Electrical & Computer ENGINEERING

5th Carnegie Mellon Conference on the Electricity Industry: SMART GRIDS

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Electrical and Computer Engineering

Carnegie Mellon

Modern Electric Energy Systems

- *Why Carnegie Mellon?*
- *What are we doing?*

Carnegie Mellon University

- ***A collaborative interdisciplinary entrepreneurial environment***
- ***A broad integration of disciplines ranging from engineering and science to the arts and design***
- ***A tradition of problem solving – real solutions for real problems***
- ***A strategic view of our role as an educational and research organization***

Carnegie Mellon University (CMU)

- ***CMU is divided into colleges***
  - *Carnegie Institute of Technology*
  - *College of Fine Arts*
  - *College of Humanities and Social Sciences*
  - *David A Tepper School of Business*
  - *H. John Heinz III College*
  - *Mellon College of Science*
  - *School of Computer Science*
- ***About 10,000 students on Pittsburgh campus***
- ***About $300 million/year of research (not incl. SEI)***

Broad expertise required for Energy Systems:

- ***CIT (College of Engineering)***
  - *Chemical Engineering*
  - *Civil and Environmental Engineering*
  - *Electrical and Computer Engineering*
  - *Engineering and Public Policy*
  - *Materials Science Engineering*
  - *Mechanical Engineering*
- ***SCS (School of Computer Science)***
  - *Computer Science Department*
  - *Robotics Institute*
  - *Institute for Software Research*
- ***CFA (College of Fine Arts)***
  - *School of Architecture*
- ***David A. Tepper School of Business***

In addition there are a number of research labs and centers whose focus cuts across departments and colleges

ECE Dept Overview – Numbers

- *ECE includes nearly 1000 individuals*
- ***114 Faculty Members (9 NAE)***
  - *55 tenure-track/emeritus (34 IEEE Fellows)*
  - *7 research/teaching*
  - *39 courtesy*
  - *13 adjunct/special*
- ***80 Staff members (technical and non-technical)***
- ***446 undergraduate students (not incl. Freshmen)***
- ***350 graduate students (M.S. and Ph. D.)***
- ***About $30+ M/year research expenditures***

ECE Focus Areas

- *Computer Systems*
- *Computer and Network Security*
- *Wireless and Broadband Networking*
- *Embedded Systems*
- *Sensor Networks*
- *Modern Energy Systems*
- *Signal, Image, & Video Processing*
- *Information Storage Systems*
- *Integrated Circuit Design, Manufacturing & Testing*
- *Microelectromechanical Systems*
- *Nano-enabled Technologies*

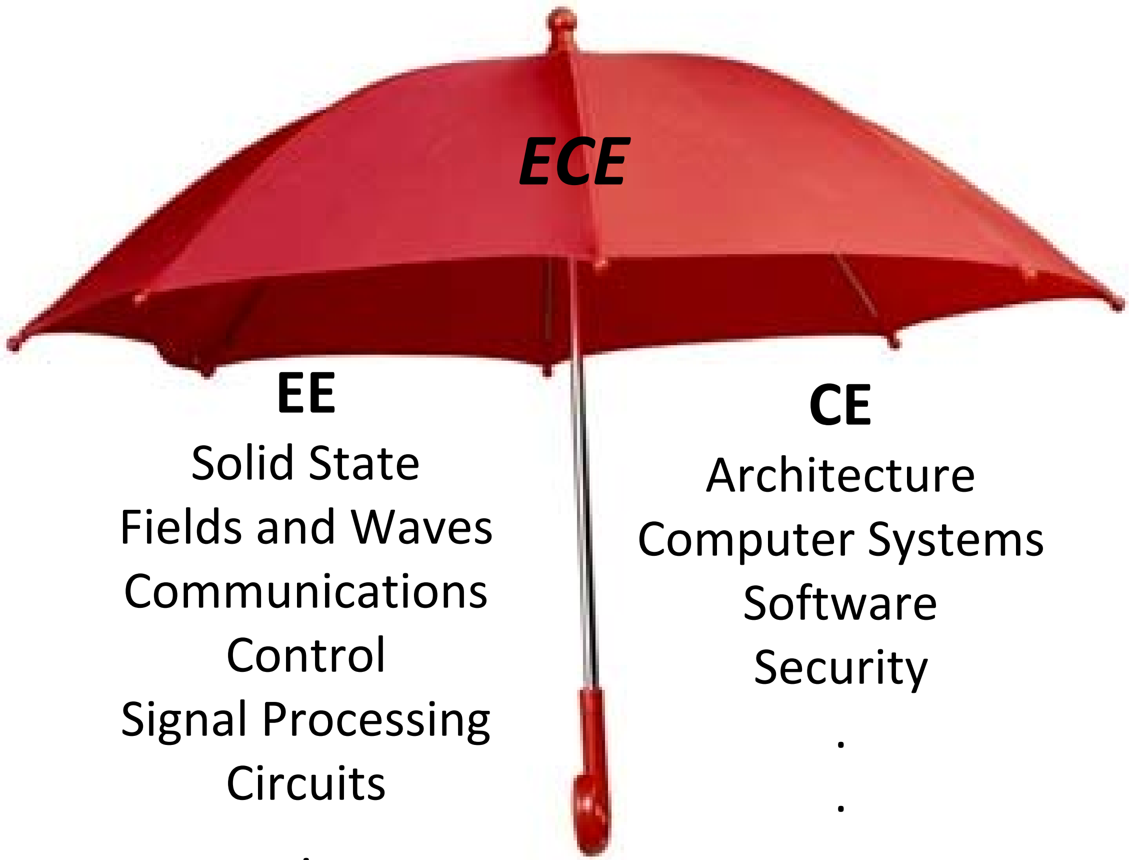
ECE Spin Off Companies

- *Ansoft (1984) Cendes*
- *Ultrasystems (1986) Siewiorek*
- *Dasys (1991) Thomas*
- *PDF Solutions (1991) Maly Strojwas*
- *Quantapoint Inc (1992) Khosla, Kanade*
- *Omniview (1992) Siewiorek*
- *Inmedius (1995) Siewiorek*
- *Scalable Networks (1996) Bianchini, Kim*
- *TimeSys (1996) Rajkumar*
- *Neolinear (1997) Rutenbar, Carley*
- *Xactix (1998) Gabriel*
- *Applied Electro Optics (1998) Schlesinger, Stancil*
- *Panasas (1999) Gibson*
- *Spinnaker Networks (1999) Bianchini*
- *Accelight Networks (1999) Kim*
- *Proxicast (2000) Peha*
- *Akustica (2001) Gabriel*
- *IC Mechanics (2001) Carley*
- *Verimetra (2001) Gabriel*
- *Cyphermint (2002) Peha*
- *Helium Networks (2002) Hills*
- *New Electricity Transmission Software Solutions (2002) Ilic*
- *Extreme DA (2003) Pileggi*
- *Fabbrix Inc (2004) Pileggi*
- *Xigmix Inc. (2005) Pileggi*
- *Testworks (2007) Blanton*
- *Silicon Vox (2007) Rutenbar*
- *…*

Electrical and Computer Engineering (ECE)

- ***Despite the large number of "electrical and computer engineering" and similarly named departments at US universities, there are currently only 16 universities offering accredited BS degrees in Electrical and Computer Engineering.***
- ***Most universities continue to have separate BS degree programs in Electrical Engineering (268) and Computer Engineering or Computer Systems Engineering (165)***
- ***Our university introduced the BS in ECE as a single degree over 15 years ago.***

The "Traditional" View



EE

Solid State
Fields and Waves
Communications
Control
Signal Processing
Circuits
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CE

Architecture
Computer Systems
Software
Security
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A Modern View

Sensor Networks
Embedded Systems
Energy Systems
IC Manufacturing
Energy Systems
Wireless Communications

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There is no clear demarcation between EE and CE

Electrical & Computer ENGINEERING

ECE as a Unified Discipline

- ***The evolution of the field of electrical and computer engineering demands a new breed of ECE graduates with a broad set of competencies that cannot be classified into "EE" and "CE".***
- ***The core requirements should assure students have a foundation in a set of essential concepts and skills for an ECE career.***
- ***The breadth, coverage, depth and capstone design requirements should assure students have a sufficiently rich ECE education.***
- ***The number of free electives should be sufficient to encourage students to:***
  - *specialize deeply in a particular area of ECE; OR*
  - *become broadly educated in a number of areas of ECE; OR*
  - *complement their ECE experience with education in another field (e.g., biomedical engineering, public policy, computer science, business, life sciences, humanities, music, etc.).*

Core ECE Courses

- ***18-100: Introduction to Electrical and Computer Engineering***
  - *Provides an overview of the field of ECE and introduces some of the fundamental tools needed to solve problems in this field.*
- ***18-220: Devices and Circuits***
  - *Provides an introduction to semiconductor devices and circuit analysis with links to digital electronics and signal processing.*
- ***18-240: Structure and Design of Digital Systems***
  - *Provides a foundation and working knowledge in the application, operation and implementation of digital systems.*
- ***18-290: Signal & Information Processing***
  - *Provides mathematical and computational tools for processing signals and information.*
- ***18-243: Introduction to Computer Systems***
  - *Provides concepts underlying how programs are executed on computer systems*

Courses Specific to Energy Systems

- ## *18-418: Electric Energy Processing: Fundamentals and Applications*

This course provides an introduction to the fundamentals of electric energy conversion, and its use in several real-life electric energy systems. The course starts with a brief review of electromagnetic and electromechanical conversion underlying electric power generation. The first part of the course introduces basic components found in today's electric energy systems, such as; Electric machines (generators and motors); Power electronics for converting between AC and DC portion of an electric energy system, and; Control of these components for their efficient use.

The principles underlying design, operations and control of these components are introduced using conversion fundamentals and basic electric circuit knowledge. The second part of this course introduces several key electric energy systems used in today's industry. Examples of such systems are; Home distribution electric power systems; Electric power systems for vehicles; Electric power systems for ships, and; Airspace electric power systems (such as airplanes and space shuttles).

- ## *18-618: Smart Grids and Future Electric Energy Systems*

The course offers an advanced presentation of modern electric power systems, starting from a brief review of their structure and their physical components, through modeling, analysis, computation, sensing and control concepts. Great care is taken to avoid presenting "practical" techniques built on dubious theoretical foundations and also to avoid building elaborate "mathematical" models whose physical validity and relevance may be questionable. Mastering both principles and relevant models is important for those who wish to seriously understand how today's electric power grids work and their challenging technical issues. This prepares students for working on applying many novel information processing concepts for designing and operating more reliable, secure, and efficient electric energy systems. Students interested in both applied physics and signals and systems should consider taking this subject. Once the fundamentals of today's power systems are understood, it becomes possible to consider the role of smart electric power grids in enabling evolution of future electric energy systems. Integration of intermittent energy resources into the existing grid by deploying distributed sensors and actuators at the key locations throughout the system (network, energy sources, consumers) and changes in today's Supervisory Control and Data Acquisition (SCADA) for better performance become well-posed problems of modeling, sensing and controlling complex dynamic systems. This opens opportunities to many innovations toward advanced sensing and actuation for enabling better physical performance. Modeling, sensing and control fundamentals for possible next generation SCADA in support of highly distributed operations and design are presented.

Courses Specific to this Area

■ 18-777: Complex Large-scale Dynamic Systems

This course is motivated by the ever-growing complexity of man-made dynamic systems and the need for flexible monitoring, operations and design techniques for such systems. Of particular interest are systematic model-based methods for relating the key real-life problems for such systems and the state-of-the-art techniques for large-scale dynamic systems. Examples of such real-life complex systems are critical man-made infrastructure systems (electric power systems, gas networks, transport industries, data networks, and their interdependencies) as well as large-scale systems on chips.

In this course we will first review the traditional large-scale methods for model simplification (aggregation), time scale separation of sub-processes and singular perturbation techniques to account for these, stability analysis, and estimation and control. In the second, novel part of this course, we recognize the highly interactive nature of the evolving complex systems, in which much monitoring, data gathering, and decision making is made at the lower, physical levels of the system, and some coordination exists at the higher system level at which physical layers interact. Several conceptual challenges are posed for minimal coordination of such decision makers under high uncertainties, in order to have predictable performance. These concepts will be illustrated using the same man-made network systems of interest introduced at the beginning of the course.

■ 18-875: Engineering and Economics for the Changing Electricity Industry

The course has two parts. The first part introduces basic components and networks used in the electric power industry. This is followed by systematic modeling of these components, as well as of the entire system. Methods for modeling and analyzing both system equilibria and dynamics are presented. Simulations and lab demos are given to simulate and analyze typical system blackouts. This is followed by introducing decision and control methods for preventing these problems, as well as for managing the system more reliably, securely and efficiently over broad ranges of its operating conditions. The emphasis is on IT, software and control (both distributed and coordination) for achieving pre-specified system performance. This part of the course will involve simulation demos and hands on studies in which students create their own power network, simulate it and assess for performance. The second part of the course will review the industry structure, the experience with deregulation, and economic issues concerning choice of generating fuel and technology, the costs of blackouts, and environmental discharges. The course will integrate engineering and economic aspects to examine the design, investment, and operations that satisfy public desires for low cost, nonpolluting, reliable, and secure power. Knowledge of basic electric circuits and/or basic economics is assumed.

Courses

■ *18-879: Control Techniques in Power Systems*

The course covers different control techniques applied in power systems including Optimal Power Flow control discussing different control objectives. As it is often not possible to formulate and solve an optimization problem for the entire system, the problem has to be decomposed into sub-problems each associated with a certain area/country of the system which then have to be solved in a coordinated way. There are various possibilities to do this such as Lagrangian Relaxation Decomposition, Optimality Condition Decomposition, etc. Consequently, the course gives an insight into optimization and decomposition theory. An application of these control techniques is the calculation of the optimal settings of control devices in the system, such as FACTS devices. Therefore, an introduction into FACTS devices is given and how they can be used to improve the state of the power system. In addition, general control concepts used in power systems such as frequency or voltage control, etc. are discussed. But also possible future concepts such as Model Predictive Control will be part of the course.

Research Labs and Centers

Electrical & Computer ENGINEERING

► Center for Nano-enabled Device and Energy Technologies (CNXT)

CNXT
Center for Nano-enabled Device and Energy Technologies

Research in Energy Systems

- ***Research programs uniquely built on the university's strength in information processing, engineering, science, business and in technically focused policy research.***

- *The Electric Energy Systems Group (EESG) curriculum, research programs, a software laboratory, and an outreach program for modern electric energy systems to advance future electric energy systems as physical systems enabled by sensing, computing, communications, and control technologies.*
- *The Carnegie Mellon Electricity Industry Center (CEIC) research areas are; Markets and Investment, Distributed Energy Resources, Advanced Generation, Transmission, and Environmental Issues, Reliability and Security, Demand Estimation*
- *DYMONDS Fellowships – Dynamic Monitoring and Decision Systems for Future Electric Energy Systems*
- *Three university consortium (CWP) addresses issues in fossil fuel energy research by focusing work on; Materials for energy technologies; Process and dynamic systems modeling; Catalyst and reactor development; Carbon management; Sensor systems and diagnostics; Energy conversion devices; Gas hydrates; and Ultradeep and unconventional oil and gas production technology.*

- ***We are focused on advancing the underlying science and engineering associated with "bringing IT" to electric energy systems***
- ***We are focused on understanding the problems, challenges and opportunities facing the electric power industry today***
  - *Ready to help industrial partners bring expertise, ideas, and talent to addressing industry problems*

Researchers

Jay Apt, Tepper School of Business and EPP,
Wandi Bruine de Bruin, SDS Faculty,
Baruch Fischoff, Departments of EPP and SDS,
Franz Franchetti, Department of ECE
James Hoburg, Department of ECE,
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Jose' Moura, ECE Department and ICTI Director,
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Bruno Sinopoli, ECE Department,
Sarosh Talukdar, ECE Deparment, (Emeritus)
Ozan Tonguz, ECE Department,
Rahul Tongia, SCS and EPP, Carnegie Mellon

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Conclusion

- ***Uniquely positioned to educate students and conduct research in modern energy systems.***
- ***ECE and CMU are committed to maintaining a modern electric energy systems program of research and education***
- ***Our objective is to prepare engineers for leadership in energy systems technology and having impact in academia, industry and government.***