# A Multidisciplinary Undergraduate Course in Energy Engineering

**Dr. Radian G Belu, Southern University and A&M College**

Dr. Radian Belu is Associate Professor within Electrical Engineering Department, Southern University, Baton, Rouge, USA. He is holding one PHD in power engineering and other one in physics. Before joining to Southern University Dr. Belu hold faculty, research and industry positions at universities and research institutes in Romania, Canada and United States. He also worked for several years in industry as project manager, senior engineer and consultant. He has taught and developed undergraduate and graduate courses in power electronics, power systems, renewable energy, smart grids, control, electric machines, instrumentation, radar and remote sensing, numerical methods, space and atmosphere physics, and applied physics. His research interests included power system stability, control and protection, renewable energy system analysis, assessment and design, smart microgrids, power electronics and electric machines for non-conventional energy conversion, remote sensing, wave and turbulence, numerical modeling, electromagnetic compatibility and engineering education. During his career Dr. Belu published ten book chapters, 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, renewable energy, microgrids, wave and turbulence, radar and remote sensing, instrumentation, atmosphere physics, electromagnetic compatibility, and engineering education.

**Dr. Fred Lacy, Southern University and Agricultural & Mechanical College**

Dr. Fred Lacy earned his B.S.E.E. from Howard University in Washington, DC in 1987, his M.S.E. from Johns Hopkins University in Baltimore, MD in 1989, and his Ph.D. from Howard University in 1993. Upon completion of his Ph.D., Dr. Lacy joined the Bioengineering Department at University of California, San Diego from 1994 – 1998 as a postdoctoral fellow. Upon completion of his postdoctoral research, Dr. Lacy held a position as a medical device reviewer at the US Food and Drug Administration. Dr. Lacy joined the faculty at Southern University in Baton Rouge, Louisiana in August 2002 and is currently a professor and chair of the Electrical Engineering Department. Dr. Lacy specializes in developing, manufacturing, and characterizing electronics based microsensors for various applications (including sensors for biomedical applications).

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## 1. Introduction, Motivation and Rationales

Over the last three decades, power and energy engineering industries are experiencing fast growth due to the transition to smart grids, the high penetration of renewable energy, and energy conservation and efficiency improvements. As we are fast moving into a future with increasing global energy demands, limited fossil fuel resources, and harmful environmental impacts of conventional energy generation and uses, the very nature of human existence will rely to a great extent on our ability to successfully shift away from unsustainable fossil fuel based energy systems towards increased use of renewable energy resources and reasonable consumption patterns. Moreover, among the greatest challenges that our society is facing are those of delivering growing, secure and affordable supplies of clean energy and water. Success of such enterprises requires a well-trained workforce as well as a public that is energy literate. It is not surprising that in this context about half of the grand engineering challenges of the 21$^{st}$ century, as identified by the U.S. National Academy of Engineering (NAE) [1], are from the energy and power engineering fields or from the engineering education. Examples include making solar energy affordable; providing energy from fusion; developing carbon sequestration methods; advanced personalized learning; and engineering the tools for scientific discovery. Meeting our energy demands requires not just producing more, but also producing in a sustainable way or using what we do produce more efficiently while supplying consumers with affordable energy allowing the maintenance of a comfortable living standards. Development, design and implementation of innovative technical solutions are fundamental to addressing such challenges, whilst also offering exceptional opportunities for economic growth to the nations which are able to deliver them. However, this rapid pace of technological and scientific advancements in power and energy engineering fields brings interesting challenges and opportunities for educators, professionals, engineers, and students working in these dynamic industry areas. With such increased demand in professionals trained in the STEM field, and more specifically in energy and power engineering, the United States of America is creating opportunities to increase the number of professionals in the fields of engineering and technology [2-7]. Power and energy industries are the cornerstone of a prosperous society; all critical and crucial socio-economic functions depend on secure, sustainable and reliable energy and power infrastructures.

Growing concerns for the environment and increased demand for sustainable energy generation, requiring new approaches in the power and energy industries, which are receiving significant attention from educators, professionals, public and governmental officials. As penetration of new energy technologies, renewable energy systems, distributed generation, and energy storage technologies keep increasing there will be higher and significant needs for well qualified professionals to address these new challenges. For example, considerable attention has been given to power generation and transmission technologies in the first century of electrification, but in more recent years, there has been recognition for higher investment levels and research in to power distribution, smart monitoring infrastructure, and advanced power applications of the computing and information technologies. Many students have often only a passing knowledge of the new energy and power engineering technologies and few fully understand the fundamental issues related to renewable energy, smart grids, grid integration and emission reductions. Hence, there is a critical need to prepare the next generation of engineers to meet the growing needs in alternate energy while revising the engineering curriculum.. In addition to educational issues there are many research challenges and opportunities in such new power and energy areas.

Enrollment in engineering programs, although increasing modestly over the past decades, is still unable to keep pace with industry needs and with the number of engineers leaving workforce [1-8]. Indeed fewer engineering students are studying or planning to study energy engineering, further compounding to the issue of energy engineer's shortages. However, preparing students for these career opportunities is quite a challenging task, further complicated because it must be accomplished using often limited resources and within stringent time constraints of a crowded curriculum. Power and energy engineering education has undergone significant changes partially due to an increased student interest in such programs [2-14]. There also are new challenges due to the transition to smart grids and increased use of renewable energy and distributed generation. Development, operation and maintenance of smart grids or renewable energy systems require engineers to have a solid power engineering background, and a good understanding of some of the auxiliary fields, e.g. information technology, cybersecurity, communication, smart controls, meteorology, or socio-economic issues. The smart grid initiative requires engineers to have deep understanding of operations, requirements, limitations and capabilities of the future power systems or distributed generation. There are great industry needs for cross-trained professionals to meet the modern energy infrastructure challenges [4-18]. Engineers of modern energy industries are required to have advanced scientific capabilities, deep understanding of the interdisciplinary connections, as well as to possess soft engineering skills such as project management, economics, self-learning abilities, communication and interpersonal competence. Which are the best approaches and methods to educate the next generation of engineers remains an open question. Moreover, significant changes in the current industry are creating challenges, new requirements and opportunities for engineering education. In addition of teaching traditional courses in electrical machines and power systems, new courses and topics must be included, e.g. advanced power electronics, distributed generation, renewable energy, smart grids, smart protection and control, DC power networks, energy storage, information and communication, energy economics and management, to mention a few of them while still ensuring a four-year graduation timeframe. There are also increased demands for continuing education of engineers in the emerging energy technology area. A well-designed power or energy engineering curriculum must offer a judicious balance between basic science, mathematics, and a strong engineering foundation with a particular focus on the laboratory and hands-on experience, computing background, communication skills, management, and economics.

During Academic Year 2017-2018, our department proposed to establish energy and power engineering minor. The new minor was strongly supported by the college, by our Industrial Advisory Board and our major sponsors, such as Entergy Corporation. Major. Project challenges include: appropriate course materials, content, textbooks, developing new learning materials and laboratory experiments, inclusion or not of projects, limited financial resources, and finally inadequate laboratory equipment and space. Facing these challenges, a three-step development and implementation approach was decided upon, consisting of: 1) upgrading and updating existing power engineering courses, through new course materials that still meet the objectives of the original courses; 2) developing upper division elective courses that address specific topics, such as: Power Electronics, Power Distribution, Smart Grids, Energy Systems, and Renewable Energy Systems; and 3) restructuring, upgrading and expanding power engineering laboratory, as an integrated modular laboratory facility for energy conversion, electric machines, power electronics, power systems and renewable energy. The proposed new courses were approved and strongly supported at both the department and college levels. Among them, a multidisciplinary junior undergraduate course on energy engineering addressing the gaps in current power and energy engineering education, providing knowledge and skills as required by the local energy and power industry, was proposed. The course structure and content focused on what the energy industry is expecting, e.g. general energy engineering training for all new engineers in a power plant. The goals and objectives of the course are to cultivate energy literacy to all engineering students, regardless the program, creating a formal basis for future energy and power engineering education. The course is now offered, for the first time, in the Spring 2020 semester, as a required course for power and energy minor students, as an elective course for students enrolled in all engineering programs. It is also offered as a technical elective for students enrolled in physics, mathematics, chemistry and teacher education programs. Given the current requirements of typical undergraduate engineering course plans, adding general energy engineering course to the existing undergraduate programs is not trivial. We need to find creative ways to fold this course to all engineering students and as an elective to the students enrolled into sciences programs. In this paper, we discuss the challenges to this course development, topic selections, pedagogical approaches, planned course activities and lessons' learned. We are actively looking to engage others in this effort and any suggestions are highly valuable and appreciated.

## 2. Course Content and Structure

Traditionally, the first course on electric energy in most of the engineering programs is taught as an energy conversion course, covering mainly conventional electric machines. However, this field of electrical engineering includes a number of new specialties such as digital systems, power plants, renewable energy, power electronics, energy storage, energy conservation, computer engineering, communication, networks, etc. With such a wide spread field, energy conversion turned into a topic for only students specializing in power [13-21]. An energy engineering course with a wider view of the key aspects of electric energy, covering quite a few of the above areas seems to be useful and timely. Since electric energy is encountered daily by the students, carefully selected energy topics has the potential to stimulate the interests of engineering students for power and energy careers. This new course is presenting the major energy sources, fuels, power plant configurations, operation and types, and alternative energy technologies. In this course the student will gain an understanding about energy technologies including how they work, how they are quantitatively evaluated, what they cost, and what is their benefit or impact on the natural environment, as well as the proposed energy systems and how they might become a part of the existing energy infrastructure. The role of energy systems technologies, energy economics, demand-side management, and the effects of market forces on energy and modern power systems are also briefly discussed in this course. Discussions of economic and environmental and social policy are integral components of the course. The purpose of the course is to provide students with a background education of the major current and future energy conversion processes, operation and management of the power and energy systems, their main components and related issues. The students should be able to demonstrate competence and understanding of how power and energy systems function, their operation and performances; what the technologies costs and how they can be constructed and designed, understand fundamentals of power and energy systems, type, grid operation and structure of power plants, and electrical components associated with energy infrastructure, and the environmental impacts of energy use, the operation principles, characteristics and performances of the power system components and devices, and AC power, three-phase circuits, power quality, and blackouts. During the course activities the students will utilize common industry tools and software packages for renewable energy analysis, simulation and design, and become familiar and know the drivers and requirements of the smart grids.

The syllabus provides a detailed course description, main topics, weekly readings, assignments, project dues dates, exam dates, course objectives, grading policy, instructor contact information, administrative issues, etc. The overall objective of this course is to provide students with both the science and technology of different energy sources, alternative and renewable sources, power system operation, as well as the policies that heavily influence this industry. The course main goals involve student in-depth understanding of the energy sources, their characteristics and operation, types of the used fuels, energy system components, structure, configurations, types and characteristics of the common generation units, grid integration issues of the renewable energy and distributed generation units, major types of alternative energy sources, their characteristics and performances, assessment and analysis, the infrastructure of existing energy systems, economic and environmental issues of the current energy generation, transformation and uses [15-24]. Notice that during the first week, students must read the syllabus, acknowledge the fact that they read it and understood what is expected of them. In this week, students are given the opportunity to introduce themselves to classmates and present their interests into the energy engineering. In addition, they can state their expectations from the course, and any issue of interests.This course also covers the critical technical constituents of the electricity generation, transmission, distribution, utilization, energy conversion and storage. The course required textbook is M. A. El-Sharkawi, Electric Energy – An Introduction [13], while the recommended textbook is Vanek et al., Energy Systems Engineering [21]. The instructor is also providing comprehensive lecture notes, power point presentations and timely solutions of the homeworks and assignments. Both the required and recommended textbooks are well written, covering key aspects of energy engineering, from energy sources, fuels, power plants, generation, transmission and distribution, to electric machines, power electronics, electric safety, power quality, future electric grids and energy uses. The required textbook includes several solved examples in each chapter, as well as end-of-chapter questions and problems. Many of the topics covered in each chapter are encountered daily life, therefore are of great interest to all engineering students, regardless their program of study. Being a generic energy engineering course no specific software packages or tools are required. However, the use of MATLAB is strongly encouraged for solving the advanced problems. The course covers the following major topics:

1. Introduction and History Power Systems and Energy Infrastructure
2. Energy Resources
3. Power Plants
4. Thermal Cycles, Refrigeration, Heat Recovery
5. Alternative Energy
6. Fuel Cells and Hydrogen Economy
7. AC and Three-phase Circuits
8. Power Grid Structure, Components and Operations
9. Power Grid Operation
10. Future of Energy Systems, Smart Grid

The course is divided into ten modules or units where each one tackles one major topics of the energy engineering. Each of the course modules 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: basic knowledge, and deepened, advanced knowledge, and additional contents of teaching, and references. Modules are ended with a multiple-choice quiz, covering the module/unit theoretical aspects of the topic, conducted online, by using Moodle, our university Learning Management System. 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. 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 and codes to students enabling them analyze and better understand the main energy systems. Upon completion of the course, students should be able to explain the various types of non-renewable and renewable energy technologies, including: their structure, characteristics; environmental problems associated with non-renewable and renewable sources of energy as well as possible improvements; and the future of renewable sources of energy, power and energy infrastructure or smart grids. The course starts with a brief history of electric power generation, transmission and distribution. Emphasis is placed on the energy resources and the electricity generation environmental impacts. This discussion is followed with projections of electric energy consumption and shortage of electricity generation coupled with transmission line congestion, which all encourage the use of distributed generation. The environmental impacts of electricity generation in conventional power plants are also covered. Other topics are concerned with types, structure and characteristics of power plants, thermal cycles, major alternative energy sources, energy storage technologies, fuel cells and hydrogen economic. One unit of the course is reserved to in-depth presentation of the AC and three-phase systems, while the rest of the course is focusing on the operation, structure and components of modern power systems and future smart grids. By the end of the course students should:

- Have a good understanding of the energy and power industries, power plants, energy sources, generation, transmission, the energy market, economics and the history of energy sources.
- Have an understanding of the role of government in shaping energy policies and mandates.
- Know in-depth the power systems and energy infrastructure components, characteristics and
- Be able to explain and analyze the basic power systems components, their operation principles, configurations, performances and characteristics.
- Know and able to perform basic analysis and calculation of the AC power, three-phase circuits, synchronous generator operation, power transformer and transmission lines
- Be able to analyze the operation of the power plants, types, environmental impacts.
- Understand the operation and performance parameters of the basic power converters, and apply and use the techniques for analyzing and designing these converters.
- Be able to assess, compare, contrast and select different renewable energy conversion systems for specific applications.

This course could be improved in many ways, in particular identifying and presenting information technologies to discover and monitor natural resources, modern and more efficient conversion technologies, energy transfer and creating materials explaining the technologies that are easy to understand by all sophomore and junior, regardless of their engineering program. We are realizing that this is one of the most challenging courses to set, design and offer due to the need of the student to have an expertise and background in many engineering and applied sciences disciplines, from power engineering, electric machines, to thermal sciences, electrochemistry, fluid mechanics to computer science and lack of easily accessible relevant information. Moreover, during recent years, the traditional education systems have witnessed significant transformations aligned to research related to how learning occurs, new educational technologies, and the resurgence new standards to design learning environment and delivery modalities to foster deeper learning competencies and accommodate students with various learning needs [18-24]. In the recent years, the adoption of innovate the learning process and to increase college affordability and success through online and e-Learning, or zero-textbook-costs has been at the core of 21st century curricular revisions agend. Defining competencies is currently used as an objective measure of curricular revisions. Aligned with our college and university mission objectives, we are intended to offer next academic year this course in a hybrid online and onsite format, in order to facilitate the enrollment of the Entergy engineers, enhancing our partnership. Besides the regular end-of-semester survey, an informal survey is planned between the first and second mid-term tests and during the last week semester. The students will be asked to provide feedback on course content, topics, teaching methods, assignments and tests, and the overall opinion of the course usefulness. The surveys' results will be discussed during the end of semester department faculty meeting and presented to our Industrial Advisory Board.

## 3. Course Assessment

The primary goal of this course is to increase the level of interest of our students in the energy and power industries and motivate them to think about issues related to the energy conversion, alternative and renewable energy sources. We hope that some of our students will be inspired to think about future careers in these fields and continue to be part of the on-going conversation and the debate about the energy and power industries. The long-term aim for our efforts is to create a set of courses in our curriculum that deal with different aspects of the energy and power industries and to create an energy certificate and a minor concentration as part of the our engineering undergraduate programs. The assessment of the course is and will be performed through various activities, e.g. class exercises, case studies, open discussions, assignments, two tests and exams that are given to the students throughout the semester. An example of a good course assessment is the performance of students when they are solving the advanced problems of each of the major course topics. The final examination is comprehensive and covered all the lecture materials. This course includes a final mini-project or case studies and paper to allow the students to explore one specific alternative energy source in more detail and investigate a scientific, social or environmental issue related to that source. Students present their final projects in class and receive feedback both from their peers and their instructors. A quantitative analysis is not considered to date, but is planned for future academic years. However, the satisfactory completion of the semester tests and the final exam will be a positive indication of this course. So far, we have received quite a positive informal feedback from the students at the mid-term regarding this course and we are planning to continue to improve the course in the near future. At the end of the semester a questionnaire will be administrate to the students. The survey questions are summarized below, and the answers will be presented on a Likert scale, e.g. 5 = Strongly Agree; 4 = Agree; 3 = Satisfactory, 2 = Disagree; and 1 = Strongly Disagree.

Q1: How much the course contributed to your understanding of the energy engineering?
Q2: The course materials posted on Moodle were helpful?
Q3: How much did you enjoy the course content?
Q4: How much did you enjoy the course mini-project?

## 4. Conclusions and Future Developments

The power and energy industry are looking for well-trained graduates with advanced engineering background to manage these challenges. Energy and power industry are in full transition to smart grids, extended use of distributed generation, alternative energy and advanced generation and storage technology. Such changes and challenges lead to increased demands for energy engineering graduates, indicating that there are long-term needs for quality power and energy engineering programs. Taking these issues into account, our department and college decided to develop and implement a power and energy minor. One of the new courses proposed is the Introduction to Energy Engineering, a junior-level course offered for all our engineering students. This paper provides an overview of the steps to initiate to set, develop and implement a general engineering course into our engineering programs, providing an overview of steps to initiate and implement energy engineering concepts, providing the students with the energy systems background, in-depth concepts and understanding how energy systems operate, what there are the important aspects, structure and configurations. In keeping up with advances in 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 junior-level undergraduate course on energy engineering. The course is first offered in Spring 2020 semester with a total enrollment of 18 students. Detailed coverage of course topics, structure and content of the course units are presented in this paper. The materials presented herein may be used as model for other instructors considering offering a similar course on energy systems engineering. Future development consists of offering this course in future academic years as a hybrid course or fully online. Course materials, content and topics are planned to be adapted and restructured to be fitted with the online and hybrid format.

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