AC 2012-4071: A MULTIDISCIPLINARY POWER AND ENERGY ENGINEERING PROGRAM

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A Multidisciplinary Power and Energy Engineering Program

I. Introduction

Declining enrollments in power engineering over the last decade and the anticipated loss of engineers through retirements from the power and energy workforce have focused attention on the need for a rapid increase in new engineering graduates prepared to join this workforce. Furthermore, there are a wide variety of challenges facing the nation in power and energy, including changing mixes of energy, development of alternative energy sources, creation of a Smart Grid, minimizing environmental impacts of energy, using available fossil fuel resources more efficiently in an evolving regulatory climate, and others. Addressing these challenges will require engineers from multiple traditional disciplines to address an array of discipline-specific technical, business, and policy problems relying on fundamental core knowledge of power and energy.[1] This mirrors the larger movement calling for engineering graduates to have an interdisciplinary and system-based viewpoint, in order to address the complexities of the major challenges (such as energy) that face our world. [2]

In response to this need for a power and energy engineering workforce, a Power and Energy Institute (PEIK) was created at The University of Kentucky, which already had a strong history of power and energy education across the college of engineering but lacked a program integrating these efforts. The task of the new institute was to bring together the existing activities and then expand upon them. This institute brought together a core set of faculty from across the college who shared a common interest in power and energy education. With the help of a grant from the US Department of Energy, the institute created undergraduate and graduate certificate curricula, with new courses and instructional laboratories to support these certificates. In addition, the Institute offers scholarships, professional development courses, and even an international summer program.

As shown in figure 1, both the graduate and undergraduate certificate programs are multidisciplinary across engineering, including electrical, mechanical, biosystems, chemical, civil, computer, materials, and mining engineering. All students pursuing one of these certificates take a core of common classes to give them a base of knowledge across power generation, transmission and distribution, power economics, and public policy. Following the core, students take more focused courses that go deeper into power and energy topics within their specific engineering discipline. For the graduate certificate, there is an Energy Experiences course where students make weekly visits to regional power and energy related sites. Students in the program are also eligible for scholarships for a 4-week international renewable energy program offered in Pamplona, in the region of Navarre, Spain.

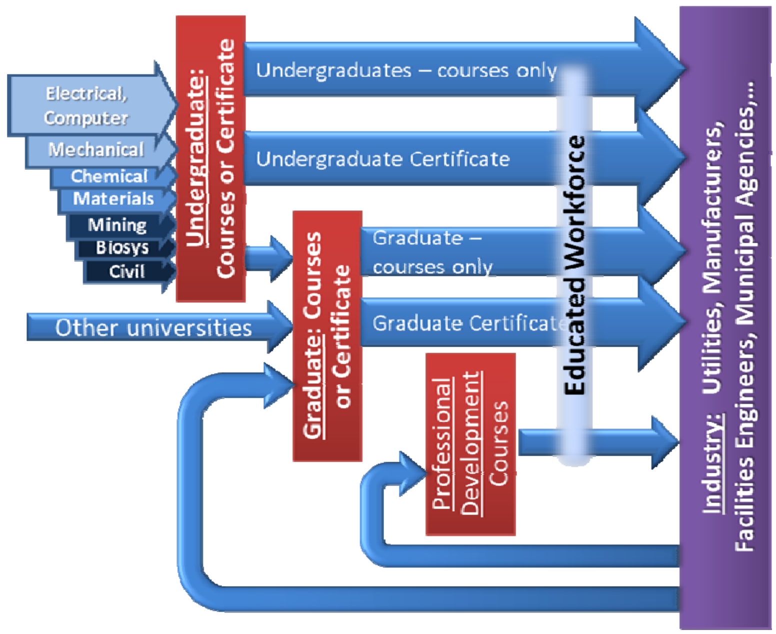

Figure 1. Education Paths

These new certificate programs have attracted positive interest and involvement by students, but have also encountered implementation challenges in the form of administrative logistics and integrating multiple curricula and degree requirements. In the sections below, we overview the structure of the institute's certificate programs. We then discuss some of the challenges faced in developing the multidisciplinary program, and our efforts to overcome these challenges.

II. Program Structure

The Power and Energy Institute offers an undergraduate certificate and a graduate certificate.

A. The Graduate Certificate

The *Graduate Certificate in Power and Energy* requires coursework amounting to 15 credits. The structure (Figure 2) is made up of four required core courses and one energy elective.

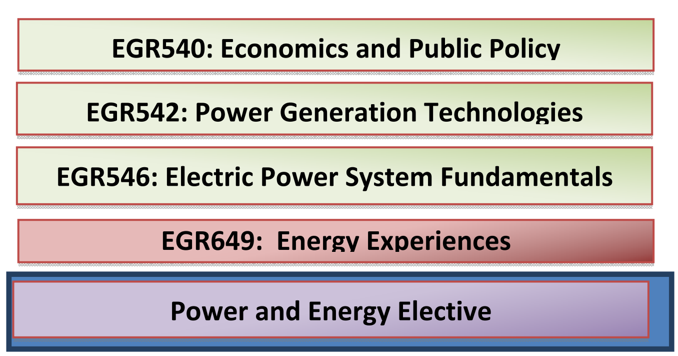

Figure 2: Structure of the Graduate Certificate

The program design is ambitious. The plan was to make it possible to complete the certificate within one academic year by meshing certificate course requirements with course work required for a graduate degree in each of the participating engineering majors. The curriculum has a total of four required courses; students then can choose one or more additional electives:

- **EGR 540* Electric Power Economics and Public Policy:** This course provides an introduction to the theories and industry practices related to power economics and power public policy. Topics studied include: U.S. power markets, electric utility business regulation, electric utility environmental regulation, public policy theory, political science theory, development of new electric generation facilities, utility business operation, engineering influence on public policy, and engineering economic analysis.

- **EGR 542* Electric Power Generation Technologies:** This course provides an overview and general design principles for generation technologies in current practice, including those using coal, nuclear, gas turbine, hydro, solar, wind, and biomass, as well as how each fuel or energy resource is recovered, processed and converted into electrical power. The goal is to provide an understanding of the environmental consequences/benefits of each fuel source and how each technology must adapt to meet future energy demands.

- **EGR 546* Electric Power System Fundamentals:** This course is an introduction to power transmission basics, reactive power, power flow, control and stability issues, and distributed generation issues with the grid. This course also introduces smart grid issues such as communications and security.

- **EGR 649* Power and Energy Experiences:** This class is intended to provide students with unique exposure to industry personnel and facilities. The class meets once per week, and takes field trips that last from a few hours to an extended day (with one overnight trip). Visits during the Spring 2011 semester included sites such as various types of coal power electrical generation facilities (supercritical, fluidized bed, and pulverized) and their respective pollution control devices, gas turbine peaking plants, hydroelectric facilities, a nuclear plant, a transformer manufacturer, a pumped storage site, a wind farm, a power operations center, a landfill gas site, a smart grid demonstration center, a solar power site, a high efficiency building, and others. More than simply tours, these visits include presentations from operators and engineers at the facilities, and are prepared for in the coursework through readings and lecture materials. Students keep journals, take photographs and write reports on what was learned during the visits and from the readings.

  Because many of the field trips are full-day, care was taken to schedule the course on Fridays, with all other power and energy related courses scheduled on Monday/Wednesday schedules or Tuesday/Thursday schedules. When possible, other courses students might take (such as required core courses for majors) were also scheduled for these other days. Monday/Wednesday-only class schedules are not typical at the University, so special permission was required for this scheduling.

These required core courses provide a foundation in energy economics, public policy, generation, and transmission and distribution. Through the Experiences class, the students matriculating through the program also gain an extensive and unique exposure to electric power and energy sites and to industry experts. Students are also expected to participate in a seminar series where speakers from industry, government, and academia speak on current power and energy topics.

The Graduate Certificate program is designed to mesh with the requirements for an MS in Biosystems, Civil, Electrical, Manufacturing, Mechanical, or Mining Engineering. Efforts are also underway to integrate with requirements for the PhD programs in Biosystems, Civil, Chemical, Electrical, Manufacturing, Materials, Mechanical, and Mining Engineering. Courses beyond the four required courses and one elective course necessary for the certificate can be used to satisfy the requirements for these graduate degrees, as well as to provide depth in power and energy topics. Whereas the foundational core courses provide an introduction to topics, the power and energy electives courses give students in-depth knowledge that allow them to design, analyze, or evaluate systems or devices associated with power and energy. These include courses targeted at topics in generation, transmission, distribution, renewable energy, storage, monitoring, control, system protection, power electronics, energy-efficient facilities design, cyber-security and telecommunications issues for power systems, and others.

B. The Undergraduate Certificate

The Undergraduate Certificate in Power and Energy consists of 15 credit hours. It is structured (Figure 3) to include a “Global Energy issues” course, a selection of one of the core courses from the Graduate Certificate (either Policy and Economics, Generation, or Power Systems), and three electives that can, in many cases, be chosen from the student’s undergraduate major curriculum requirements. The Undergraduate Certificate program will thereby mesh with the requirements for a BS in Biosystems, Electrical, Chemical, Computer, Manufacturing, Materials, Mechanical, or Mining Engineering. The structure of the Certificate program will allow certification through electives requirements, with few -- often no -- additional courses beyond those required for the degree. For example, in electrical engineering, an existing electric power "track" includes many power-related courses available to undergraduates and applicable to the certificate.

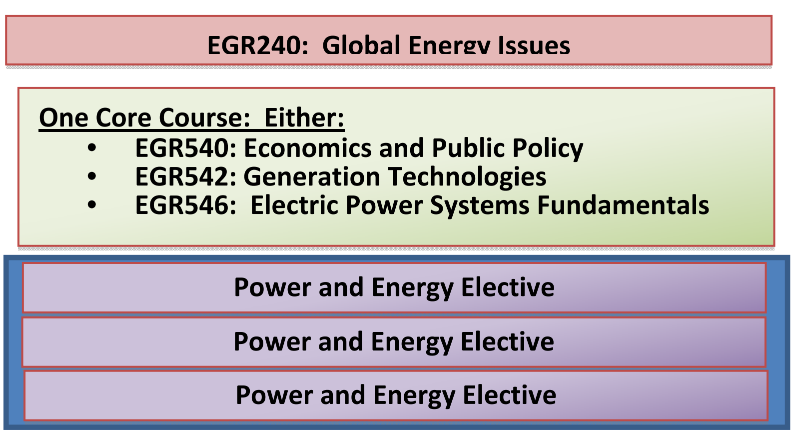

Figure 3: The structure of the Undergraduate Certificate.

The required EGR 240 “Global Energy Issues” is a sophomore level course intended to give students broad exposure to the social, cultural, political, environmental, economic, and technological aspects of energy. The goal is for students to critically examine issues associated with the broader impacts of energy. Open to both engineers and non-engineers, this course has been designed to satisfy a “Global Dynamics” general education requirement for all undergraduates, not just electrical engineers or even engineering majors, and so it's hoped it will function as a broader recruiting mechanism and gateway, drawing other engineering majors into the certificate program. At least one engineering department has discussed making the course required for all undergraduates in their discipline, as a way of satisfying the ABET accreditation requirement that students understand the broader impact of engineering in a global, economic, environmental, and societal context.

C. Power and Energy Electives

The University of Kentucky already had numerous power and energy courses in the College of Engineering before the creation of the institute. These included Electromechanics, Advanced Electromechanics, Electric Drives, Power Systems Fault Analysis and Protection, Power Systems 1 & 2, Power Distribution Systems, Power Systems Analysis Software Methods, Power Electronics, Renewable Energy Systems, Biofuels Production, Building Energy Modeling, Power Generation, and others. Creating the institute made it possible to expand the list of available courses by creating new ones. These included courses already discussed above as requirements for the certificates, but also courses on Introduction to Nuclear Engineering, Nuclear Engineering Design, Smart Grid: Automation and Control of Power, Smart Grid: Communications and Information, Solar Power, Electrochemical Energy Storage, Environmental Consequences of Energy Production, and Energy Assessment. These courses can be taken by students as electives within their major, or as electives applying to the certificates.

The institute also offers an international, 4-week, 3-credit hour intensive summer course on Renewable Energy (6 weeks if Spanish language courses are included). The course is taught in partnership with the Pamplona Learning Spanish Institute and the Association of Industrial Technical Engineers of Navarre, in Pamplona, in the region of Navarre in Spain. Navarre gets 70% of its energy from renewable sources, so the course is an excellent opportunity for students to understand more about renewable energy challenges and opportunities, as well as to understand broader global perspectives on power and energy. This summer course counts as an elective in either of the certificate programs.

III. Challenges for the Program

Implementing the multidisciplinary Power and Energy program has encountered difficulties. While dealing with administrative challenges is not as intellectually stimulating as other aspects of faculty work, solving them has its satisfactions. We agree with Fairweather's assessment[3] that describing what it takes to implement an innovative program has value in making such innovations more easily adopted by others. That's our hope in providing the information that follows. Here we outline some of the challenges, and discuss our responses to them.

A. **Prerequisites:** A major challenge in implementing a multidisciplinary certificate program is ensuring that students from different engineering majors will be able to successfully take each required course, and will be able to succeed in several electives as well. This means a careful consideration of prerequisite requirements to ensure that most students in the targeted majors will have the necessary background to take the course. For the EGR 542 Power Generation Technologies class, the concern was whether students would have sufficient knowledge of thermodynamics. It was determined that the base level of expected knowledge of incoming students would be achieved through engineering physics course that all engineering students are required to take (several majors, such as Electrical Engineering, do not require a course on thermodynamics). For the EGR 546 Electric Power System Fundamentals, the material covered is focused on electric power transmission and distribution. The material in most institutions would be targeted towards electrical engineers (EEs), but the goal is to provide other engineering majors with knowledge of power systems, so the course had to be more broadly based. After considerable debate, the course prerequisite was for students to at least have had one or more circuits courses -- for EE students, this would be the EE circuit sequence, but for non-EE-majors, it would require students take the EE service course for non-majors. The course will then be accessible to non-EE majors, but with the expectation that non-EE students may require some additional reading at times during the course. Most non-EE undergraduate majors are required to have this service course, and thus would be able to take the EGR 546 course without additional prerequisites. One exception is civil engineering majors, who do not normally have this prerequisite.

B. **Differing Requirements and Allowable Electives for Majors:** As shown in figure 1, the certificate program is intended to appeal to students from most engineering majors. Different majors, however, have different levels of flexibility in their required curricula, and different expectations of what would be appropriate for a student in power and energy. Regarding flexibility in the curriculum, the different majors have a given number of electives allowed within the major, and a given number of electives allowed outside the major, but still in the curriculum. In an attempt to minimize the number of courses required by students outside their curriculum, we worked to ensure that there would be some power and energy courses that could be cross listed as electives within each discipline. As examples, the EGR 542 core course on power generation technologies (which is taught by a chemical engineering faculty member) is cross listed as chemical engineering, the EGR 546 core course on power systems fundamentals is cross listed as electrical engineering, the nuclear engineering courses are cross listed as mechanical engineering and materials engineering, and the Environmental Consequences of Energy

Production is cross listed for civil engineers. We also identified, when possible, power and energy-related courses that already existed within the different majors. For example, Thermodynamics II (mechanical engineering) was determined to have enough content specific to power generation to count as an elective for the certificates. Some of the electives eventually accepted were not self-evidently power and energy-related courses; in those cases, the instructor was required to submit an explanation of the relevance and the content of the course.

The integration of the power and energy curricula into the different majors is an ongoing challenge. The program should work to communicate better with departmental advisors so that these advisors can tell students how to achieve the certificate best within the constraints of the different curricula. Also, additional work needs to be done with departmental curriculum committees to get better integration of the power and energy coursework into the curricula.

C. **Getting supportive involvement from the different disciplines:** For a multidisciplinary program to succeed, it is important to involve a representative from each discipline in the design and other decision-making. The power and energy institute includes faculty from each of the engineering departments on its leadership team. The team meets regularly to review and evaluate course proposals and program direction. Each representative on the team also represents his or her home department. Thus they function to communicate in both directions, providing the institute with information from their home departments about potential problems, as well assisting the institute in seeking solutions to problems that can work for all parties. It's important that the representatives are self-chosen and thus motivated to put in the time and effort needed to launch such a project. The current leadership team (which corresponds to the coauthors of this paper) came together based on a shared commitment to power and energy education, and began working together as participants on the grant proposal. A challenge for the future will be to determine how to maintain an effective core leadership team, as additional faculty outside the initial team become interested and as faculty in the original team leave to pursue other interests or opportunities.

Another vehicle for involvement is an Internal Advisory Board that meets once each semester. This Internal Advisory Board consists of the department chairs of each discipline in the college of engineering, as well as directors of other relevant multidisciplinary programs and centers within the college. This Internal Advisory Board functions to provide advice and feedback to the institute. But it also functions to persuade department chairs of the value of the project. It is important for department chairs and center directors to understand the value and purpose of institute programs so they will permit faculty members to direct some part of their teaching load towards programs in the power and energy area. In retrospect, it would have been good to also have more interactions with the undergraduate and graduate program directors and advisors right from the start, so that they could have been better prepared to advise students on the new program.

D. **Balancing the needs of different industrial constituents:** The institute created an External Advisory Board with thirteen initial companies and organizations. The members of the board represent utilities, design engineering firms, manufacturing firms, industrial associations, and the state energy cabinet. The goal of the board is to ensure that the institute's curricula is appropriately targeted towards developing the future engineering workforce for these industries. The challenge is that the different industries on the board have different needs. An ideal graduate for a manufacturer of smart-grid appliances is different than the ideal for a utility, which is different again than the ideal for a contracting or design engineering firm. By having the different industries represented on the board, we are attempting to create a program that appeals not only across different engineering disciplines, but also that develops graduates that are appealing to companies in several sectors of the power and energy industry.

IV. Achievements

The power and energy institute has seen steady increases in enrollment. In Fall 2010, there were 250 student enrollments in power and energy related courses, then 332 in Spring 2011, and 409 in Fall 2011. According to the registrar, at least 141 students have completed 2 or more power and energy related courses over a 2 year period, with over half of these electrical engineering students. To put this in context, the college has 2481 undergraduates (413 are EE) and 485 graduate students.

The program actively markets its offerings. Each semester, the institute advertises its power and energy courses to students through emails and flyers. General presentations on the power and energy program have been made to several freshman classes, emphasizing the exciting opportunities in the field and the growing need for power and energy engineers. Interest is fostered also through regular power and energy seminars sponsored by the institute, as well as through programs from a very active "Energy Club" on campus. Collectively, the courses, the seminars, the marketing, and the club, as well as an increase in coverage of energy issues in the media, all contribute to a growing interest in power and energy in the college, and consequently to growing enrollment in power and energy courses.

Regarding certificates, after the first one and half years of the program, nine undergraduate and 14 graduate students have completed requirements for the certificates. This total is lower than projected but administrative delays in getting official university recognition for the certificate programs account for some of the shortfall. (The certificates have been approved at the university pending official recognition of permanent course numbers for the courses that are required. Thus, the certificates are not officially recognized until the university completes its review and approval of those course applications.) It is projected that future years will see significantly more students completing the certificate. Interestingly, in a recent informal survey of undergraduates in the program and the industry members of the External Advisory Board, both groups indicated a preference for a "minor" rather than an "undergraduate certificate" designation; the institute is currently reevaluating whether to reclassify the undergraduate program as a minor.

V. Summary

This paper outlines a newly implemented multidisciplinary program in power and energy. The program's goal is to create more engineers with power and energy backgrounds in order to address national and industry needs. The paper also outlines several of the challenges that have been faced in implementing such a program across disciplines and departments.

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[1] Needs of the power and energy workforce are discussed in National Science Foundation (2008), *National Science Foundation Workshop on the Future Power Engineering Workforce;* NERC (2008), *Key Issues: Aging Workforce. www.nerc.com*; U.S. Department of Energy (2006), *Workforce Trends in the Electric Utility Industry: A REPORT TO THE UNITED STATES CONGRESS;* U.S. Power and Energy Engineering Workforce Collaborative (2009), *Preparing the U.S. Foundation for future Electric Energy Systems: A Strong Power and Energy Engineering Workforce.* IEEE Power & Energy Society. Future energy issues, including smart grid and renewables, are discussed in National Academy of Sciences (2009), *America's Energy Future.* Washington DC: National Academy Press; National Academy of Sciences (2009b), *Electricity from Renewable Resources: Status, Prospects, and Impediments.* Washington DC: National Academy Press and National Science Board (2009), *Building a Sustainable Energy Future,* Washington D.C., National Academy Press.

[2] National Academy Of Engineering. 2005. Educating The Engineer Of 2020: Adapting Engineering Education To The New Century. Washington, DC: The National Academies Press. **www.nap.edu**

[3] Fairweather, James. 2009. Linking Evidence and Promising Practices in Science, Technology, Engineering, and Mathematics (STEM) Undergraduate Education: A Status Report for The National Academies National Research Council Board of Science Education (BOSE). Commissioned Papers.
http://www7.nationalacademies.org/bose/PP_Commissioned_Papers.html