AC 2011-488: AN UNDERGRADUATE COURSE ON RENEWABLE ENERGY CONVERSION SYSTEMS FOR ENGINEERING TECHNOLOGY STUDENTS

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Dr. Radian Belu is Assistant Professor within the Engineering Technology (ET) program - Drexel University, Philadelphia, USA. He holding the second position as Research Assistant Professor at Desert Research Institute, Reno, Nevada. Before joining to the Drexel University Dr. Belu hold faculty and research positions at universities and research institutes in Romania, Canada and United States. He also worked for several years in industry as a project manager and senior consultant. He has taught and developed undergraduate and graduate courses in electronics, power systems, communication, control and power electronics, electric machines, instrumentation, radar and remote sensing, numerical methods and data analysis, space and atmosphere physics, and physics. His research interests included power system stability, control and protection, renewable energy system analysis, assessment and design, power electronics and electric machines for wind energy conversion, radar and remote sensing, wave and turbulence simulation, measurement and modeling, numerical modeling, electromagnetic compatibility and engineering education. During his career Dr. Belu published several papers in referred journals and in conference proceedings in his areas of the research interests. He has also been PI or co-PI for various research projects United States and abroad in power systems analysis and protection, load and energy demand forecasting and analysis, renewable energy analysis, assessment and design, turbulence and wave propagation, radar and remote sensing, instrumentation, atmosphere physics, electromagnetic compatibility, and engineering education.

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Dr. CiobanescuHusanu is Assistant Professor in Engineering Technology at Drexel University. She received her PhD degree in mechanical engineering from Drexel University in 2005 and also holds a MS degree in aeronautical engineering. Her research interest is in thermal and fluid sciences with applications in micro-combustion, fuel cells and research of alternative and green fuels as well as expanding her research work towards new areas regarding plasma assisted combustion. Dr. Ciobanescu-Husanu has prior industrial experience in aerospace engineering areas, that encompasses both theoretical analysis and experimental investigations such as designing and testing of propulsion systems including design and development of pilot testing facility, mechanical instrumentation of the tested prototype, and developing industrial applications of aircraft engines. Also, in the past 6 years she gained experience in teaching Mechanical Engineering courses with emphasis on thermal-fluid and energy conversion areas from various levels of instruction and addressed to a broad spectrum of students, varying from freshmen to seniors, from high school graduates to adult learners. She also has extended experience in curriculum development at both community college and university level.
Abstract

In the present energy scenario, the demand for electrical energy is increasing and conventional energy resources are fast depleting. In this context, the exploitation of renewable energy sources for the generation of electrical power is the only alternative. Interest in the production of electricity from renewable energy sources and by fuel cells is rapidly increasing. The renewable energy sector is growing rapidly with both the global and national level. The solar and wind energy industries alone are seeing more than a 20% growth per annum over the last five years. Furthermore, the market for fuel cells for standalone and static power generation is also starting to grow. There have been significant advances in renewable energy conversion technologies, as well as increased demand for engineers, technologists and technicians trained in this area. This requires the development of innovative curricula, new courses, and laboratories to educate engineering students to work in this rapidly developing industry. This paper presents the development of a multi-disciplinary course on alternative energy technology. The motivation for the course is outlined and a detailed description of the topics covered in the course is given. Sample student projects, and students’ responses, as well as the students’ evaluations to the course are also presented. The course is a part of our new projected renewable energy concentration of the Engineering Technology (ET) program at our university. The course is also offered as an elective for the new graduate ET program at our university.

Introduction

Environmental concerns, the ever-increasing need for electrical energy, and steady progress in power deregulation have created increased interest in environmentally conscious distributed power generation. These impacts of the traditional fossil fuels in our environment and the fact that these are non-renewable sources have encouraged the need to find alternative energy sources to the fossil fuels. Therefore, the renewable energy sources have been one of the most important topics of research in the last years. They are constantly replenished and will never run out. Of particular interest are renewable energy resources and distributed generation (RES&DG) systems such as wind, photovoltaic (PV), solar-thermal and fuel cell (FC) power generation devices with zero (or near zero) emission of greenhouse and hazardous gases. 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 RES&DG 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&DG systems, evaluate their performance, and perform analytic evaluation of their impact on power systems to which they are connected. In response to the above need, a graduate and senior level course on alternative energy and distributed generation (AEDG) was developed in the Engineering Technology program at our university. This course is based on a multi-source renewable energy conversion systems, as one described in the Figure 1.

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, 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 to learning through experimental hand-on activities based on applications of technology and design. Education, training and learning plays an important role in taking the necessary steps that will re-shape our way of living into a sustainable one.

In the area of sustainability, due to rapid development in the past years it became obvious the need of training in both formal and informal systems. Therefore special attention needs to be given to developing programs at both graduate and undergraduate level in renewable energy and sustainability, developing training programs for workforce in these emergent areas of industry, adult education, as well as lifelong learning.

Our curriculum covers fields such as electronics, electric machines, energy conversion, power electronics, materials and control. It is also necessary to learn about the renewable energy systems and their applications and interactions with power systems. This course focuses mainly on renewable energy sources, conversion technologies and the impact of the renewable energy systems on power systems. One objective of this paper is to present our effort in developing the course and the supporting laboratory and to present the course outline and content, including the subjects, projects, experimental activities and references in renewable energy technology course for ET students. An important part of this course is student project implementation and presentation. Each student is required to pick a project topic (on system design, system modeling, or analysis) by the end of the fifth week of the term and have it approved by the course instructor. They work on their project for the remainder of the term at the end of which they submit a written report on their project and also give an oral presentation to the class.

Due to continuous growth in the use of renewable energy sources for electricity generation and the necessity of keeping students abreast of the current engineering developments and trends, it
is our strong beliefs that it was not only necessary, but was also timely to develop an introductory course for upper-level undergraduate students on renewable energy systems and technologies. The course focuses mainly on renewable energy sources, conversion technologies (especially those of wind turbines and PV systems), and the impacts of the intermittency of renewable energy on power systems. Materials presented herein may serve as template for other instructors considering offering a similar undergraduate level course on renewable energy.

There is a long-term demand and need in offering program study and courses in the areas of renewable energy and power system. This is because there is a continuous demand of power engineers knowledgeable in renewable energy, storage and conversion technologies. In addition, the federal government and various states have instituted programs and incentives to promote the use and development of renewable energy sources. Many states such as Texas, California, Nevada and New Mexico — to mention just a few — have various market-based policies at their disposal to encourage renewable energy deployment such as the renewable portfolio standard^3.

**Course Content, Description and Objectives**

This course is for upper level undergraduates and early graduate students interested in the scientific challenges of alternative energy generation, storage, and efficient use. The course will cover photovoltaic and solar power in depth, with additional coverage of fuel cells, hydrogen, energy storage, wind power, and more. Upon completion of this course, students should be able to analyze important devices and predict the power output under various conditions, compare their strengths and weaknesses, plan a sustainable power grid, and describe the technical, economic, and political challenges to making each of these alternative energies successful. Our upper-level undergraduate course on renewable energy systems and technologies was first offered in the spring quarter of the academic year 2008/2009 at our ET program. It is a three credit-hour course.

The course covers the principles of energy conversion in the three distinct areas of wind, solar PV, cogeneration and fuel cell power generation, system planning and design. It also covers the modeling, analysis, and control of major components of the AEDG system shown in Figure 1. This course is different from the renewable energy courses recently developed at other universities^7,8, being broader in scope and covering the principles of operation of fuel cells, distributed generation and cogeneration systems, and the life cycle assessment of the renewable energy sources. The topics covered include the need and benefits of AEDG, modeling of wind and PV power generation, energy storage devices, power electronic interfacing, and principles of operation of cogeneration, fuel cells and hydrogen production. The benefit of such broad coverage is to give the students “the big picture” of the various components of AEDG. However, the course primarily focuses on wind energy, solar energy, fuel cells and batteries, wind power and PV systems. To a lesser extend it focuses on batteries, storage systems and other renewable energy sources and related technologies. Wind energy, solar energy, wind power and PV systems make up about 75% of the course since wind energy and PV represent the fastest growing areas of renewable energy in the past decade and generates the bulk of electricity generation. Therefore this course has the following key focus areas: distributed generation, fuel cells, wind energy conversion systems (WECS), solar energy and photovoltaics.
Other alternative energy power generation sources (e.g., geothermal, biomass, micro-hydro, and micro-hydro turbines) are highlighted during the course and the merits of each are given. The coverage of wind and PV generation is more design-oriented, while the coverage of fuel cell power generation is limited to fuel cell working principles, electrical characteristics, and applications. As described in the previous section, the course also includes student term paper presentations and projects. A summary of the topics covered in the course is given in Table 1. The course topics covered are discussed in the following subsections. The course structure, content and instructional approach, discussed in the next section of the paper are in part based on the experience gained by one of the authors, when he was involved in the design, development and teaching of similar courses, as well as in the design, test and implement of the course associated laboratory and experiments for other institutions that he used to work for9-13.

Table 1: Course topics and modules

<table>
<thead>
<tr>
<th>Module/Week</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction, Conventional Energy Provision Systems; Power System Components</td>
</tr>
<tr>
<td>2</td>
<td>Wind and Solar Energy Resources; Basic of Renewable Energy Supply</td>
</tr>
<tr>
<td>3</td>
<td>Distributed Generation; Fuel Cells and Energy Storage Systems</td>
</tr>
<tr>
<td>5</td>
<td>Wind Energy Conversion Systems</td>
</tr>
<tr>
<td>6</td>
<td>Electrical Aspects of Wind Energy Conversion Systems</td>
</tr>
<tr>
<td>7</td>
<td>PV/Solar Energy Conversion Systems</td>
</tr>
<tr>
<td>8</td>
<td>Other Renewable Energy Sources</td>
</tr>
<tr>
<td>9</td>
<td>Design of Hybrid Power Systems; Grid Integration of Renewable Energy Systems</td>
</tr>
<tr>
<td>10</td>
<td>Life Cycle Assessment of Renewable Energy Sources</td>
</tr>
</tbody>
</table>

The renewable energy course is divided into 10 modules (see Table 1 for details). Each module can be completed within three 50-minute lecture sessions. Due to the diverse subjects that need to be covered, the following reference texts are used14,15. Based on these texts, the following course’s syllabus was developed, with the topics presented in Table 1. A detailed course description, objectives is given in the next section of the paper. Additional references, strongly recommended for the end of the class mini-project included16-18.
Course Objectives, Description, and Instructional Design

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. During this course they will also be introduced to basic research needs. Renewable energy technology 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 applications. The class will explore society’s present needs and future energy demands, examine conventional energy sources and systems, including fossil fuels and nuclear energy, and then focus on alternate, renewable energy sources such as solar, wind power, geothermal, and fuel cells. Energy conservation methods will be emphasized. Students are expected to be well-rounded in general renewable energy issues and conversion technologies. They are expected to be particularly skillful in analyzing, and solving wind and solar/PV power systems and related problems.

Due to the time constrains, since our university is a quarter-based institution, course materials are divided in ten modules, as illustrated in table 1. 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 technologies. The students will also explore the use of electrical equipment required for power transmission and conditioning, including storage, and understand their principles and operating methods. It introduces industry’s specific standards to students enabling them to design, analyze, simulate and implement small scale stand alone and grid connected renewable or hybrid energy systems. During the second part of the quarter the students are required to design, via a mini-project a hybrid power systems, integrated 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.

Upon completion of the 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 as well as possible improvements, 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
Description of Some of the Course Topics

The course (first unit of the course) starts with a brief history of electric power generation, transmission and distribution. Emphasis is placed on the energy resources and the environmental impacts on the electricity generation. This discussion is followed with projections of electric energy consumption and shortage of electricity generation coupled with transmission line congestion, which all encourage distributed generation (DG) deployment. The environmental concerns over generation of greenhouse and toxic gasses by conventional power plants are covered next. Students are asked to solve a quiz requiring estimating the amount (number of tons) of carbon dioxide and hazardous gases emitted into the atmosphere each year as a result of oil- and coal-based power generation using published data. Hence, the degree of contribution of AEDG to a clean environment is emphasized. Module 1 also provides an overview of various sources of renewable energy, the current state and outlook of renewable energy in the U.S and worldwide. Statistics of renewable energy generation and trends are included. Materials for this module are based on up-to-date data provided by the International Energy Agency (IEA) through its World Energy Outlook reports and the U.S. Energy Information Administration.

The second module covers methodologies for analyzing wind and solar resource characteristics, and estimating wind and solar energy production using statistical and descriptive methods. Very good reference texts describing these subjects are chapters dedicated to wind and solar resources in the required and recommended textbooks. The materials covered in this module include: wind speed characteristics and variations, wind speed distribution and statistics, meteorological parameters (air density, pressure, and humidity), wind power law, solar energy maps, solar radiation estimates and variability, solar irradiation (W/m²) and potential for solar power generation in different areas around the world. The need and importance of daily, monthly, seasonal and annual average wind speed profiles or the available solar radiation of a site for estimating the potential energy production of a wind turbine or PV system is discussed. For example, the statistical models of wind speed profiles, represented by the Weibull probability distributions $f(v)$, given by (1), are presented. The importance of this distribution function in estimating the maximum wind energy potential of a site – a critical piece of information needed for system planning - is discussed.

$$f(v) = \left(\frac{k}{c}\right) \left(\frac{v}{c}\right)^{k-1} \exp\left(-\left(\frac{v}{c}\right)^{k}\right)$$

(1)

In (1), $v$ is the wind speed, $k$ is the shape parameter (normally equal to 2 for typical wind distribution found at most sites), and $c$ (m/sec.) is the scale parameter, chosen to best fit the wind frequency distribution for a given site.
The coverage in this unit of the course includes the principles of operation of DG systems, cogeneration, and fuel cells, their electrical characteristics, and their application. It includes an overview of different types of fuel cells with emphasis on those types of fuel cells that have potential for DG and fuel cell vehicle applications, namely, polymer electrolyte membrane fuel cell (PEMFC), solid oxide fuel cell (SOFC), and molten carbonate fuel cell (MCFC)\textsuperscript{14,15}. The steady-state and dynamic characteristics of these fuel cells are explained, and the need for controller design is discussed. Also, it is emphasized the actual modeling necessity for fuel cells to predict their behavior. Figure 2 shows the schematic diagram of a PEMFC; it has a solid polymer electrolyte made of a Teflon-like material, which is an excellent conductor of protons and an insulator of electrons. At the anode, with the help of a platinum catalyst, hydrogen atoms break into electrons and positive ions. The positive ions move through the membrane and are attracted to the cathode, while the electrons travel through the external load, producing a voltage across the load. Positive ions and electrons recombine at the cathode (again with the help of the catalyst). Steam is produced at both electrodes as a result of the chemical reactions. The above coverage gives the students an understanding of the operation and principles of cogeneration systems and fuel cells from an energy conversion point of view.

![Figure 2 Schematic diagram of a PEM fuel cell.](image)

Module 5 provides basic principles of wind energy converter systems. Although there are various types of wind energy converters, due to time constraints, this module emphasizes on wind turbine technology (horizontal axis type). Other types of wind energy converters such as the Darrieus wind turbine are introduced. Students learned about the Betz limit that determines the maximum power that can be extracted from any wind energy converter, aerodynamic principles of wind turbines and power controls, and rotor power characteristics (power coefficient vs. tip ratio, $C_p-\lambda$) characteristics. Although this module requires some of an intermediary physics background, students seemed to absorb the material very well. Excellent reference texts, besides the required textbooks for this module are the well-known wind energy manuals and handbooks\textsuperscript{16-18}. General layout of a wind turbine and components of a wind energy conversion
system are presented (see Figure 3, for details) is discussion includes the function of each block in the energy conversion and/or processing, the available power input to different blocks, and their power conversion or transmission characteristics. For example, the coverage includes the available power in wind, torque vs. rotor speed characteristic of the drive train and electrical generator, constant-speed and variable-speed wind turbines, rotor blades and their control, etc.

Figure 3 Components of a wind energy conversion system.

Module 6 focuses on the electrical aspects of wind turbines. Therefore, it discusses synchronous and induction machine applications as a wind turbine generator. Students will need sufficient background in electric machines. Otherwise, one to three additional lectures might be needed to provide a quick introduction. Students learn about the operation and characteristics of fixed-speed wind turbines, the relationship between generator torque-speed characteristics, and the aerodynamic torque produced by a wind turbine. Chapter 9 of reference [21] provides an excellent discussion of electrical aspects of wind turbines, for the interested students, beyond the required textbooks. The materials of this unit cover topics, such as: electromechanical energy conversion, induction and synchronous generators, constant-speed wind turbines, rotor blades and their control, etc.

Module 7 is the last module in the course that covers in depth an important renewable energy system. This module provides an introduction and review of the solar cells, photovoltaic modules and systems and technologies. Different PV cell technologies, their advantages, limitations, PV efficiency, PV modules and arrays are presented during the lecture. Electric circuit models of a PV cell (Figure 4), PV cell characteristics, including open-circuit voltage, short-circuit current, current vs. voltage and power vs. voltage characteristics at different solar intensities, effect of temperature on PV cell characteristics, PV array are discussed [14,15,17]. Module also covers power electronic interfacing circuits: DC/DC and DC/AC converters and maximum power tracking of PV arrays. An important part of this module is dedicated to the PV power system design, hybrid stand-alone systems, and the electrical load matching.

After covering the wind and PV power generation, units 5 through 7, the design of hybrid wind/PV power generation systems, e.g. unit sizing of the stand-alone generation systems for application in remote areas is covered in the unit 9. This unit also covers the aspects, power electronics interfaces, inverters and the technical challenges of the grid integration of the renewable energy systems. During this week the students start to finalize their mini-projects, and have the opportunity to discuss with the instructor, the project details and implementation. The project timetable is also discussed during this week.
Enrollment, Students’ Response and Course Evaluations

Students’ response and evaluation of the course have in general been very good, with an average over 3.5 of 4-point scale student evaluations, see Table 2 for details. The enrollment was also unexpectedly high, with 32 students enrolled (see Table 2). They become motivated by the challenge involved, for example, in the proper selection of a wind turbine-generator for a given site, or in the estimation of wind and/or solar resources of a site based on engineering principles, or when they find the opportunity to learn the working principles of fuel cells. Their satisfaction stems largely from having an opportunity to do a real project during the quarter independently. Several students from other disciplines such as mechanical engineering and physics have shown interest in taking the course. Such students have been admitted to the course on an individual basis depending on their academic background on principles of energy conversion.

Table 2 Student enrollment and evaluations

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Enrollment</th>
<th>Course Details</th>
<th>Instructor</th>
<th>Overall Course and Instructor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 2009 (main campus)</td>
<td>20</td>
<td>3.56</td>
<td>3.70</td>
<td>3.60</td>
</tr>
<tr>
<td>Spring 2009 (satellite campus)</td>
<td>12</td>
<td>3.80</td>
<td>3.72</td>
<td>3.70</td>
</tr>
<tr>
<td>Spring 2010</td>
<td>24</td>
<td>3.69</td>
<td>3.75</td>
<td>3.75</td>
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</tbody>
</table>

Conclusions

This paper outlines the motivation for the development of a course on AEDG covering wind, PV, storage systems and fuel cell power generation which has been offered in the ET program at our university. In keeping up with advances in renewable energy conversion technologies and the continued growth in the renewable energy area along with its impacts on electrical power systems, we feel it is important and timely to develop a upper-level undergraduate course on renewable energy technology. The course was first offered in spring 2009 with a total enrollment of 32 students. Students were general excited and receptive about the course. The course promotes generation of electricity without emission of harmful gases to the environment. Detailed coverage of course topics are given, and sample student paper presentation topics, student projects, and student response to the course are also presented in the paper.

Since the course was first offered, several improvements were conducted. These improvements include additional exercise problems on induction generator systems, and laboratory sessions on simulation models. The latter is particularly desired since simulation enhances the understanding of fundamental concepts presented in the classroom settings. The materials presented herein may be used as model for other instructors considering offering a similar course on renewable energy.

References