Renewable Energy Education at Clemson University - A Certification Program with Solar, Wind & Electrical Grid Classes

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Abstract: *The rapid growth of the global renewable energy industry has created a need for professionals who are knowledgeable about the subject matter and can help integrate these green resources into the electrical grid. The Electrical and Computer Engineering, and Mechanical Engineering Departments at Clemson University offer a renewable energy certificate for undergraduates and industry professionals based on solar, wind, and electrical grid courses. The certificate follows a multi-disciplinary approach that introduces students to the diverse field of renewable energy. Specifically, the comprehensive program exposes students to the fundamental electrical, mechanical, control, environmental, societal, and economic concepts related to the generation, transmission, and usage of renewable energy technology. Student and industry assessments show that the certificate program successfully follows a pragmatic approach that integrates theory with real world applications to prepare students for a career in the diverse green energy industry.*

1. Introduction

The world faces concurrent energy and pollution crises. Rapid population growth and an increase in the living standard in many emerging countries have led to a greater demand for fossil fuels. Over the next 25 years, the societal requirement for energy is forecasted to increase by 36% with the bulk attributed to developing countries[1]. The demand for energy will eventually outpace the ability to supply energy from traditional resources. Most industry experts believe that an energy crisis is likely for countries dependent on conventional energy sources. Greene *et al*.[2] found that there is a high probability that conventional oil production will peak or become severely strained before 2025. Sorrell *et al*.[3] concluded that there is a significant risk that oil production could peak before 2020. The use of traditional sources of energy such as oil, coal, and gas has increasingly devastated the earth's environment. Fossil based fuels produce large amounts of greenhouse gases and air pollutants like nitrous oxide, heavy metals, chlorofluorocarbons (CFCs), and volatile organic compounds; many which have caused acid rain, climate changes, and other environmentally destructive results. Although power generated from nuclear fission is sustainable and reduces pollution, it's noted that nuclear energy is expensive and radiation poses a serious threat to human beings and the environment. Consequently, a need exists for the widespread adoption of green energy sources.

Shifting to renewable energy can help reduce pollution and alleviate the current strains on energy supply[4]. Solar, wind, geothermal, and tidal energy are green sources of energy that are abundant and environmentally friendly. Using these resources to produce energy can supplement the current energy generating plants while also reducing the environmental impact caused by conventional energy sources. Renewable energy has grown rapidly over the past two decades, with solar and wind increasing by 86.3%[5] and 25.8%[6], respectively, in 2011. The accelerated growth in alternative energy based development and utilization has created a need for engineers who can plan, design, and operate these systems, evaluate alternative energy system performance, and perform analytical comparisons with conventional power plants to supply electricity to the power grid[7]. Currently, green energy industries employ more than 5 million people globally[6] and this labor trend will steadily increase due to demand. Universities have an

opportunity as well as a responsibility in creating and implementing courses that equip engineers, scientists, and energy planners with an ability to work with alternative energy systems[8].

Many schools offer courses or programs in renewable energy. Hassan[9] reported the formulation of a Bachelor of Science in Electrical Engineering curriculum with a concentration on alternative energy. Somerton and Bernard[10] discussed an alternative energy course at the Michigan State University which also introduced the related political, social, and economic issues. The course required students to complete a project on solar, wind, or fuel cell technology. Tamizhmani *et al.*[11] at Arizona State University offered an introductory course in fuel cell technology which incorporated a multi-disciplinary teaching approach. Shahidehpour and Li[12] proposed setting up a world-class smart grid education and workforce training center at the Illinois Institute of Technology to offer a university-level degree and certificate program in smart grid technology. Reed and Stanchina[13] presented course models for a post baccalaureate certificate in the clean energy - smart grid area. Finally, Rouch and Stienecker[14] conducted a Delphi study that suggested the course components that universities should consider in alternative energy.

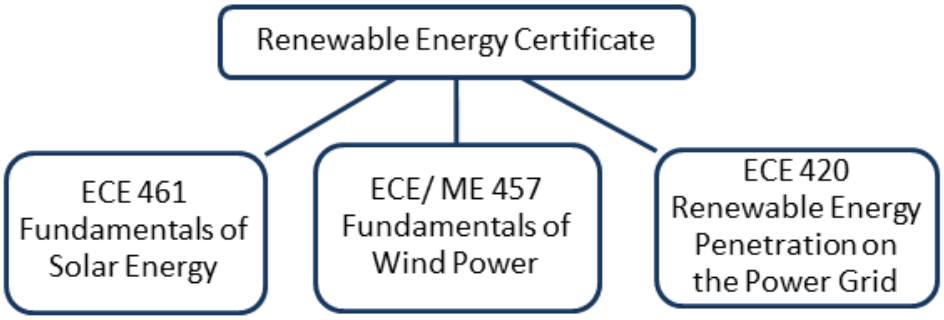

Fig. 1: Renewable Energy Certificate (REC) program at Clemson

Clemson University offers a renewable energy certificate that consists of three courses as shown in Fig.1. The certificate is aimed at students and industry professionals who seek to learn and broaden their knowledge on renewable energy power generation and their related issues. The Holcombe Department of Electrical and Computer Engineering, provides the "Fundamentals of Solar Energy" (ECE 461) and "Renewable Energy Penetration on the Power Grid" (ECE 420) classes. The "Fundamentals of Wind Power" (ECE/ME 457) course is a cross-listed course offered by the Mechanical Engineering Department. These courses and class certificate are part of a "Fundamentals & Advanced Power Systems Certificate Programs for Training the Power Industry Sector" grant. Undergraduate and graduate level courses on solar energy have been offered since 2006, while a similar course on the impact of distributed energy sources on power delivery systems has been taught since 2004. This course was modified to include renewable energy penetration on the electric grid and has been offered since 2010. The wind energy course was taught on campus during the 2011 summer session, and then provided as an on-line course starting in the summer of 2012. All courses associated with the certificate will eventually be available on-line.

This paper describes three alternative energy technical elective courses offered at Clemson University. The remainder of the paper is organized as follows. Section 2 reviews the solar energy course with an emphasis on photovoltaic systems. Similarly, Sections 3 and 4 present the

wind power and grid penetration courses, respectively. Finally, the conclusion will be presented in Section 5.

2. Fundamentals of Solar Energy

Solar energy has the theoretical potential to power the entire world. Over the course of a year, the earth receives 173×10^6 GW of energy from the sun. Approximately 30% of the solar radiation is reflected back into space while the rest is absorbed by clouds, oceans, and land masses. So the earth's surface receives roughly 89×10^6 GW of energy. The yearly global consumption of energy is 16×10^3 GW[5]. Therefore, capturing all the global solar energy for a small time period can nearly fulfill this amount. Solar energy can be converted to both heat and electricity. Solar heating can be used to provide domestic hot water, space heating, cooking, and drying. Direct solar electricity can be generated by photovoltaics (PV), concentrated PV, and/or by concentrated solar power (CSP). Globally, the cumulative installed solar PV capacity has topped the 100-gigawatt (GW) milestone[15]. Theoretically, it is possible to have a combined Photovoltaics/Thermal (PV/T) system with efficiency higher than either a PV or thermal system. However, the thermal system offers optimal performance at higher temperature while the PV system offers optimal performance at lower temperature. Due to this fundamental limitation, it is difficult to design an ultra-low cost high performance PV/T system.

The solar energy course offered by Clemson University is designed to provide students with a fundamental understanding of solar energy conversion systems. It is primarily focused on solid state energy conversion devices (photovoltaic cells) with accompanying components needed for installation in a small scale residential application (refer to Fig. 2). The first few sessions introduce the fundamental principles, design, processing, and the manufacture of photovoltaic cells. The course later delves into the various subsystems associated with PV systems, along with their design and classification. Students also experience solar thermal, concentrated solar power, and hybrid photovoltaic/thermal systems. Additionally, the course explores the various energy storage devices and smart grids. Since solar energy is a promising technology with the potential to provide clean and cheap energy to millions, the course discusses the prospects of providing solar energy to rural communities and the associated benefits.

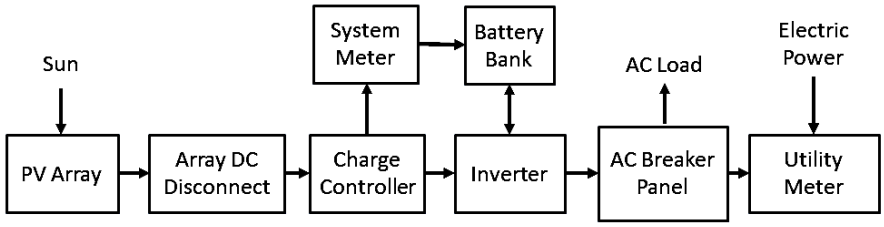

Fig. 2: System level diagram of an installed PV system as discussed in the ECE 461 course

ECE 461 Catalogue Description:

"Introduction to solar energy conversion systems. Topics include environmental benefits of solar energy, solar thermal systems, concentration solar power, photovoltaic (PV) cell design and manufacturing, sizing of the PV system, hybrid photovoltaic/thermal systems, energy storage, and urban/rural applications. Preq: ECE 320 or consent of instructor."

Topical Outline for ECE 461:

1. Course Overview
2. Introduction to Solar Energy
3. Importance of Solar Energy as Clean & Sustainable Energy
4. Fundamentals & Technology of Solar Thermal Systems
5. Fundamentals & Technology of Concentration Solar Power
6. Operating Principles and Design of Photovoltaic (PV) Cell
7. Processing and Manufacturing of Photovoltaic Modules
8. Design, Sizing and Sub-Systems of PV system
9. Operating Principles Design of Hybrid Photovoltaic/Thermal Systems
10. Manufacturing of Hybrid Photovoltaic /Thermal Systems
11. Batteries and Capacitor based Electrical Energy Storage Systems
12. Smart Grid and PV Systems
13. Urban and Rural Applications of Solar Energy
14. Topics of Instructors Choice

As part of the course teaching methodology, the first objective is to create a comfortable and non-threatening learning environment for the students. After introductions, the instructor explains their expertise and interests in the topic of solar energy on the first day. From the beginning of the course, students are encouraged to ask questions. The majority of the students are from electrical engineering (EE) while some are from mechanical (ME) and chemical (CHE) engineering. Students are assured that careful attention will be paid to provide any background knowledge they may lack. Powerpoint files are used in the lectures and students are provided with class materials before each session. Although an emphasis is placed on the core fundamentals, the classes, homework, quizzes, and tests also consider practical engineering problems related to solar energy. At the beginning of each class, the instructor connects the day's ideas, concepts, and/or problems to materials that have been presented in previous classes. In each lecture, students are provided a clear sense of the day's topics and their relation to the course as a whole. The instructor uses gestures, eye contact, and movement around the room to engage the student's attention.

Each student is expected to research and select a solar topic of their interest. Students have to report their progress at different intervals during the semester. Although feedback is given for corrections and modifications, only the final version of the term paper will be graded. Similarly, feedback is continually offered on the powerpoint file and students are graded on the final presentation. Graduating students are provided with job opportunities where the instructor has personal industrial relations; several students have been successfully placed as solar energy engineers. This 3 credit hour course has been primarily offered to senior (although some junior) students at Clemson University who have completed the required prerequisites or received consent from the instructor. Two questions on the university wide assessment survey have been considered in this paper – G3: "The course was well organized" or G3*: "The course covers very interesting material," and G10: "Overall, the instructor is an effective teacher". The ECE 461 course was completed by 20 and 21 students over the Fall 2011 and 2012 semesters. The evaluations by the students reported that G3= 2.7/5.0 and G10= 3.8/5.0. In general, students have appreciated the instructor's pragmatic and comprehensive teaching method. Further, several

students found the course to be a springboard for a position in the energy industry and recognize the material and research direction provided by the instructor to be helpful in their careers. Future plans include inviting industry experts as guest lecturers to enrich the students with current developments of the industry and research.

3. Fundamentals of Wind Power

Wind power has great potential to be a major source of future energy. The placement of wind turbines in non-forested, ice free, and rural areas of the world should be sufficient to supply the world electricity demand[16]. Currently, wind power is one of the fastest growing energy sources on a global basis. For several millennia, mankind has used wind powered machines for transportation, grinding grain, pumping water, and recently producing electricity. Throughout the world, wind energy has contributed to 26% of new electric generating capacity between 2006 and 2011[6]. In 2011 alone, the United States added more than 6.8 GW of wind power capacity, bringing the total capacity to 47 GW. Since 2007, wind energy represents 35% of the United States' new electric generating resources[17]. Wind energy has the potential to stimulate economies by creating new business opportunities and jobs while providing clean power. The availability of an on-line wind power course offers students an opportunity to learn about this green energy technology and to help prepare individuals for electric power careers.

The wind energy course has been designed so that students will have a fundamental background on wind power systems, particularly wind turbines. The course begins with a series of lectures introducing the students to the wind energy resource, technology, its history, and the evolution of the modern wind turbine. Students learn about the components which make up a typical wind turbine system (refer to Fig. 3), and the different manufacturing methods used to make them. The course places a heavy emphasis on the engineering aspects of wind energy systems. Students learn the principles of wind energy conversion, modern wind turbine blade design, and differences in wind energy extraction technology. Next, the mechanical, electrical, and electronic systems of the wind turbines are explored. Topics include rotor dynamics, loading, electrical power generation and turbine vibration analysis. Given the importance of control systems in wind turbine operation, the course discusses the wind turbine system dynamic behavior, component integration, sensors, actuators and controllers. Like other power production technologies, wind energy technology impacts human life and the environment; hence the course also delves into the environmental, political, and economic issues associated with wind energy.

ECE/ME 457 Catalog Description:
"Introduces wind turbine systems, including wind energy potential and application to power generation. Topics include wind energy principles, wind site assessment, wind turbine components, power generation machinery, control systems, connection to the electric grid, and maintenance. Prerequisite: ECE 307 or ECE 320 or consent of instructor."

Topical Outline for ECE/ME 457:
1. Introduction
2. Historical Perspectives on Wind Turbines
3. Wind Energy System Components
4. Turbine Design
5. Mechanics and Dynamics

6. Electrical Aspects of Wind Turbines
7. Fatigue and Wind Turbine Design
8. Wind Turbine Control
9. Wind Energy System Economics
10. Wind Farm Feasibility Studies
11. Conclusion

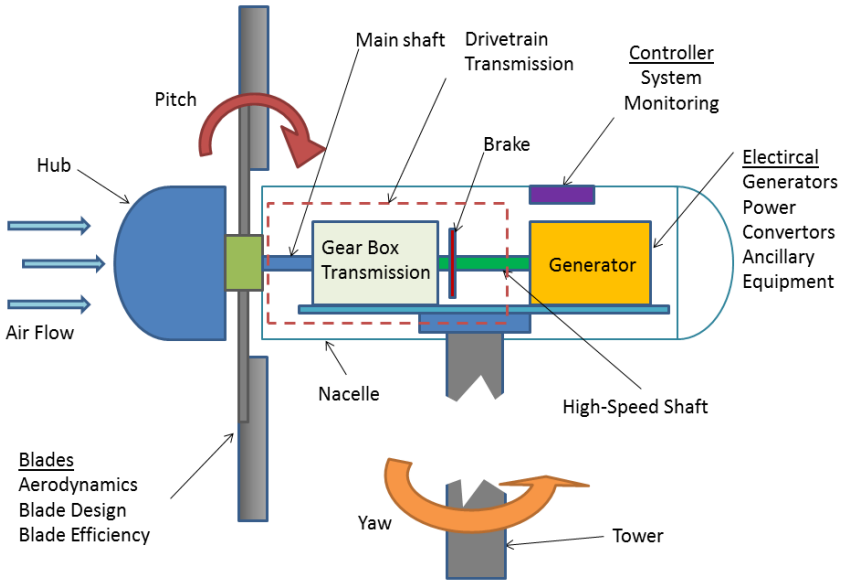

Fig. 3: System level diagram of a horizontal wind turbine for ECE/ME 457 course

The fundamentals of wind power course is offered on-line and designed for undergraduates and professionals who desire to learn and enhance their knowledge about wind power systems. Delivering the course on-line empowers distance learning and offers flexibly for students to complete classes per their daily schedule. Since presentations that use both visual and auditory modalities reinforce learning for all students[18], the course is taught using lecture videos and published course notes. Students can stream the videos and download materials and assignments through Blackboard. The course is divided into 11 chapters with each chapter addressing a specific topic relating to wind power. A primer for chapters containing advanced topics has been provided since the course attracts students of different engineering backgrounds. Each chapter contains examples dealing with real world problems related to wind power; for instance, wind turbine design, control, economics, and environmental effects. During the length of the course, students receive daily instructions and words of encouragement from the instructor containing suggested activities for the day and reminders about approaching deadlines and tests. Despite being an on-line course, students are encouraged to communicate with the course instructor via the telephone, email, and on-line video chat.

Periodic assessment with feedback provides direction and enhances student learning while confirming the course objectives and learning outcomes[19]. Students can view their performance through Blackboard. There were 11 homework assignments containing both conceptual and subjective problems related to wind power. Course examinations are taken on-line through

Blackboard. The exams contain multiple-choice, short answer, and essay type questions. The course assesses students based on their performance on two tests and submitted assignments. This 3 credit hour engineering course has been offered to senior undergraduate students at Clemson who have completed the required prerequisite. For ECE/ME 457, 4 and 26 students were enrolled in the Summer 2011 classroom and 2012 on-line sessions. The students' responses on G3 and G10 were 4.6/5.0 and 4.7/5.0, respectively. Overall, the class participants found the course interesting and indicated that it provided an excellent foundation for understanding wind power. Moreover, the students found the course material enriching and lauded the instructor for making the course interesting.

4. Renewable Energy Penetration on the Power Grid

The increase use of renewable energy resources has created a new set of challenges for the well-established electric power industry. Renewable energy technologies such as solar and wind use power sources that are not continuously available due to uncontrollable factors (e.g. seasons, weather, time of the day, location, etc.) and hence should be viewed as intermittent. Power generated from intermittent sources is variable in output and less predictable than conventional power generation resources which have raised electric utilities concerns about the possible large scale integration of renewable energy in to the existing grid. The variation in electricity demand (load) from consumers and the distance of most renewable energy generation plants from the centralized grid further exacerbates the problem. If not adequately resolved, these concerns could severely impact the development of renewable energy across the world. Furthermore, the characteristics of renewable energy generation are different than those of conventional power plants, around which existing grid systems have evolved. Electric utilities and policy planners have identified the need for new parameters in transmission planning and the use of a decentralized generation framework. This would require upgrading existing electric grids to be smarter and would necessitate the use of grid planning, computer simulations and advanced component technology. The successful integration of renewable energy would require engineers who are knowledgeable about power engineering and trained in the area of smart grid integration.

This course will provide students with a fundamental understanding of the conversion of solar and wind energy in to electricity and its impact on the power grid. Since this class is focused on grid penetration of renewable energy, the first few sessions of the course are devoted to teaching the basic concepts of electricity, power generation, electric loads, and interfacing of the primary resources as shown in Fig. 4. Solar and wind energy are the most prominent sources of renewable energy[20]. The course places a heavy emphasis on the principles of electricity generation by these renewable technologies and the associated issues with their grid integration. Since energy storage plays a crucial role in the development of green energy, the course devotes a few sessions related to batteries with topics such as performance characteristics, charge regulators, recharging, and management. Students are also introduced to concepts related to electric performance including harmonics, distortions, and voltage sags. Furthermore, the national electric standards are discussed.

ECE 420 Catalogue Description:

"Introduction to the basic definitions of electrical power, interfacing primary sources, generator/load characteristics, and renewable energy resources. Topics include solar energy

grid interfacing, wind energy grid interfacing, battery charging/management, harmonic distortion, voltage sags, and national standards."

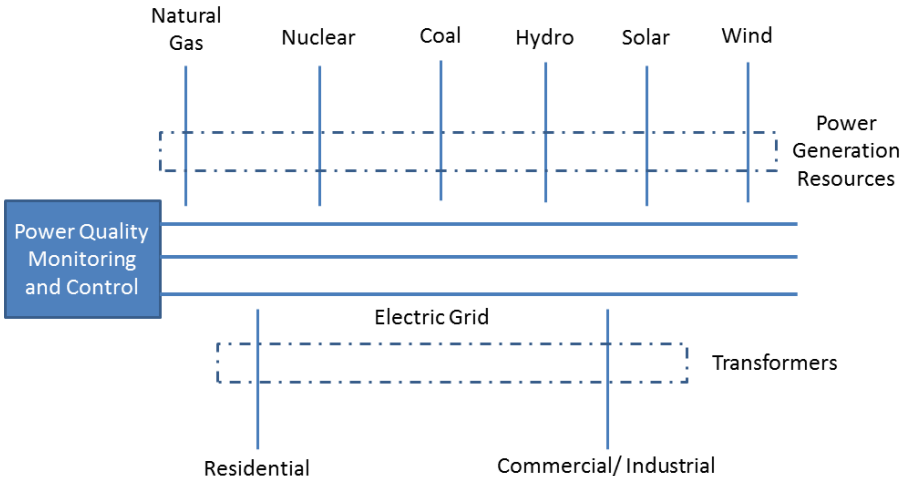

Fig. 4: Example of a distributed generation system for ECE 420 course

Topical Outline for ECE 420:

1. Principles of Renewable Sources of Energy and Electric Power
2. Wind Energy
3. Solar Energy
4. Energy Storage
5. Power Quality Issues
6. National Standards and limitations.

It is well established that students learn better when they have opportunities to experience or practice what they learn[21]. The course adopts this learning approach by offering sessions devoted to solving examples which allow the students to practice recently acquired concepts. Students are also expected to submit weekly assignments to promote a better understanding of the course material. The course is conducted in an open environment where students can voice their questions and discuss relevant course topics. Industry experts provide guest lectures to review current practices and on-going developments in the power industry. As part of their assignment, students must submit a report which summarizes the presentations provided by the industry experts. Students are tested on their basic and conceptual understanding of the subject materials. Further, they prepare a design project where the topics include the grid simulation with renewable energy sources; the top five projects are presented in class. Weekly homework are also part of their grade. From on-going course surveys, the students learned much about power grids and power monitoring. From the guest lectures, they gained valuable insight into the industry point of view and new technology that has been introduced into the market. Students have generally fared well in the course.

Over the past two academic years, the 3 credit hour undergraduate course has been offered to senior engineering students at Clemson. The number of students who participated in ECE 420 was 18 and 26 for the Spring 2011 and 2012 semesters. For the two questions, the responses were G3*= 5.0/5.0 and G10= 4.8/5.0. In the near future, the course will be available on-line so

undergraduates who are on internships and/or co-ops, as well as working professionals can access the class. The instructor plans to offer new material dealing with security concerns and protection due to cyber-attacks on the grid. For smart grids to be reliable and efficient, it must be seamlessly integrated with the cyber infrastructure.

5. Conclusion

The renewable energy certificate program at Clemson University has the potential to help prepare students for emerging careers in alternative energy. Participants become acquainted with existing and future energy generation technologies, fundamentals of solar and wind energy harvesting, energy conversion, storage methods and electrical power grid. They have a better understanding of the emerging renewable energy generation sector and its impact on the economy, society, and environment. This paper presents the topics, teaching methodology, and assessment practices of three courses offered as part of the certificate program. In summary, an opportunity exists for today's students to be tomorrow's leaders in alternative energy and this program is one effort to help society transform their generation of energy to power all aspect of mankind's existence.

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