Proceedings of the Fifth IASTED International Conference
POWER AND ENERGY SYSTEMS
June 15-17, 2005, Benalmádena, Spain

A PROPOSAL FOR AN INTEGRATED UTILITIES ENGINEERING MANAGEMENT ME PROGRAM

Frank S. Barnes Ewald F. Fuchs Jill S. Tietjen
Dept. of Electrical and Computer Engineering
University of Colorado
Boulder, Colorado 80309-0425 USA
barnes@colorado.edu, ewald.fuchs@colorado.edu,
jill.s.tietjen@colorado.edu

JoAnn Silverstein Hon-Yim Ko
Dept. of Civil, Environmental & Architectural Engineering
University of Colorado
Boulder, Colorado 80309-0428 USA
joann.silverstein@colorado.edu,
ko@colorado.edu,

Tom Lookabaugh Timothy X. Brown Douglas C. Sicker
Interdisciplinary Telecommunications Program
University of Colorado
Boulder, Colorado 80309-0530 USA
tom.lookabaugh@colorado.edu, timxb@colorado.edu, douglas.sicker@colorado.edu

ABSTRACT: Electric, telecommunications, water, gas and transportation utilities face severe challenges associated with a combination of technical, economic and social issues. To meet the educational needs for engineers and managers the University of Colorado at Boulder is proposing a novel integrated utilities management program for Master of Engineering (ME) candidates. The ME program will consist of four interdisciplinary paths dealing with business, management and legal topics as they relate to federal and state regulatory issues and people-related leadership issues. The electric utilities option of this program will be centered on three core courses related to electric power generation/transmission and distribution, security and availability, quality and reliability, economics and environmental policy, and utility finance; two electives from a group of courses that address nuclear power, waste water, solid waste, telecommunications, renewable energies, data communication, fuels and case studies; and one capstone course. Courses will be taught both on campus and nationwide via the Center for Advanced Engineering and Technology Education (CAETE) of the University of Colorado at Boulder.

KEY WORDS: Utilities management Master of Engineering program, electrical engineering, civil engineering, telecommunications, educational program

I. INTRODUCTION

The prerequisite of a traditional MS program of electrical power engineering is a BS degree focusing on calculus, computer engineering, circuits/electronics, electro-magnetic fields and waves, communication theory, linear systems, and introductory power system/energy conversion courses. The duration of such an MS program, including a thesis, is about two years. The advantage of this program is that it concentrates on technical power/energy conversion issues: so, the end product is a well-versed engineer. The disadvantage of such a program is that the newly graduated engineer has not been exposed to management, environmental, business, regulatory, and telecommunications issues. The changing technical, environmental, regulatory and business environments, however, demand that individuals with a more interdisciplinary education be available in today’s competitive electric utility business.

A. Traditional Education of Power Engineering

Power systems based on central power stations rely on natural and business monopolies. Graduate students learn about the reliability of power generation, distribution and consumption, automated and non-automated metering, load management, system stability, transients, flexible AC transmission systems (FACTS), load flow, contingency operation, load shedding, frequency/voltage control, relaying, automated substations, re-closing, emergency uninterruptible power supplies, rotating machine dynamics, and the spot market for electric energy.

B. Emerging New Technologies for Power Engineering

In addition to the above-mentioned concepts in a less-regulated electric utility environment, the following additional topics gain importance: distributed generation, renewable energy sources, power electronics, power quality, probability, environmental issues, competition, security, response to emergencies due to terrorism, and frequency/voltage control without many central power stations. Additionally, constrained optimization techniques will be needed where the objective function is calculated for given performance constraints. Students will be required to know about telecommunications control of relays and switches, interrupters and circuit breakers, fuel cells, batteries, air quality, scrubbers, spot markets, the intermittent characteristics of wind and solar energy, weather forecasting, and the ethics of business dealings. The use of power lines for broadband communications (BPL) [1] may also provide new opportunities for energy utilities to integrate information systems with the operation of power delivery systems.

It appears that today's electric utilities are not very well prepared for such changing technical/business environments: the recent brownouts and blackouts give testimony to this. A government report [2] concludes that inadequate system understanding, inadequate situational awareness, and inadequate reliability diagnostics are some of the main reasons why blackouts occur. Indeed, some researchers suggest that the power grid of today and tomorrow exhibits aspects of uncontrollability that demand entire new perspectives on management and expectations on feasible stability [3].

C. Future Electrical Power Generation, Transmission and Distribution

In future electric utilities the following engineering tasks will be more important: the transport of fuel, wastewater treatment, environmental issues, state and federal regulations, rights-of-way of transmission lines, legal issues, security, reliability indices [4], load growth due to increase of population and due to environmental changes (e. g., increased use of air conditioning), decrease of electric loads due to efficiency improvements, active load management with cooperating customers, disposal of spent fuel, business/management operation of a utility, leadership issues, the emergence of competition, sources of power (e.g., coal, oil, nuclear, hydroelectric, wind, solar, and biomass resources) and their availability, control via power line carriers, and retrofitting of older plants with new equipment – just to list a few.

D. Civil and Mechanical Engineering Issues

Civil, environmental and architectural engineering is concerned with major public infrastructure systems including water, wastewater, and transportation utilities. Traditional graduate and undergraduate students get exposed to technologies that are required for design, construction, and operation of infrastructure. In the water resources areas of hydrology, allocation, storage and conveyance, the students deal with clients such as regional and state water planning institutions, the U.S. Army Corps of Engineers, and the U.S. Bureau of Reclamation.

Environmental courses cover water and wastewater treatment facilities, which are operated by municipal and multi-city utilities ranging in size from the Denver Water Department, which operates a large network of reservoirs and pipelines that serve over one million people, to small rural providers with several wells. Emerging technical issues in the arid West include advanced wastewater treatment processes for water reuse and/or aquifer storage, solid waste management and reclamation of damaged watersheds, physical elements that are the basis of transportation systems (bridges and tunnels) as well as dams and foundations, design-built contact management, construction scheduling and risk assessment.

Recently, interdisciplinary efforts have been made with respect to long-term management such as sustainability and decision support. For example, applications of probability analysis to both normal service cycle analysis covering technical approaches such as the demands and extreme events as well as integration of economic costs, burdens on limited natural resources, and environmental impacts into infrastructure design and operation are now commonly accepted practice.

E. Business, Finance, Legal and Ethics Issues

The business climate of the country has changed from one of open competition that led to the big railroad, steel, and oil corporations, to government antitrust actions and regulation during the early 1900's, and it is now moving back towards a more competitive environment. At this time, it is not clear how these shifts in the electrical and other utility industries will unfold. However, if they develop in a manner that is at all similar to that which has occurred in the telecommunications industry [5], there will be a large number of new companies and a major shortage of trained personnel who have the background to deal with the diverse requirements of modifying the structure of industries such as electric power, water and gas.

One objective of this program is to provide students and practicing engineers with the business, finance, legal and ethics background that will be needed for managers in these industries. For example, they will need to know the environmental implications, both technically and socially, of using coal, oil, natural gas, hydroelectric, wind, solar and nuclear energy as sources of electric power. They will need to understand the economics of power generation, transmission and distribution, and the implications of competition on the reliability of the system [2]. The legal history and current changes in the law often dictate what can be done and who the players can be. As pointed out later in Section III, there are convergences in the industry that call for an interdisciplinary education of managers.

II. THE ROLE MODEL OF TELECOMMUNICATIONS

The successful Interdisciplinary Telecommunications Program (ITP) at the University of Colorado was founded about 30 years and has now graduated over 2,000 students as well as serving as a model [5] for other program both in the US and around the world.

ITP combines state-of-the-art technology skills with the business, economic, and regulatory insights necessary to thrive in a world of increasingly ubiquitous communications networks. Instructors are drawn from faculties in economics, electrical engineering, computer science, law, and business, as well as dedicated instructors and an adjunct faculty drawn from key contributors in the telecommunications industry and government. Faculty and student teams are active in current research in wireless, cyber-security, network protocols, telecom economics and strategy, current national policy debates, multimedia, and so forth. ITP has established relationships and access to leaders in the telecommunications industry locally, nationally, and globally. The coursework can be broken down into three broad areas: technology, economics and policy. These courses will be described in section IV.

Course Delivery

For 20 years, the College of Engineering and Applied Science at the University of Colorado has been a leader in offering graduate distance learning courses. The Center for Advanced Engineering and Technology Education (CAETE) offers professionals a way to continue their education at a distance from campus via live transmission, various media, or the Internet. Founded in 1983, CAETE receives over 1,300 enrollments a year from more than 250 sites in Colorado, across the nation, and abroad.

III. NEED FOR AN INTEGRATED PROGRAM

Electric, water, gas and transportation utilities face severe tasks associated with security, quality, availability, reliability, lifetime considerations, and environmental impact and profitability issues. They must solve interrelated system problems with respect to generation, distribution and consumption of electricity, transportation of fuel, and potable as well as wastewater. In the future, engineers and managers of utilities must be well-versed in the different areas of engineering such as electrical, civil, mechanical, and telecommunications.

The availability of the Internet – as a medium of communications – opens new possibilities for sensor location and access, measurement collection, and control applications. As an example, the turbine of a power plant can be remotely digitally controlled using power lines for broadband communications (BPL) [1]. Load shedding, peak power, frequency and reactive power/voltage control are currently important issues that must be addressed. Frequency control will become very difficult for distributed generation systems [6] due to the lack of a large central power plant dictating the frequency to the remaining but smaller power generators.

Economic and business issues related to the selection of fuels for new and retrofitted power plants – from a long-term point of view – have increasing importance: prime examples are combined cycle power plants consisting of a gas turbine and a steam turbine. These types of power plants have relatively high overall efficiencies (60%); however, the long-term (lifetime of 40 years) availability, due to scarcity of fuel, is not certain.

Civil infrastructure and the environment provide multidisciplinary topics: Civil, Environmental and Architectural Engineering is concerned with major public infrastructure systems including water, wastewater, and transportation utilities. Traditional graduate and undergraduate students get exposed to technologies that are required for design, construction, and operation of infrastructure. In addition, water utilities manage assets that include the water resource itself through complex mechanisms such as water rights and watershed reserves. In the water resources areas of hydrology, allocation, storage and conveyance, the students deal with clients such as regional and state water planning institutions, the U.S. Army of Engineers, and the U.S. Bureau of Reclamation.

Environmental courses cover water and wastewater treatment facilities, which are operated by municipal and multi-city utilities ranging in size from the Denver Water Department, which operates a large network of reservoirs and pipelines that serve over one million people, to small rural providers with several wells. Emerging technical issues in the arid West include advanced wastewater treatment processes for water reuse and/or aquifer storage, solid waste management and reclamation of damaged watersheds, physical elements that are the basis of transportation systems (bridges and tunnels) as well as dams and foundations, design-build contract management, construction scheduling and risk assessment. Privatization of activities is a relatively new issue for water and wastewater utilities, which will impact resource and asset management and long-range planning activities. Environmental Engineering faculty evaluate the effect of power plants, automobiles and other utility activities on air quality and contaminant transport in the atmosphere.

Recently interdisciplinary efforts have been developed for the study of long-term management concerns such as sustainability, cost and financing, and decision support. For example, life-cycle analysis curriculum covers application of probability analysis to both normal service demands and extreme events as well as integration of economic costs, burdens on limited natural resources, and environmental impacts into infrastructure design and operation.

Management, legal and regulatory topics become more complicated as they relate to state and federal laws and regulations. This applies to agency and people-related issues, ethics, and environmental policy.

There are convergences in the industry such that power companies may wish to become a part of the telecommunications industry or other utilities such as gas or water, and there is convergence with gas companies to become energy providers. Many of the issues such as what constitutes a natural monopoly, how many lines or pipes do we want in the street, and how do we introduce competition when one company has had a regional monopoly are the same for many of these industries even though the answers may differ. Thus a person with knowledge of more than one utility is likely to find himself/herself in high demand.

We found that the majority of (high-level) managers within the Rocky Mountain Electrical League have engineering degrees. These managers emphasized the need for their engineering workforce to have education in marketing, business strategy, human resources management, and government policy.

IV. INTEGRATED UTILITIES ENGINEERING-MANAGEMENT (IUEM) ME PROGRAM

A.. Goals of IUEM Program

Most managers have a background in a single discipline, but lack the fundamentals in others. Managers in industry need to educate themselves while on the job. This on-the-job training is not optimal by itself, although it is indispensable, even after they have taken courses in different disciplines. The goals of the IUEM program are as follows:

- provide graduate students with the best possible technical, legal and economic/business backgrounds needed to manage utilities in the 21st century;
- offer courses that are industry-related and cannot be sourced elsewhere;
- ensure program is available via distance learning;
- enable cooperation with universities located throughout the world with the expertise to contribute to making this the best possible program;
- facilitate program flexibility as the industry evolves.

B. Courses for IUEM-ME Program

The world has changed for engineers and others who are working in the field of public utilities. In the past, the major problems have been technical, however, today utility problems include technical problems as well as a large number of political economic and regulatory constraints. Thus, the background required for leadership in the utility industries requires not only a thorough knowledge of the technology including such things as power generation and distribution systems but also knowledge of economics and dealing with public utility commissions and public hearings. In order to prepare students for work in this area we propose a program that includes work in all the forgoing areas as follows:

- Core courses: Fundamentals of Electric Power Generation, Transmission and Distribution; Telecommunications Systems; Scientific, Technological, Business and Regulatory History; Economics
- Elective courses covering topics such as: Renewable Energy; Power Electronics and Power Systems; Power Quality and Machines; Nuclear Power; Water and Fuel Resources and Solid Waste Utilities; Utility Finance; Data Communications and Information Systems; Legal Issues as Applied to Utilities; Computer Models, Environmental Policy, Economics, Predicting the Future.
- Capstone Operations Research Utilities Modeling seminar project: Each student in the IUEM program must enroll in this capstone project course to experience working with a Utility System Model (USM) that includes an investigation of technical, economic, social, environmental and resources issues, and must write a term paper report on these issues suggesting how the USM may be improved to more adequately provide quantitative information on issues.

Representative courses, not limited to these topics, are:

- Power Generation Systems: This course will look at the characteristics of various kinds of generation systems. This will include the advanced concepts of mechanical to electrical conversion. It will examine various sources of energy including coal, oil, nuclear, hydro, wind [7], biomass and solar [8]. The design of power plants – with its auxiliaries - will be discussed. Fundamental power flow programs will be introduced. Security, reliability and availability will be associated with the pricing of electricity.
- Analysis of Transmission and Distribution Systems: This course will include the design of transmission lines, the design of systems for reliability, protection, relaying and security. Fundamental load flow calculations will be extensively employed and problems of distributed controls will be addressed. The problems associated with system design and control have become more complex as the industry has evolved into more of a competitive environment, as reliance has increased on distributed generation and with the possibility of terrorist activity aimed at the electric supply and distribution systems
- Power Electronics and Power System**:** Discussions of applications of power electronics to DC transmission, variable-speed drives, active power line conditioners, flexible AC transmission system, and controlled rectifiers begin this course. Power electronic switches and their gating will be introduced. Review of various commutation techniques will follow and will be applied to

controlled rectifiers and inverters, uninterruptible power supplies, and protection devices.

- Power Quality Phenomena in Power Systems and Machines: After a review of the definition of power quality indices, the modeling of harmonic equivalent circuits for transformers, induction and synchronous machines will be discussed [9]. Temperature increases and torques due to harmonics and the associated aging of power system components will be analyzed. Optimization techniques, Newton-Raphson, and harmonic power flow programs serve as tools in mitigation and improving of power quality. Discussion of measurement techniques based on sampled data concludes this course.
- A History of Competition and Regulation: This course will review the history of the development of utility systems as private and publicly managed enterprises. This course will examine water, sewer, telecommunications, and power systems both in the US and other parts of the world. The advantages and disadvantages of competition and deregulation will be highlighted based on the "Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations" [2].
- The Current Legal and Regulatory Environment: This course will review the current state and federal regulatory environment including such topics as restructuring, retail competition, renewable portfolio standards, environmental protection, product liability, intellectual property, and antitrust laws.
- Security and Reliability of Utility Systems: This course will address a range of security-related issues on physical and information security as well as vulnerability assessment and management. We will use a combination of lectures, case studies and mini-projects to examine security with respect to utility systems. The major areas covered include: physical security and access control, asset protection, information systems analysis and protection, vulnerability, assessment, risk management, redundancy, review of existing security and reliability in power systems, new security guidelines, threat response plan, and contingency operation.
- Problems in Risk Analysis and Public Safety: This course will review various kinds of risks ranging from floods, power outages, shock, to biological hazards. It will look at the various approaches to setting safety standards and minimizing risks.
- Telecommunications Systems*:* Examines current, future, and basic technical concepts and related telecommunications operations. Includes an in-depth look at basic telecom terminology and concepts, introductions to voice and data networks, signaling, and modulation/ multiplexing. Topics: frequency band and propagation characteristics, spectral analysis of signals, modulation (AM, FM, PM, and PCM), digital coding, modulation multiplexing, detection, transmission systems and switching systems. Provides an introduction to different network configurations and traffic analysis.
- Data Communications*:* Introduces data and computer communications terminology, standards, network models, routing and switching technologies, and communication and network protocols that apply to WANs, MANs, CWNs, and LANs. Studies therefore focus on asynchronous and synchronous wide-area networks such as frame relay and SONET, the Internet, routers, selected Internet applications, and Ethernets. This class includes selected network laboratory experiments and troubleshooting.
- Applied Network Security: Examines the critical aspects of network security. A technical discussion of threats, vulnerabilities, detection and prevention is presented. Issues addressed are cryptography, firewalls, network protocols, intrusion detection, security architecture, security policy, forensic investigation, privacy and the law. Students can expect to gain a working knowledge of the critical areas of security that large networks face today. The objective is for students to gain a working understanding of network security, with a focus on real world issues.
- Environmental Policy: Environmental impact of electric power generation, transmission, distribution and consumption, such as air, water, thermal ionizing radiation and nuclear waste products and electromagnetic fields. Thereafter biological and health implications will be addressed, e.g., biological interactions, disease possibilities, effects on climate and biosphere. The latter half of the course will cover strategies for minimizing impacts, and the public perception of hazards and regulatory agency responses.
- Utility Finance: Electric utility customers – retail, commercial, industrial, and agricultural – have historically, and continue today, to pay rates for electricity that are determined by cost-of–service studies. The rate-of-return studies that underlie these electricity rates rely on assumptions for ratios of capital in the form of preferred stock, common stock, and debt and their associated yield. Dividend determination has been critical over the years. These and related topics of issuing stocks and bonds, refinancing bonds, debenture conditions, options, derivatives, futures, and hedging will all be presented in this course.
- Civil, Environmental and Architectural Infrastructure Systems**:** This course starts out with traditional topics related to infrastructure systems such as water, wastewater, and transportation utilities. The water resource area includes hydrology, allocation, storage, and conveyance. Also discussed: special topics related to long term (life-cycle analysis) management issues such as sustainability and decision support. Treatment of bio-solids by private and public companies raises legal and regulatory issues.

In addition to these courses there will be additional courses from the traditional program in electrical and civil engineering and computer science in subjects like computer-aided design, numerical methods, control systems and either an independent study or a masters thesis.

C. Distance Learning

The teaching mode will be simultaneous classroom and distance learning. Students can register to take courses either for credit or noncredit and apply the courses toward a master's degree or enroll for professional development [10-12]. Classes are graduate courses taught on the Boulder campus. CAETE provides courses via several modalities: live microwave TV broadcasts to companies, video tape, and via video streaming or downloading from the Internet. Graduate courses are delivered directly to business and industry along Colorado's front range via live microwave TV broadcast and over the Internet.. Two-way audio interaction brings the classroom discussion to the workplace so that students can participate live.

Lectures are available within 24 hours on the internet or, in the case of physical media, are sent approximately twice weekly depending on when the class meets (on campus). Many courses are supplemented with on-line learning portals including lectures, readings, links to other resources, quizzes, tests, threaded discussions, chat capability, etc. More than 100 courses taught in previous semesters are available for academic credit and for rent or purchase through the CAETE Media Library. Several telecommunications and electrical and computer engineering courses are now delivered via video streaming or downloading from the Internet.

Distance learning students take exams proctored by an education officer (EO). Students and EOs submit assignments and exams directly to the instructor for grading. Instructors are available to students by phone, fax, or e-mail. Whether students are watching classes live, on various media, or via the Internet, CAETE brings education directly to them. Students can complete a master's degree or professional certification without having to drive to campus or fit classes into busy schedules.

V. CONCLUSIONS

The objective is to establish a program that can educate professionals and students at the Master's level that transcends one single area of expertise. In particular, this program will educate individuals with a diverse set of backgrounds including engineering, law, and business, with the objective of providing them with the knowledge of the fundamentals that will be required to lead the utility industry as it continues through changing environments. The basic strategy is to provide information that enables students with either an engineering or a non-engineering education to fill holes in areas where they have not had previous training and to deepen their knowledge in areas of strength in such a way that they can help utilities adapt to a competitive and deregulated environment.

REFERENCES

[1] K. Stahlkopf, "Dream Jobs 2004, Engineer in Paradise," *IEEE Spectrum*, February 2004, p. 32.

[2] U.S. - Canada Power System Outage Task Force, "Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations", April 2004, 228 pages.

[3] P. Fairley, "The Unruly Power Grid," *IEEE Spectrum*, v. 41, i. 8, Aug. 2004, pp. 22-27.

[4] R. Billinton and R.N. Allan, *Reliability Evaluation of Power Systems*, Pitman Books, New York and London, 1984.

[5] F.S. Barnes, Julian Holtzman, "An M.S. Curriculum in Telecommunications," *IEEE Transactions on Education*, 31, (3), 213-214, August 1988.

[6] M. Hassan and J. Klein, "Distributed Photovoltaic Systems: Utility Interface Issues and Their Present Status," *Report DOE/ET-20356-3*, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, September 15, 1981.

[7] D. Yildirim, E.F. Fuchs, and T. Batan, "Test Results of a 20 kW, Direct Drive, Variable-Speed Windpower Plant," *Proceedings of the International Conference on Electrical Machines*, Istanbul, Turkey, September 2- 4, 1998, pp. 2039 –2044.

[8] M.A.S. Masoum, H.Dehbonei, and E.F. Fuchs, "Theoretical and Experimental Analyses of Photovoltaic Systems with Voltage- and Current Based Maximum Power Point Tracking," *IEEE Trans. on Energy Conversion*, Vol. 17, No. 4, December 2002, pp. 514-522.

[9] E.F. Fuchs, D.J. Roesler, and M.A.S. Masoum, "Are Harmonic Recommendations According to IEEE and IEC Too Restrictive?," *IEEE Trans. on Power Delivery*," Vol. 19, No. 4, October 2004, pp. 1775 – 1786.

[10] F. Barnes, "A New Frontier in Engineering Education: Importing Courses," *Frontiers in Education 2003*, Boulder, CO, Nov. 5-8, 2003, pp. T4F_3 - T4F_4.

[11] T. Lookabaugh and D. Sicker, "Technology Mediated Education – Revolution not Evolution," *Frontiers in Education 2004*, Savannah, GA, Oct. 20-23, 2004.

[12] W. Dick, L. Carey, and J.O. Carey, *The Systematic Design of Instruction*, 5th ed., amazon.com.