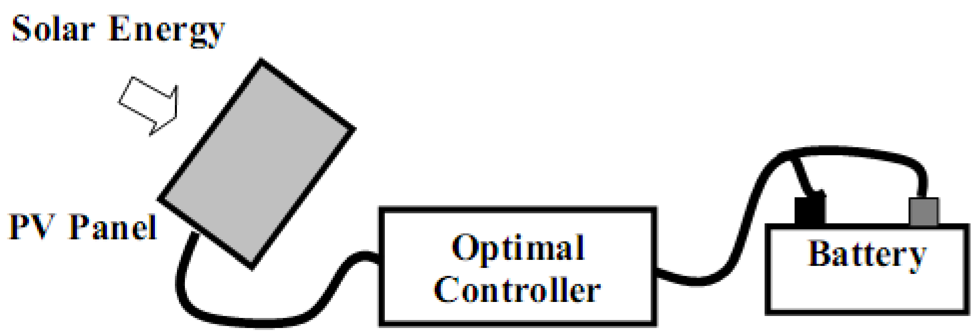

Figure 2: Schematic Diagram of a Solar Powered Battery Charger with Optimal Controller

The controller is usually a DC/DC converter. It should be a buck/boost to take into account conditions where the PV panel voltage is higher or lower than the battery voltage. In such a system an optimal control algorithm can be implemented to convert the maximum available solar power into electricity and charge the battery. The battery charger is an important device that is used to manage the electrical energy from solar arrays as shown in Figure 3. To manage the electrical energy from the photovoltaic power system, the power switching circuit is usually applied in the battery charger of the photovoltaic power system due to the fact that it doesn't consume more energy to operate.

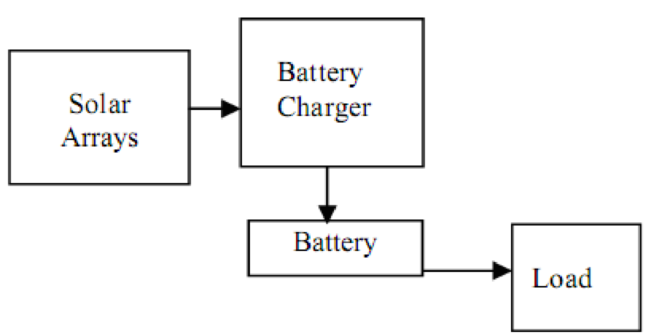

Figure 3: Implementation of photovoltaic power system.

In power switching circuit design, higher switching frequencies allow reduction of the magnetic component size with switching converter. However, increased switching frequencies can cause higher switching losses and greater electromagnetic interference (EMI). The switching loss mechanisms include the current and voltage overlap loss during internal switching and capacitance loss during turn on. DC-DC boost converter is a good switching converter and it was selected for this project because of its simplifications in power circuit and control circuit implementations[17-19]. The switching losses of an active switch device of the boost converter, which is typically a MOSFET, consist of turn-off and turn-on losses. These losses lead to a significant decrease in converter efficiency. In order to reduce the losses caused by hard switching problems, active auxiliary circuit implementations were required. These switching loss reduction methods were performed by managing the operation of main switch and auxiliary switches. So, the additional control circuitry of the active switches was necessary. In this project, a circuit implementation that required only one active switch, four passive switches, one resonant inductor, and two resonant capacitors for operating the switching losses reduction was proposed in the switching battery charger of PV power system shown in Figure 2.

A lead-acid battery, commonly used in solar power systems is used. The battery is composed of several single cells connected in series. Each cell produces approximately 2.1 V, thus a 6-volt battery having only three single cells, will, when fully charged, produce an output voltage of 6.3 V. A 12-volt battery has six single cells and produces an output voltage of 12.6 V when fully charged. The lead-acid battery has various versions. Deep cycle rechargeable batteries are designed to provide a constant voltage over a long period of time. They are suitable for repeated full charge and discharge cycles. A deep-cycle rechargeable battery is used for energy storage in this project. The DC output voltage is 12 V and the maximum charging current is 1.25 A. The internal resistance of the battery is 30 mΩ. The operating temperature is 4 ° to 140 °F.

The major objective of this project is to design a solar powered battery charger with an optimal controller. The goals of the proposed system are: 1) to convert the solar power into electricity as much as possible under varying weather condition; 2) to charge the battery as fast as possible in accordance to the battery life cycle conditions. The application of the proposed system can be light electrical vehicles such as golf carts, scooters, airport utility vehicles, as well as other renewable power stations using batteries as energy storage. The initial requirements for this project are as follows: 100 W solar panel, design structure strong enough to support the about 15 lbs, design enclosure to protect electrical equipment, controller and power electronics subsystems, electrical and mechanical design to rotate the solar panel, algorithm to implement tracking and control concepts, and portable system design.

System design: As shown in Figures 2 and 3 the proposed solar powered battery charger contains the following parts:

1) A photovoltaic panel (PV), which converts the solar power into DC electricity;

2) An optimal controller, controling the output power of the PV panel and the battery charging;

3) A battery, which can be either the power batteries in an electrical vehicle or the energy

storage batteries in a renewable power station. Table 1 provides the system specifications

Table 1: System Specifications

Power Rating	100 W
PV Voltage Input	12 V(9 ~16 V)
PV Current Input	8.3 A
Battery Voltage Output	18V (12 ~ 24V)
Battery Current Output	5.6 A
Over-load protection	10 A
Over-current Protection (cut-off)	15 A
Input Over-voltage Protection	16 V
Output Over-voltage protection	24 V
Input Under-voltage Protection	9 V
Output Under-voltage Protection	12 V

The converted solar power is used to charge the battery, therefore the charged level of the battery, usually the battery voltage, is checked to see if the battery is capable of taking the maximum available solar power. When a fully charged battery voltage is detected, a power limit will be given then the charging power will be much less than the maximum available solar power. Most of the time during operation, the battery is not fully charged, and maximum power is applied in the system, allowing charging the battery as fast as possible. A prototype is built following the design, and the experiment results indicate that the prototype was working properly. Further experiments planned to verify the dynamic response of the optimal control algorithm, shown that the prototype characteristics fulfilled the design constrains very well.

Student Assessment

Table 2: Questionnaire for the evaluation of the senior project design courses

Q1	Are the new course topics challenging and interesting?
Q2	Have you learn more than expected with the course?
Q3	Is the team project useful to you?
Q4	What was the level of “hands-on” experience has been achieved through the laboratory exercises?
Q5	Please, provide an overall evaluation of the course.

The senior project design courses, using the renewable energy topics was offered for the first time in the 2009-2010 academic year. At the end of each quarter, all students have been requested to answer (with a five point scale: 1-very poor, 2-poor, 3-satisfactory, 4-good and 5-very good) an anonymous questionnaire as shown in Table 2. According to the results, the new project-based approach received a 3.9/5.0 rating, comparing with an average rating of 3.3/5.0 for all the 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. Similar surveys were or are planned to be conducted at the end of each quarter in each academic year.

Conclusions

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 extensice 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 course sequence 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 represents one of the ways to enhance engineering education in our college.

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