

2006-489: AN UNDERGRADUATE POWER ENGINEERING CURRICULUM: A UNIQUE AND PRACTICAL APPROACH TO BRIDGING THE GAP BETWEEN ACADEMIA AND INDUSTRY

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An Undergraduate Power Engineering Curriculum: A Unique and Practical Approach to Bridging the Gap between Academia and Industry

Abstract

Currently the electric power industry is facing a looming shortage of qualified and well-educated candidates to fill a large number of positions within the electric energy sector. The job of preparing electrical engineering students for careers in the broad interrelated areas of electrical power systems, machines and energy is a formidable challenge. This task is further complicated because it must be accomplished using very limited financial resources within the short time frame available in a typical undergraduate engineering curriculum. This situation provided Colorado School of Mines (CSM) with a unique opportunity to design a very effective undergraduate power engineering curriculum. After presenting an overview of the “power engineering option” at CSM, this paper discusses the course outline, the scope, and the methodology that was adopted to design a very successful and effective advanced power systems laboratory. Our advanced undergraduate energy systems laboratory promotes power engineering education by showcasing the modern simulation tools used by the utility sector. Working closely with industrial representatives helps to prepare the students for the real world problems they will eventually be asked to evaluate.

Introduction

Established in 1874, Colorado School of Mines (CSM) is one of the oldest institutions of higher education in the State of Colorado.^[1] It is known both nationally and internationally for its education and research in all areas of earth sciences including “energy.” CSM is predominantly a comprehensive engineering research university. While offering all the usual benefits of an excellent undergraduate education, CSM places emphasis on programs which lead to professional opportunities. The multi-disciplinary BS degree program in “General Engineering” offered by the Division of Engineering is relatively new. Within this General Engineering degree program, there are currently four areas of specialization: Mechanical, Electrical, Civil and Environmental Science and Engineering.^[2]

Currently (2005) at CSM there are 3,846 students including 3,098 undergraduate and 748 graduate students. There are 13 divisions/departments offering ABET accredited engineering degree programs. The Division of Engineering is the largest single unit, about a third of the entire campus and currently has 1,171 students; 1,072 undergraduate and 99 graduate students. The electrical engineering specialty comprises approximately one-fourth of the Division and has eleven full-time faculty members (eight tenure/tenure track plus three lecturers). The Division graduates annually approximately 70 undergraduate students in the electrical specialty. Since CSM has a small group of EE faculty, the program focuses on two “tracks” of multi-disciplinary interest: (i) Energy Systems, Machines and Power Electronics, and (ii) Automation, Sensing and Communication. Both undergraduate and graduate programs at CSM are tailored to meet the distinct needs of the students’ professional ambitions based on the available faculty and research expertise.

Because of the nature of a multi-disciplinary General Engineering program, and the tradition of an earth science related university, students are required to take approximately 140 credit hours for the undergraduate engineering degree (compared to 120 -128 credits in most other universities). A large part of the course work is designed to provide a much broader engineering education than in traditional “Electrical (and Computer) Engineering” programs offered elsewhere throughout the nation. The undergraduate General Engineering degree program at CSM emphasizes a breadth of fundamental studies in electrical engineering with some opportunities for specialization. Students are allowed to take three “electrical technical electives” and three “free electives.”

Scope of “Power Engineering” Education at CSM

“According to U.S. Department of labor, by 2012 there will be about 10,000 more power jobs available than people willing to fill them. The average age at utilities is about 48. The matter is compounded because younger people view utilities as part of the industrial age and less thriving than other technical fields such as nanotechnology.”^[3] The U.S. electric power industry is faced with a shortage of well trained engineers. In the Rocky Mountain Region, many colleges have abandoned their power engineering curriculum entirely. In fact, this has been the trend nationwide as many university power programs have declined in recent years.^[4] At Colorado School of Mines we are working to reverse the trend of diminishing interest among U.S. students in the electric power industry.

Deregulation during the 1990’s caused tumultuous change for the energy sector. During these turbulent times the utility sector also largely neglected its need to cultivate technical expertise. Reorganization of the industry caused many of the technically-oriented jobs to disappear. At the same time, fewer students were studying power engineering, because they found the “glamorous and exotic (and quite often better paying)” high-tech areas of electrical engineering to be more appealing. As a result, the utility sector and energy industry now finds itself faced with a looming shortage of qualified and well-educated candidates. Many of the energy related companies in the Denver Metropolitan area are mindful of the anticipated shortages of qualified technical personnel. Companies like Tri-State Generation and Transmission, Inc. and Xcel Energy, and government organizations like the Bureau of Reclamation and the National Renewable Energy Laboratory (NREL) are active partners with CSM. This paper illustrates how CSM works closely with the local industries to offer a high quality power engineering education to the students. The power engineering curriculum at CSM serves as an example of how a program with limited resources can take advantage of the capabilities of local industries to enhance the quality of instruction. The primary objective of the CSM “power engineering program” is to help meet the anticipated shortages of qualified workers by preparing our graduates for careers such as:

- Application Engineers
- Power System Design Engineers (both utility and non-utility sectors)
- Plant Electrical Engineers
- Equipment Design Engineers
- Engineers in the R & D Field
- Pursue Advanced Degrees

Contrary to the misperception by many young students, the power industry is introducing many advanced technologies, particularly in the design of advanced control systems, system optimization, economic dispatch, open-access transmission systems, improving system reliability and security, equipment design and protection. By working closely with industrial representatives, CSM students are exposed to more advanced and practical aspects of power systems engineering. Observing first hand the technical problems faced by the energy sector and seeing the new technologies being implemented, helps the students to understand that pursuing a career in the power industry can provide them with a lifetime of exciting and rewarding challenges. The educational philosophies and teaching techniques followed by the CSM power faculty have yielded some tangible results. For example:

- Increased recognition of the CSM graduates by local, regional and national industry. This is reflected by an increased demand for our power engineering graduates (multiple job offers and higher salary) and positive feedback from both our students and their employers.
- Student ratings of the CSM instructors in power area are significantly above our division and university average.
- Greater enthusiasm and interest in our power program from our student body. This is evidenced by the increased number of higher quality students enrolling in senior (optional) power elective courses. (Average of almost 20 students/year)
- Students' frustrations with laboratory work have been relieved to a large degree by our lab procedures and lab coordination efforts.
- Laboratory reports (writing skills and organization) have improved remarkably in presentation and content and are approaching a professional level quality.
- Higher enrollments of non-traditional students (approximately 40 students currently enrolled) pursuing advanced education and degree (MS and PhD).
- Since the industry sees a tangible benefit from our approach they are supporting the program.

A description of CSM's power engineering curriculum, a practical approach to bridging the gap between academia and industry, is provided below.

Required Courses

In the specialization areas of "electric power systems and machines," CSM by way of its charter has always had more courses offered than are available in other traditional departments and programs. Two such classes that are required for all the electrical specialty students are briefly described below.

Fundamentals of Electric Machinery (Course No. EGGN 389): All students in the electrical engineering specialty are required to take a four-credit (three-credit theory plus one-credit lab) junior level class (in the second semester) titled *Fundamentals of Electric Machinery*. The main idea of this class is to familiarize the students with the fundamentals of electric power systems, machines and energy. The primary focus throughout is on electromechanical energy conversion. The course stresses the application of transformers, ac synchronous machines, ac induction machines, and dc motors in industrial power systems. The class at CSM is approached from the systems standpoint as opposed to treating the various types of electric machines as discrete entities. The theory, operation, testing and performance of electric machines are explored in

depth. Equal emphasis is placed on their respective functions in industrial, commercial and utility power systems. The laboratory component of the class is designed to complement the theory. Students have the opportunity in lab to work directly with the ac and dc electric machines that are featured in the lectures. In addition to learning about electric machine operation and performance, a unique feature of the laboratory experience (as an example) is a field trip to the City of Boulder Municipal Water Hydroelectric Facilities. The City of Boulder has five hydroelectric facilities installed on its water pipelines to generate electric power.^[5] The Electric Machines Laboratory Instructor, having over 25 years of experience, provides our students with an excellent opportunity to see large electric machines in operation and observe how they are integrated into the power grid. The students are usually given the chance to start one of the machines and synchronize it with the utility system. This is an excellent example of the educational philosophy used in the CSM power engineering program, making use of industrial contacts to enhance the undergraduate education that our students receive.

Electrical Specialty Field Session (Course No. EGGN 334): All CSM engineering undergraduate students are required to take a three-week (3-credits) Field Session course during the summer months between their junior and senior years. This gives us a unique opportunity to introduce and educate the future engineers about the important topic of electrical safety along with other subjects. A more detailed description of CSM's Electrical Safety Training Module is provided in another paper accepted for publication at the 2006 Annual Conference of the American Society for Engineering Education.^[6] The students learn the skills required to recognize, evaluate, and control electrical hazards. A number of industrial experts are involved in the delivery of the electrical specialty field session material. An introduction to the National Electrical Code (NEC) is provided by a local industrial authority. A Senior Industrial Safety Engineer from the National Renewable Energy Laboratory (NREL) provides a look at safety from a research lab perspective. A number of tours are conducted as well. For example, CSM Plant Engineering provides a tour of the campus electrical distribution system and Xcel Energy (the local utility) provides a tour of a large power plant and their energy management systems. All the tours focus on safe work practices in an industrial environment.

Multidisciplinary Senior Capstone Design (EGGN 491/492): In addition to the power related curriculum described above, all CSM engineering undergraduate students are required to take a two-semester (6-credits) capstone design course sequence. The course sequence represents the culmination of the students' undergraduate engineering training and education. Student teams interested in the power engineering field have the opportunity to select a design project that complements their interest in the energy sector. For example, last year eight students from the electrical and mechanical specialties investigated the CSM campus energy needs for the year 2020 and beyond. Working closely with the campus architect, CSM plant facilities, Xcel Energy, NREL, and the group of power faculty, the students developed a detailed technical engineering study focusing on the reliability and sustainability of the campus energy system.^[7]

Power Engineering Electives

There are at least three senior level theory classes and one advanced laboratory class offered at CSM so that students can pursue more in-depth study in the interrelated areas of electrical power systems, machines and energy. These classes are offered regularly (once a year).

EGGN 484 (3): Power Systems Analysis (Fall): This course introduces the students to the fundamentals of power system analysis and design. The topics covered include system modeling, power flow, symmetrical and unsymmetrical faults, system grounding, selection of major equipment, and the design of electric power distribution systems.

EGGN 485 (3): High Power Electronics (Spring): This course introduces the students to the basic principles of analysis and design of circuits utilizing power electronics. Applications include control of power flow on major transmission lines, variable frequency drives in industrial facilities, and electric vehicles.

EGGN 498 (3): Special Topic: Design of Small Renewable Energy Systems (Fall): This course introduces the students to the practical topics related to the design of alternative energy based systems. The main objective is to focus on the interdisciplinary aspects of the integration of the alternative sources of energy, including hydropower, wind power, photovoltaic, gas, biomass and energy storage for the systems. The design of stand-alone and grid-connected electrical energy systems is described.

EGGN 498 (1): Special Topic: Advanced Energy Systems Laboratory (Spring): This course is described in detail in the next section.

Students wishing to pursue careers in power engineering or other closely related fields are encouraged to take the elective classes including the advanced lab discussed in this paper. It is also common for our students to take some graduate level classes (listed in Appendix A) to fulfill their free electives. The graduate level power systems engineering classes are scheduled at 4:30 pm so that non-traditional students (practicing engineers) can also extend and update their professional capabilities through credit and/or non-credit courses, as well as graduate degrees. Figure 1 below shows a flow-chart for the undergraduate power engineering educational opportunities available at CSM.

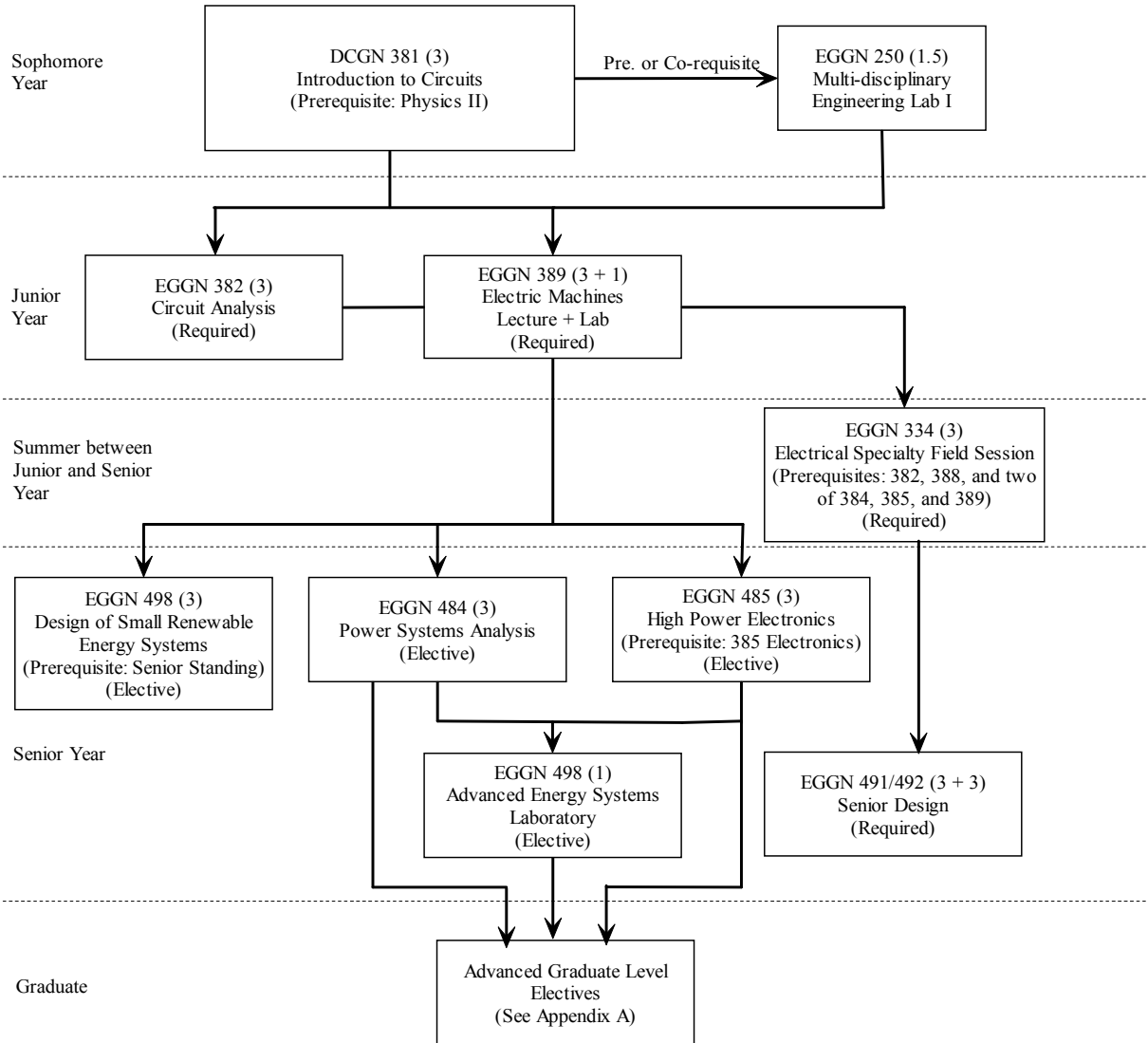


Figure 1. Scope of Undergraduate Power Engineering Education at CSM

Advanced Energy Systems Laboratory (EGGN 498)

The course featured in this paper is a one-credit upper division elective laboratory class specially designed to provide a broader background in large scale power systems and to discuss the state-of-the-art analytical techniques utilized in power systems engineering computation. This elective laboratory class is designed to complement the power systems analysis class (EGGN 484). A thorough understanding of the operational principles of basic electric machines, power systems elements, and fundamentals of power systems is a minimum requirement for this class. This class was offered for the first time during the Spring 2005 semester as a pilot program to a limited number of students interested in the power engineering profession.^[8] Based on the success of the pilot program, the course has become a permanent part of the undergraduate power engineering curriculum at CSM. Classes meet for 3 hours on a weekly basis throughout the semester and are limited to 12 students. The Advanced Energy Systems Laboratory is

equipped with six Dell Optiplex computers featuring PowerWorld Simulator Software (Version 11.0).^{[9][10]} The professional version of the software that is used in the lab will support the analysis and design of 7,000 bus power systems. Universities that still offer power engineering curriculum at the undergraduate level, commonly use computer aided simulation techniques to enhance laboratory teaching. The use of a computer aided simulation package like PowerWorld is very effective at helping students learn the complex processes involved in power system planning. PowerWorld Simulator is a powerful visualization tool; the animation capabilities help the students understand the complexity of the power-flow problem.

Students, in general, lose interest in a course that focuses entirely on computer simulation techniques and computer software. Consequently at CSM, we have taken a very different approach to developing our Advanced Energy Systems Laboratory. A special feature of our advanced laboratory is the utilization of industrial contacts. CSM is located in the Denver Metropolitan area, in close proximity to a number of electric utilities, governmental research labs and manufacturing industries. Representatives (engineers, technical personnel and managers) from the utility and energy sector graciously agreed to take part, giving us the opportunity to offer a unique course in power systems engineering. Industry participants in this joint endeavor have the chance to showcase the opportunities that exist within the electrical energy field. This industrial partnership provides an important source of motivation for the students and helps to dispel the myth that the field of power system engineering is an outdated discipline. This educational approach is evident in both the course objectives and course outline that are provided below.^{[11][12]}

Course Objectives

- Students will be able to describe the power flow problem formulated as a set of nonlinear algebraic equations which are most suitable for a computer solution, and will be able to explain and perform the Jacobi, Gauss-Seidel and Newton-Raphson methods of analysis.
- Students will demonstrate proficiency in the use of PowerWorld Simulator software, create power system models and apply the models to analyze power system operations.
- Students will be able to evaluate an existing power system and perform a contingency analysis to understand the vulnerability of the network. System planning is an important aspect of power system analysis and design. Power system design is an open-ended process so students will be able to evaluate alternatives and justify their design decisions.
- Students will have the opportunity to work with experienced planning engineers to see industrial applications of transmission and power system planning software.
- Students will be able to use the PowerWorld Simulator to calculate the short circuit currents resulting from symmetrical and unsymmetrical faults in a system and will be able to use the results from a fault study to select power system protective equipment.
- Students will have the opportunity to work with experienced operations engineers to see how fault currents are monitored and mitigated in a metropolitan distribution system.

Course Outline and Grading

Formal Lectures:

- Introduction to Power System Planning and Design

- The Power Flow Problem (Gauss-Seidel and Newton-Raphson Method)
- Introduction to the PowerWorld Simulator Software
- Fault Studies (Symmetrical and Unsymmetrical Faults)

PowerWorld Simulation Projects:

- Develop MATLAB Power Flow Program (Gauss-Seidel or Newton-Raphson Method)
- Power System Operation: Voltage Regulation and Reactive Power Control
- Power System Planning: N-1 Contingency Analysis
- Power System Expansion: Adding Generation and Load
- Power System Fault Studies: Symmetrical and Unsymmetrical Faults

Field Trips:

- Tour of an Xcel Energy Substation
- Tour of Xcel's Energy Management System
- Tour of Western Area Power Administration's Dispatch Training Center
- Tour of an Xcel Energy Power Distribution Center

Student Presentations:

- Final Design Project: Presentation and Justification of Power System Design Decisions

Grading:

- PowerWorld Simulator Assignments: 50%
- PowerWorld Simulator Final Project (Technical Report and Oral Presentation): 25%
- Class Participation and Attendance: 10%
- Tour Summaries: 15%

Two examples presented in the Appendix show how industrial input is used to develop relevant course materials for the advanced energy systems laboratory.

Assessment

Because this paper describes a course that has been presented only once, extensive assessment data has not yet been collected. At this point in the course development it is not possible to accurately establish if the course objectives have been achieved. The Advanced Energy Systems Laboratory is being taught for the second time during the Spring 2006 semester. One of the priorities is to collect more extensive assessment data to help evaluate the effectiveness of the course. Nevertheless, preliminary feedback from the students and local industries involved with the initial offering of the Advanced Energy Systems Laboratory was very positive. For example, after working with the students a power industry representative commented: *"After seeing the caliber of students that you are training, I feel much more comfortable about the long term future of our profession."* This comment is encouraging in the context of the trend of diminishing interest among U.S. students in the electric power industry.

The following quotations are representative of many of the student comments: *"The course should be expanded to accommodate more open-ended design projects,"* *"I think this course has*

great potential. Open-ended design problems help me out the most so I think you should add more of those,” and “Try to make this class 3 credits, so we can do more!”

These comments are an indication that the innovative instructional approach produced the desire and motivation to learn more. The pilot program seems to have been successful largely because the students were actively engaged in the educational process.

Conclusions

With a population of over 2 million residents, the Denver Metropolitan Area has a number of companies involved in the many aspects of power systems engineering. This includes a large investor owned utility, co-ops and REA's, consulting engineering firms, and government agencies. These firms are constantly looking for well-trained college graduates to help manage the challenges faced by the energy sector of our economy. Although a quantitative measurement of the results of the CSM power program is difficult to ascertain, the qualitative (demand for our “power” graduates and salary) indications lead us to believe that the program is very successful and is on the right track. This paper has demonstrated that university-industry interaction and cooperation is a key to a successful program. The power engineering curriculum discussed in this paper and taught at CSM has been extremely well received by the students and by the power industry hiring our graduates.

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Appendix A: Available Graduate Level Courses at CSM

- EGES 583 (3) Advanced Electrical Machine Dynamics
- EGES 584 (3) Power Distribution Systems Engineering
- EGES 585 (3) Advanced High Power Electronics (EGGN 485)
- EGES 586 (3) High Voltage AC and DC Transmission
- EGES 598 (3) Special Topic: Energy Systems Stability
- EGES 598 (3) Special Topic: Power Systems Protection and Relaying
- EGES 598 (3) Special Topic: Power Quality and Reliability
- EGES 598 (3) Special Topic: Computer Methods in Power Systems Engineering
- EGES 598 (3) Special Topic: Renewable Energy and Distributed Generation

Appendix B: PowerWorld Simulator Final (Power System Expansion) Project

This analysis and design assignment is modeled after a real world project being investigated by Tri-State Generation and Transmission Association, Inc. Tri-State, the state of Colorado's second-biggest power supplier, plans to invest \$5 billion over the next few years to generate and provide more electricity to the Western Power Grid.^[13] This assignment gives the students an opportunity to work on a realistic open-ended power system planning project using the PowerWorld Simulator to evaluate the suitability of their designs. The students are asked to make recommendations on how to best add 500 MW of generation to an existing power system. *“The project is going to strengthen the transmission system in this region that is capped out, antiquated and overused. There is a need to develop more transmission infrastructure to improve reliability of the power supply and relieve constraints in the system.”*^[14] The students are required to design a transmission system can supply the system load reliably in any base case or first-contingency (N-1) loading situation. Extensive data made available from Tri-State is provided to the students so that they can evaluate the cost of their design options.

Appendix C: Xcel's Energy Management Center Tour Quiz and Summary

The list of questions was developed by the transmission operations engineer at Xcel. The students are required to send their answers directly to the engineer along with the instructor.

1. What does ACE stand for?
2. What happens to the frequency at Lookout Center when a fully loaded 1,200 MVA generator in Washington trips? What immediate response should come from the generators in the Public Service of Colorado (PSCo) control area?
3. What group performs the Automatic Generation Control (AGC) function for PSCo?
4. If the voltage looks a little low at a particular substation, what two passive elements might a System Operator use to help boost the voltage?
5. How could you tell if a bus differential protection relay tripped given a substation display following a lockout alarm?
6. Name two reasons you might want to remove a transmission line from service.
7. On an open-ended transmission line where is the voltage the highest?
8. List three common bulk power transmission voltages.
9. The Energy Management System (EMS) computer performs Real-Time Contingency Analysis automatically for N-1 conditions. Explain why.
10. Why does a state estimator have a tougher job solving the power-flow problem?
11. The North American power system comprises of how many major synchronous interconnections?