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TWENTY-EIGHTH ANNUAL REPORT
OF THE
POWER AFFILIATES PROGRAM

University of Illinois at Urbana-Champaign
Department of Electrical and Computer Engineering
1406 W. Green St.
Urbana, IL 61801

PAP-TR 07-1

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FOREWORD

This report provides a summary of the activities of the Power Affiliates Program (PAP) in the Department of Electrical and Computer engineering at the University of Illinois at Urbana-Champaign for the calendar year 2006. The information is intended to be a progress report to the affiliate companies listed below. The PAP is the foundation of the industrial liaison effort in the power and energy systems area. The active affiliates associated with the PAP are:

Advanced Analogic Technologies, Inc.
Ameren
BP America
Citadel Investment Group
City Water, Light & Power, Springfield, IL
Electrical Manufacturing & Coil Winding Association, Inc.
Exelon
MidAmerican Energy Company
Patrick Engineering
PowerWorld Corporation
S&C Electric Company
Sargent & Lundy Engineers

2006 was an active year for the PAP and the highlights are covered in this report. We acknowledge the valuable interaction of the Affiliates and are most thankful to these companies for their continued support.

Pete Sauer, Director
Patrick Chapman
George Gross
Jonathan Kimball
Phil Krein
Tom Overbye
M. A. Pai

1. INTRODUCTION AND SUMMARY

The Power Affiliates Program (PAP) was initiated in January 1979 as part of a major effort to strengthen the power and energy systems area. The original objectives were to:

- Maintain stimulating, meaningful and high quality undergraduate and graduate programs in electric power engineering.
- Increase university-industrial interaction at all levels of education and research in electric power engineering.

These objectives are as much valid today as they were in 1979. The multi-faceted activities in 2006 under the PAP umbrella clearly were in support of these objectives.

Throughout the past twenty-eight years, the Power Affiliates Program has maintained a stable financial base during times of rapid change in the power industry. This base provided the seed money for research, which led to additional funding by other sources. This base has also made it possible for students to be exposed to industrial problems and to participate in technical and professional meetings. With the cyclical nature of funding by government agencies, the Power Affiliates Program is a critically important source of support.

This annual report is organized as follows. The financial statement for the 2006 calendar year is given in Section 2. Section 3 describes how the power program fits into the departmental structure. There is no official degree or option associated with the Power Program, but there is a significant level of specialization which is possible in this area through a set of courses developed and offered by the group of faculty who constitute the Power and Energy Systems Area. Section 4 gives a brief description of the courses for specializing in electric power and tabulates the enrollment figures for the most recent offerings. Included in this section is a historical record of the number of graduates who have taken three or more of these courses. Section 5 lists the activities of both the students and the faculty members during the 2006 calendar year. Section 6 gives information about the graduate students in the power area. In addition to personal data and interests, each student has written a brief abstract of his or her research work. Laboratories and other facilities of the power area are discussed in Section 7. The report concludes with a directory in Section 8 and the list of 2006 publications is given in Section 9.

2. FINANCIAL STATEMENT

The following tabulation of income and expenditures for the calendar year 2006 was prepared from a detailed University statement as of December 31, 2006.

Income carried over from the calendar year 2005	$25,586
Total income during calendar year 2006 *	69,275
Total available income during calendar year 2006	$94,861

Expenditure	**Expenditure Amount**
Personnel and Services	$64,917
Materials/Supplies/Equipment	12,857
Transportation/Travel	11,694
Total expenditures	$89,468

Summary

Amount of funds available during calendar year 2006	$94,861
Amount of expenses during calendar year 2006	89,468
Balance as of December 31, 2006	$5,393

* This does not include funds that were received in 2006, but not posted on the university accounting system until 2007.

3. THE POWER PROGRAM WITHIN THE DEPARTMENT

Electrical engineering undergraduate students are required to complete 128 hours of course work for a B.S.E.E. degree. Detailed descriptions of the undergraduate program and suggested curriculum in Power are given in [1]. All M.S.E.E. students are required to complete a minimum of 32 credit-hours (old system was 8 units) including a graduate thesis. All Ph.D. students must qualify through a written examination and complete course and thesis requirements. A detailed description of the graduate program is given in [2].

The Electrical and Computer Engineering Department is subdivided into seven distinct technical areas as follows:

Bioengineering, Acoustics and Magnetic Res. Engineering
Circuits and Signal Processing
Communications and Control
Computer Engineering
Electromagnetics, Optics and Remote Sensing
Microelectronics and Quantum Electronics
Power and Energy Systems

While the Department does not have official degree-granting options in each of these areas, in practice, the seven areas serve as the appropriate grouping of the faculty activities and interest. In terms of size, the Power and Energy Systems area represents about 7% of the total active faculty and about 10% of the total student enrollment. The faculty committee in each area has the responsibility for administering courses and research in that area within the Department.

The Power and Energy Systems Area Committee and associated faculty for the 2006 - 2007 academic year together with their fields of interest are:

P. Chapman	(machines, power electronics, circuits)
G. Gross	(power system economics, planning and operations; reliability; electric regulatory policy; industry restructuring; market design)
P. T. Krein	(power electronics, machines, electrostatics)
T. J. Overbye	(operations, visualization and restructuring of power systems)
M. A. Pai	(dynamics, stability and computational methods in power systems
P. W. Sauer	(modeling and simulation of machines and power systems)

Two of the primary responsibilities of the Power and Energy Systems Area Committee are to improve, keep current and staff the courses assigned to the Power and Energy Systems Area. In 2006-2007 those courses were

ECE 307	(old ECE 271GG)	Techniques for Engineering Decisions
ECE 398RES	(new)	Renewable Energy Systems
ECE 430	(old ECE 330)	Power Circuits and Electromechanics
ECE 431	(old ECE 333)	Electric Machinery
ECE 432	(old ECE 336)	Advanced Electric Machinery
ECE 464	(old ECE 364)	Power Electronics
ECE 469	(old ECE 369)	Power Electronics Laboratory
ECE 476	(old ECE 376)	Power System Analysis
ECE 477	(old ECE 378)	Power System Operation & Control
ENG 491FEC	(old ECE 371FEC)	Future Energy Challenge
ECE 530	(old ECE 598GG)	Analysis Techniques for Large-Scale Electrical Systems
ECE 568	(old ECE 468)	Modeling and Control of Electromechanical Systems
ECE 573	(old ECE 473)	Power Systems Control
ECE 576	(old ECE 476)	Power System Dynamics and Stability
ECE 588	(old ECE 488)	Electricity Resource Planning
ECE 590I	(old ECE 490I)	Seminar in Special Topics: Power Systems
ECE 598PE	(old ECE 497PE)	Power Electronic Drives and Systems
ECE 598PH	(old ECE 497PH)	Hybrid Systems Analysis of Power System Dynamics
ECE 598TO	(old ECE 497TO)	Issues in Competitive Electricity Markets
ECE 598PLC	(new)	Advanced Topics in Power Electronics

The four-hundred level (old three-hundred level) courses are advanced undergraduate or beginning graduate courses, while the five hundred level (old four-hundred level) courses are graduate. The Power and Energy Systems Area Committee periodically evaluates each course outline for possible revision for future offerings. A brief description of each of these courses, together with the enrollment of the past year, is included in the next section. In addition, the Power Faculty supervises numerous student projects performed in ECE 445 (old ECE 345). This is the capstone design course for our seniors.

4. COURSES AND ENROLLMENT

As one of seven major areas in Electrical and Computer Engineering, the Power and Energy Systems Area is responsible for the development and offering of a considerable number of courses. The current courses assigned to the power area are described briefly below. The total enrollment for courses offered in the academic year 2006-2007 is also given for each course.

ECE 307 Techniques for Engineering Decisions

This course is concerned with modeling of decisions and analysis of models to develop a systematic approach to making decisions. The focus is on the development of techniques for solving typical problems faced in making engineering decisions in industry and government. Topics include resource allocation, logistics, scheduling, sequential decision-making and explicit consideration of uncertainty in decisions. Extensive use of case studies gets students involved in real world decisions. The course has two required texts: Operations Research: Principles and Practice, A. Ravindran, D. T. Phillips and S. S. Solberg and Making Hard Decisions: An Introduction to Decision Analysis, R. T. Clemen. The total enrollment for the academic year 2006-2007 was 12.

ECE 398RES Renewable Energy Systems

A new course on the challenges of meeting the future energy needs using renewable resources taught by Prof. P. Chapman and Prof. G. Gross. A three-hour technical elective for engineering undergraduate students with a background in electric circuits at an introductory level. The course explores the technical, economic, environmental and policy aspects of renewable and alternative energy systems to provide a comprehensive picture of their role in meeting society's electricity needs. The upsurge in the world-wide demand for oil-based resources, the restructuring of the electricity industry, the advances in engineering technology and the increasing interest in environmental protection are presenting unparalleled challenges to the electric power industry. The role of new energy resource technologies, the application of power electronics, the use of demand-side management, and the effects of market forces in addressing these challenges are discussed. The course covers the basics of energy production from renewable sources, the relevant thermodynamics background, the structure and nature of the interconnected electric power system and the critical need for environmentally sensitive solutions. In addition, the economic and regulatory policy aspects of electricity and electricity markets are treated. The total enrollment for the academic year 2006-2007 was 26.

ECE 430 Power Circuits and Electromechanics

ECE 430 is a course in power circuits and electromechanics. It is a new course after the restructuring of the undergraduate curriculum. The course starts with a review of phasors followed by three phase power circuits, mutual inductance, magnetic circuits and transformers. Electromechanical systems are analyzed using energy balance concepts. Introduction to synchronous, induction, dc and small machines is given. The required text was Power Circuits and Electromechanics by M.A. Pai. The total enrollment for the academic year 2006-2007 was 171.

ECE 431 Electric Machinery

This four-hour course contains a laboratory one credit hour component, which is an elective in a list of 14 from which students select two. The fifteen experiments typically include power measurement, power factor correction, transformer characteristics, three-phase transformer connections, induction motor tests, induction motor torque-speed characteristics, synchronous machine tests, synchronous machine power characteristics, digital simulation of machine dynamics, motor control, and a written plus oral project presentation on power and energy system topics. The required text was Electric Machinery, by Fitzgerald, Kingsley, and Umans. The total enrollment for the academic year 2006-2007 was 37.

ECE 432 Advanced Electric Machinery

This three-hour course contains advanced theory and analysis of rotating and linear machines and drives. It includes power electronic drives for dc and ac motors. The analysis uses d-q transformations and related techniques. Emphasis is placed on the time scale modeling of electromechanical devices and on their function in drives. The required text was Analysis of Electric Machinery, by P.C. Krause and O. Wasynczuk, IEEE Press. This class was not offered in the 2006-2007 academic year.

ECE 464 Power Electronics

This three-hour course is a comprehensive treatment of switching power conversion systems and the devices used to build them. Concepts of switch control are developed from general switching functions. Phase control, pulse width modulation, and phase modulation are studied for applications in all types of converters. Converter topologies are introduced along with design concepts for power filters and interfaces. Devices such as diodes, thyristors, bipolar transistors, field effect transistors, capacitors, and magnetic components are examined in the context of high-power switching applications. The required text was Elements of Power Electronics by P. T. Krein. The total enrollment for the academic year 2006-2007 was 30.

ECE 469 Power Electronics Laboratory

This two-hour course is a laboratory study of circuits and devices used for switching power converters, solid-state motor drives, and power controllers, including dc-dc, ac-dc, and dc-ac converters and applications. It includes high-power measurements for silicon-controlled rectifiers, diodes, capacitors, power transistors and magnetic components. The course is designed to accompany ECE 364. A lab manual by P. Krein is used for the course. The total enrollment for the academic year 2006-2007 was 13.

ECE 476 Power System Analysis

This three-hour course is the first of two courses on power system analysis. Topics included are transmission line parameter calculations, equivalent circuits, network analysis, load flow, fault analysis, symmetrical components, unsymmetrical fault analysis, and introduction to economic dispatch. The course is designed to be a stand-alone introduction to the fundamentals of power system analysis and provide the basis for all subsequent courses in the power system analysis. The required text was Power System Analysis & Design, by Glover and Sarma. The total enrollment for the academic year 2006-2007 was 31 on-campus, 1 off-campus).

ECE 477 Power System Operation & Control

This three-hour course is the second of two courses on power system analysis. Topics included are economic operation of power systems, optimal load flow concepts, automatic generation control, state estimation, classical transient stability, modeling for dynamic and transient stability, and d-c transmission. The recommended text is Power Generation, Operation and Control, 2nd edition, by Wood and Wollenberg. This class was not offered in the 2006-2007 academic year.

ENG 491FEC Future Energy Challenge

This three-hour course is a special topics course focusing on the Future Energy Challenge (FEC) student team competition. This competition is an international event sponsored by IEEE, the U.S. Department of Energy, the U.S. Department of Defense, and other sponsors. Schools compete in two topic areas: a fuel-cell power processing topic and a motor system topic. Illinois is one of just 7 schools selected, based on our proposal, to be part of the motor topic competition. The final events are in May after graduation. This class was not offered in the 2006-2007 academic year.

Graduate Courses:

ECE 530 Analysis Techniques for Large-Scale Electrical Systems

This is a newly developed graduate course in the modeling of power systems in the steady state and dynamic regimes. It includes the analysis and simulation techniques for power and power electronic systems as well as computational issues in power systems and power electronics. Topics covered are: advanced power flow, sparsity techniques, power flow control, least squares and estimation applications averaging techniques for power electronic systems, numerical integration of differential equations and Krylov subspace applications. The course uses the notes of George Gross in lieu of a text. The total enrollment for the academic year 2006-2007 was 10.

ECE 568 Advanced Modeling and Control of Electromechanical Systems

This course addresses issues of electrical drives in a modern control and circuit framework. Dynamic models of electric machines are presented. There is special emphasis on field-oriented control methods for ac motors. Power electronic systems for high-performance drives are studied. Nonlinear system methods such as periodic transformations, averaging, geometric control, and feedback linearization are presented. Special topics covered include electrostatic micromachines and permanent magnet machines. The required texts were Control of Electrical Drives, 2nd edition by W. Leonard and Analysis of Electric Machines, 2nd edition by P. Krause, O. Wasynczuk and S. Sudhoff. This class was not offered in the 2006-2007 academic year.

ECE 573 Power Systems Control

The course provides an overview of power system operations and control with major emphasis on security and economics. The role of the EMS (energy management system) and the principal EMS functions are discussed in depth. The major topics include: optimal power flows; economic dispatch problems; role of reactive power; resource scheduling and commitment; state estimation; observability; bad data identification/detection, analysis and processing; electricity restructuring; competitive electricity markets; market design; congestion management; and, ancillary services. The two suggested texts are Power Generation, Operation and Control, 2nd edition by Wood and Wollenberg, and State Estimation in Electric Power Systems: A Generalized Approach by A. Monticelli, Kluwer Academic Publishers, Boston, 1999. This class was not offered in the 2006-2007 academic year.

ECE 576 Power Systems Dynamics and Stability

The course includes the dynamic representation of interconnected power systems - electrical plus mechanical, linearized dynamic models of multimachine systems, methods of coherency identification, order reduction by singular perturbation, time scale decomposition and aggregation techniques, dynamic equivalents, direct methods of stability analysis and power system stabilizer design. The required text was Power Systems Dynamics and Stability by P. W. Sauer and M. A. Pai. The total enrollment for the academic year 2006-2007 was 10.

ECE 588 Electricity Resource Planning

This course provides coverage of the basic techniques in electricity resource planning including methodologies for reliability evaluation and assessment, production costing, marginal costing, supply-side and demand-side planning and integrated resource planning. Throughout the course, probabilistic approaches are emphasized. In place of a text, notes specifically prepared by George Gross are used. The total enrollment for the academic year 2006-2007 was 6.

ECE 590I Seminar in Special Topics: Power Systems

This course is a graduate seminar on advanced topics of current interest. Both faculty and students participate by presenting either current research results or topics of interest in journal publications. Guest speakers from industry and other universities are also scheduled periodically throughout the semester. Approximately 33 students participated in this course for both semesters.

ECE 598PE Power Electronic Devices and Systems

This advanced course in power electronics considers the unique devices and models used for switching energy conversion systems. Emerging nonlinear approaches to operation and control are discussed. Design issues for fast dynamic converters are presented. The goal of the course is to provide students with a rich background in the broad issues of high-performance power electronics at the graduate level. Specific topics include magnetic device design, power semiconductor device models, interfaces and gate drives, small-signal and large-signal converter control models. Averaging methods are presented for power converters. Concepts and methods of geometric control are addressed. The required text is Elements of Power Electronics by P.T. Krein. This class was not offered in the 2006-2007 academic year.

ECE 598PH Hybrid Systems Analysis of Power System Dynamics

The purpose of the course is to present a new approach to the analysis of large scale complex networks, such as power systems, by viewing them as interconnections of dynamic devices, discrete devices and algebraic constraints. Such hybrid systems can display very interesting forms of behavior. Trajectory sensitivity analysis used as a tool for security monitoring, stability analysis and model verification. Aspects of hybrid system control are presented. This class was not offered in the 2006-2007 academic year.

ECE 598TO Issues in Competitive Electricity Markets

This course provides an introduction to competitive electricity markets. The course covers topics including market structures and paradigms, transmission services, transmission congestion management, allocation of real power losses, optimal bidding strategies, and market power analysis. This class was not offered in the 2006-2006 academic year.

ECE 598PLC Advanced Topics in Power Electronics

This course extends the topics of the undergraduate power electronics course. The goal is provide the students with a theoretical basis for advanced research in power electronics. Device and converter modeling are studied in detail. Analog and digital pulse width modulation methods are explored. Averaging and nonlinear control theory relevant to power electronics is studied. The course includes a large-team design project that requires the students to draw from current literature. This class was not offered in the 2006-2007 academic year.

NUMBER OF ELECTRIC POWER AND ENERGY SYSTEM AREA GRADUATES IN RECENT YEARS

1950-1970 Annual Average Power Area Graduates

B.S.E.E.	-	25
M.S.E.E.	-	3

1970-1980 Annual Average Power Area Graduates

B.S.E.E.	-	44
M.S.E.E.	-	7

1980-1990 Annual Average Power Area Graduates

B.S.E.E.	-	32
M.S.E.E.	-	5
Ph.D.	-	2

1990-1995 Annual Average Power Area Graduates

B.S.E.E.	-	40
M.S.E.E.	-	6
Ph.D.	-	2

1995-2000 Annual Average Power Area Graduates

B.S.E.E.	-	35
M.S.E.E.	-	9
Ph.D.	-	3

2000-2005 Annual Average Power Area Graduates

B.S.E.E.	-	40
M.S.E.E.	-	8
Ph.D.	-	3

2005-2006 Power Area Graduates

B.S.E.E.	-	41
M.S.E.E.	-	10
Ph.D.	-	2

2006-2007 Power Area Graduates

B.S.E.E.	-	47
M.S.E.E.	-	7
Ph.D.	-	10

5. ACTIVITIES

The faculty and students in the Power and Energy Systems Area participated in a considerable number of special activities during the calendar year 2006. The major events are listed below:

January

- Hawaiian International Conference on System Science, Waikoloa, HI
  - Pete Sauer chaired a session and presented a paper
  - Tom Overbye presented a paper
- Patrick Chapman attended the National Science Foundation Panel, Washington, D.C.
- Tom Overbye attended the DOE Project Meeting, Cambridge, MA
- Tom Overbye invited to give a talk at Arizona State University, Phoenix, AZ
- Pete Sauer participated in the NSF DDDAS Workshop, Washington, D.C.
- Pete Sauer chaired an NAE Committee Meeting, Washington, D.C.
- Philip Krein invited lecturer at Comanche Electric Station, Granbury, TX
- Philip Krein collaborated with Grainger CEME colleagues at Georgia Tech, Atlanta, GA

February

- Pete Sauer participated in the PSERC Executive Committee Meeting, San Diego, CA
- Pete Sauer participated in the NAE Membership Policy Committee, Newport Beach, CA
- Patrick Chapman:
  - participated in the National Science Foundation Workshop on Hurricane Science Research Priorities, Washington, D.C.
  - attended the National Science Foundation Workshop – Electric Energy Systems, Orlando, FL
  - participated in the Military Energy Alternatives Conference, Washington, D.C.
- Tom Overbye met with the Tennessee Valley authority to discuss the visualization project, Chattanooga, TN
- George Gross was an invited lecturer at the University College, Dublin and evaluator of proposals submitted to the Science Foundation of Ireland
- Philip Krein
  - collaborated with Grainger CEME colleagues at the University of Wisconsin, Madison, WI
  - collaborated with Grainger CEME colleagues at Georgia Tech, Atlanta, GA
  - invited IEEE and CENIDET lecturer, Morelos Section, Cuernavaca, Mexico
  - invited IEEE distinguished lecturer, Universidad Autonoma de San Luis Potosi, San Luis Potosi, Mexico

March

- Patrick Chapman attended the Applied Power Electronics Conference, Dallas, TX
- Philip Krein
  - presented invited lecture at Bosporas University, Istanbul, Turkey and Jordan International Electrical and Electronics Engineering Conference, Aman, Jordan
  - presented papers and attended committee meetings at the IEEE Applied Power Electronics conference, Dallas, TX
  - presented invited lecture at University of Wisconsin Madison
- Pete Sauer took students from the ECE 431 class to Siemens Energy and Automation, Inc., West Chicago, IL

April

- Philip Krein and Patrick Chapman attended a Proposal Planning Meeting with the Georgia Tech Team, Indianapolis, IN
- Patrick Chapman presented a paper at the AUS-ISM06 International Symposium on Mechatronics at the American University of Sharjah, United Arab Emirates
- Tom Overbye met with Guangxi Electric Power Industry to discuss power system visualization, Nanning, China
- Tom Overbye made a presentation at the MISO short course, Minneapolis, MN
- George Gross attended the PSERC Executive Forum at UIC Gleacher Center, Chicago, IL
- George Gross, invited speaker at the UIUC ACDIS Seminar Series
- Philip Krein
  - keynote speaker, invited paper and chair special session at the AUS International symposium on Mechatronics at the American University of Sharjah, United Arab Emirates
  - collaborated with CEME colleagues at Ohio State University, Columbus, OH
  - organized a Proposal Planning Meeting with Purdue and Georgia Tech collaborators, Indianapolis, IN

May

- Pete Sauer chaired a panel session at the 2006 IEEE PES T & D Meeting and Exposition, Dallas, TX
- Tom Overbye met with Tennessee Valley Authority to discuss the CTC Project, Chattanooga, TN

- Tom Overbye, George Gross and Pete Sauer attended the IEEE PES General Meeting, Montreal, Quebec, Canada

- George Gross

  - attended and presented a paper at the 13th IEEE Mediterranean Electro-technical Conference, Malaga, Spain

  - presented a short course at Politecnico de Milano, Milan, Italy

  - invited lecturer and presenter at the University of Pavia and University of Cagliari, and Politecnico di Torino, Italy

  - attended the RTE Workshop and met with RTE and EdF, Paris, France

- Pete Sauer participated in a review of the Department of Energy electrical distribution research program, San Ramon, CA

- Philip Krein collaborated with Grainger CEME colleagues at Oregon State University, Corvallis, OR

June

- Patrick Chapman attended and presented papers at the 37th Annual IEEE PESC 2006 Conference, Jeju, Korea

- Tom Overbye met with Exelon, Chicago, IL

- Pete Sauer and Tom Overbye attended and participated in committee meetings of the PSERC IAB Meeting, Madison, WI

- George Gross invited speaker at the Iowa-Illinois Section IEEE Meeting on The New Transmission Business: Challenges and Opportunities

- George Gross attended and chaired a panel session, participating as a panelist in two other sessions and attending committee meetings at the 2006 IEEE PES General Meeting and participated in the MicroGrid 2006, Chicago, IL

July

- George Gross participated as faculty of a short course on Transmission Services for Tai Power, Taipai, Taiwan

- Patrick Chapman made a presentation at the IEEE Workshop on Computers in Power Electronics, Albany, NY

- Pete Sauer attended a meeting with S & C Electric Power Affiliates, Chicago, IL

- Pete Sauer and Tom Overbye participated in the 2006 PSERC Summer Planning Workshop, Ashland, WI

- Philip Krein, Patrick Chapman and Jonathan Kimball attended with graduate students and presented papers at the IEEE Workshop on Computers in Power electronics, Troy, NY

August

- Tom Overbye attended the Modern Grid Initiative, Nashville, TN

- George Gross and Pete Sauer participated in the 2006 International Control Systems Security and Standards Coordination Workshop, Portland, OR

- George Gross participated in a public workshop on transmission issues, Taipan, Taiwan

- Pete Sauer attended the KEMA 6th Conference for Cyber Security of Industrial Control, Portland, OR

- Philip Krein attended the IEEE Nominations and appointments Committee Meeting, Guadalajara, Mexico

September

- North American Power Symposium (NAPS), at SIU, Carbondale, IL
    - Pete Sauer chaired a session and committee meeting and accompanied students
    - Tom Overbye attended the symposium

- Philip Krein and Patrick Chapman attended a planning meeting for a large team proposal with colleagues from Georgia Tech and Purdue University

- Philip Krein attended the IEEE International Telecommunications Energy Conference, Providence, RI

- Philip Krein participated in the IEEE Nominations and Appointments Committee meetings, Quebec City, Quebec, Canada

- Pete Sauer accompanied students to the Electrical Manufacturing Expo, Indianapolis, IN

October

- Patrick Chapman attended and presented at the IEEE Industry Applications Society Annual Meeting, Tampa, FL

- Pete Sauer attended the NAE Annual Meeting and Peer Committee Meeting, Washington, D.C.

- Pete Sauer participated in the DOE Research Project Review, Washington, D.C.

- Tom Ovebye
    - made a presentation at the Pacific Northwest Lab Visualization Conference, Pasco, WA
    - attended the DOE visualization and Controls Program Peer Review, Arlington, VA
    - made a presentation at the Workshop on Renewable Energy for Minnesota, Minneapolis, MN
    - invited to talk at Lewis University on the continental SuperGrid: A Proposal for a Sustainable energy Infrastructure, Romeoville, IL

November

- Tom Overbye invited to Nanning, Guangxi, China to discuss power system modeling with GXED
- George Gross was keynote speaker at the seminar "Strategic Cooperation in Energy Innovation", Santiago, Chile
- George Gross invited to prepare and present a report on Transmission Planning Practices for the United Nations Development Program, Brasilia, Brazil
- Pete Sauer participated in the NSF "CMU Beyond SCADA Workshop", Pittsburgh, PA
- Pete Sauer visited with the Secretary of Energy about a research center, Washington, D.C.
- Philip Krein
    - presented the IEEE distinguished lecture at the IEEE Chapter Meeting, Cambridge, MA
    - presented an IEEE distinguished lecture and keynote address at the International Conference on Power Electronic Systems, Hong Kong, China
    - presented an IEEE distinguished lecture, Dallas, TX
- M. A. Pai presented a paper and was keynote speaker at the 2006 IEEE-PEDES Conference, New Delhi, India

December

- Philip Krein and Patrick Chapman met with the Office of Naval Research to discuss research activities of the Grainger Center, Arlington, VA
- Pete Sauer, George Gross and Tom Overbye attended and participated in the PSERC IAB Meeting, Golden, CO
- George Gross participated in the SANDIA National Labs Energy-Water, Eastern Region Needs Workshop, Baltimore, MD
- Pete Sauer participated in an NAE Committee Meeting, Irvine, CA

During the 2006 calendar year, the power area group hosted the following guest speakers:

- Benjamin Hobbs, The John Hopkins University, "Model-Based Evaluation Of Generation Adequacy Markets: Approaches And Application To PJM", January
- Scott Sudhoff, Purdue University, "Design Metrics For Electric Warship Design", February
- Jason Wells, PC Krause and Associates, West Lafayette, IN, "Distributed Heterogeneous Simulation", February
- William Horak, Brookhaven National Laboratory, Long Island, NY, "The Benefits Of Energy Research Portfolio Analysis", February

- Auden Botterud, Argonne National Laboratory, Argonne, IL, "Modeling Of Generation Investments In Electricity Markets", March
- Kurt Muehlbauer, Exelon Corporation, Chicago, IL "The North American Reliability Council Cyber Security Standards", April
- Nivad Navid-Azarbaijani, MISO, Carmel, IN, "The RTO EMS And The Market Systems", August
- David Perreault, Massachusetts Institute of Technology, Cambridge, MA, "In Search Of Power Circuits: Developments In Very High Frequency Power Conversion", August
- Kai Strunz, University of Washington, Seattle, WA, "Simulation Of Power electric And Electronic circuits From Stochastic Modeling To Technology Benchmarking", September
- Annette Muetze, University of Wisconsin-Madison, "Ocean Wave Energy Conversion – A Survey", October
- Paul Hines, Carnegie Mellon University, Pittsburgh, PA, "Towards Optimal Operations", October
- Tom Kay and Mark Baranek, ComEd Exelon Corporation, Oakbrook Terrace, IL, "The ComEd Operations Management Control Systems", October
- S. D. Pekarek, Purdue University, "Using Torque-Ripple-Induced Vibration To Determine The Initial Rotor Position Of A Permanent Magnet Synchronous Machine", November
- Youngkook Lee, Georgia Institute of Technology, Atlanta, GA, "A Stator Turn Fault Tolerant-Strategy For Interior PM Synchronous Drives In Safety-Critical Applications", December

During the 2006 calendar year, the power faculty and students presented the following seminars to our local audiences:

- David Savageau, "Dynamic Influence Region Algorithm For Contouring Power System Data", February
- Jeremiah Smith, "Minimum Number Of System Elements Which Cause Voltage Collapse", March
- Philip Krein, "Ultimate Switching: Toward A Deeper Understanding Of Switch Timing Control In Power Electronics And Drives", March
- Patrick Chapman, "Frequency-Dependent, Tim-Invariant DC-DC Converter Models Without Averaging", April
- Matthew Meinhart, "Microprocessor Implementation Of Modulation-Based Harmonic Elimination", April
- Timothy O'Connell, "Investigating The Utility Of Schwarz-Christoffel Mapping Theory In Electric Machine Design And Analysis", April
- Daisy Chen, "Development And Fabrication Of Hybrid LC Devices On Silicon", May
- David Maggio, "Transmission Corridor Analysis Using PTDFs", September
- Ali Davoudi, "Parametric Average-Value Modeling of Power-Electronics-Based Systems", September
- Alireza Khaligh, "control of DC/DC Converters Driving Constant-Power Loads In Vehicular Systems", October
- James Stubbins, University of Illinois at Urbana-Champaign, "Legislative Nuclear Power Renaissance-What's Going On In Nuclear Energy, October

- Teoman Güler, "Generalized Line Outage Distribution Factors", October
- Marco Amrhein, "Design-Oiented Magnetic Equivalent Circuit Models Of Electromagnetic Structures", November
- Brett Nee, "Electric Drive And Machine Integration", December

6. STUDENT PROJECTS

This section of the report contains information on the graduate students whose major research efforts were supervised by faculty in the Power and Energy Systems Area. While not all of these students received financial aid from the Power Affiliates Program in terms of Research Assistantships, they were all associated with the program through the active involvement of their respective advisors. Those students supported by the Power Affiliates Program received maximum one-half time Research Assistantships for 11 months. The results of each student's work will be made available to all affiliate companies in the form of technical reports. The following students were associated with the Power and Energy Systems Area and their work is described in the following pages:

Amrhein, Marco (Ph.D.)
Aquino-Lugo, Angel (Ph.D.)
Balog, Robert (Ph.D.)
Banerjee, Abhishek (M.S.)
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Magnetic Equivalent Circuits Applied to Induction Machine Design

Supported by the Power Affiliates Program and Grainger CEME

New developments in power electronics technology, materials, and changing application requirements are driving advances in electric machines. But special-purpose induction machines have not enjoyed the same attention in inverter-fed applications as permanent-magnet and switched-reluctance machines. Induction machines are often not considered, particularly in the traction and aerospace community, due to their low power density and low efficiency. Because induction machines need to satisfy the standards of the National Electrical Manufacturers Association, performance capabilities are limited. Computer-aided design (CAD) tools for special-purpose machines that overcome these limitations are not available.

Three different modeling approaches for CAD have been used in the past. Analytical machine models, most common, have low computational effort and complexity but are inaccurate outside certain design restrictions. FEA has, in principle, respectable accuracy, but it requires a massive computational effort in two-dimensional (2-D), and especially in three-dimensional (3-D) models. It has been claimed that FEA would be good for use in a design tool, but realistically, its function is the detailed performance calculation of an already engineered machine. Magnetic equivalent circuits (MEC) provide a compromise between analytical models and FEA. They have reasonable accuracy combined with moderate computational effort, are flexible in size, and are easily parameterized and extended into 3-D models.

This project provides a feasibility study for a general 3-D MEC modeling approach intended for design. Theory, reluctance network generation, and modeling of motion are discussed. A force calculation approach based on the Maxwell Stress Tensor method is presented. The solution of the complete, nonlinear network equations in combination with mechanical and electrical differential equations is discussed.

An induction machine model is introduced that features a variable reluctance element mesh. Results for a 500 W induction machine designed for the Future Energy Challenge competition are compared to measurements, analytical models, and FEA. This machine has design flaws; it saturates the stator and rotor teeth during nominal load, a fact not discovered by the design software (analytical-based) and the associated FEA package. However, the 3-D MEC model estimates a limited torque capability due to a smaller air-gap flux. The model is about an order of magnitude smaller in complexity and size than the FEA model. All the presented results indicate that MEC, corrected for local saturation, is a promising option for a design tool.

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The Interaction Between the Production of Greenhouse Gases and the Electric Power Generation

Angel A. Aquino-Lugo with advisor T.J. Overbye

ABSTRACT

The electric industry is one of the major contributors to the global greenhouse gases emissions into the atmosphere. The objective of this work was to understand the interaction between the production of greenhouse gases and the production of electricity. We presented and compared the total U.S. greenhouse gases and CO_2 emissions with the U.S. electric power sector emissions. If we want to succeed in the CO_2 and other greenhouse gases reduction, emissions mitigation has to be implemented. For this reason, a review of the available renewable technologies, such as wind energy, sun energy and CO_2 sequestration, was performed. Many of these technologies and solutions that offer the possibility of reducing greenhouse gases introduce many additional challenges, especially to the transmission grid. Therefore, we also discussed the impact of incorporating these technologies into the transmission grid of the future. Finally we identified possible research topics related to the power system and the greenhouse gases.

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Robert S. Balog with advisor P. T. Krein

Supported by Grainger CEME

Autonomous Local Controls in a Distributed DC Power System

Distributed dc architectures have already become the standard for power distribution in naval ships and telecomm applications. The focus of this research is on distributed control techniques for each Point Of Load (POL) converter that act locally but in an orchestrated manner to ensure reliable system operation without necessarily relying on a central controller or communication network. Information contained in the bus voltage level, rate of change, and ripple component as sensed at the POL converter can provide control information about the state of health of the entire bus. To test these algorithms, a number of POL converters and controls have been designed and built to create a distributed dc system.

Commutation Technique for High-Frequency-Link Switching Power Converter Based on State-Machine Control Patent application filed August 11, 2005

This invention is a technique that resolves current commutation challenges in various types of ac-ac switching power converters. It also applies to inverters and rectifiers with high-frequency links. This technology commutates load current without inserting dead-time into the switching sequence or using large inductors to limit shoot-through current. Both of these prior techniques intrinsically compromise a converter's performance and efficiency. The new technology provides a continuous path for load current and control of ac-ac converter switching so voltage sources do not short-circuit during commutation. In the past, additional components or timing constraints had been required to address current commutation. This new technology prevents both shoot-through and load current disruption, and allows load-current zero-crossings to occur naturally without the distortion associated with prior techniques. The preferred embodiment of the new invention is a state-machine-based controller tht tracks the switch sequencing needed to avoid trouble.

Modular power electronics lab

Power electronics is a subject taught best by laboratory work in conjunction with formal lecture. However, the drawback is that considerable background is needed in the subject before even the simplest concepts can be demonstrated on the bench. In the past two years the undergraduate instructional laboratory has been equipped with a number of flexible modules that allow the students to quickly explore various fundamental topologies in dc to dc, dc to ac, ac to ac, and ac to dc converters without having to worry about the control or isolated gate drive support circuitry. One example is a re-designed FET box consisting of two fully isolated FET devices and flexible controls that allows numerous one and two switch topologies to be studied.

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Comparison Between Hard and Soft Turn-off of IGBTs in PWM Inverters

Abhishek Banerjee with advisor Philip Krein

Gate drive circuits are used as interfaces between power semiconductor devices and the logic level circuitry producing the enable (1) and disable (0) functions. These gate drives provide the necessary current to charge the gate capacitor during turn-on and a discharge path for the gate capacitor during turn-off. Optimal operation of gate drive circuits is crucial towards efficient use of the semiconductor switches. Comparison of hard turn-off and soft-turn off gate drive circuitry under short circuit conditions for high power IGBTs used as switching devices in PWM Inverters is being examined.

Soft turn-off is the process where when an over-current is detected, the gate voltage is brought down gradually so as to limit the current, and then a turn-off is initiated. Hard turn-off is a straight turn-off of the gate once the over-current is detected.

Appropriate operation of IGBTs is crucial to ensure optimum benefit and highest efficiency of the respective converter. Owing to conventional switching operations in Inverters such as Pulse Width Modulation (PWM), the switches are exposed to variable frequencies as well as duty cycles. Hence, they are required to be robust and consequently ensure reliability of the system; the inverter in this case. There are various issues that demand conflicting designs of the gate drive; device stress vs. switching losses being one of them. The potential gains of incorporating either turn-off techniques will be analyzed keeping them in mind. The effects of turn-off techniques on the semiconductor, such as stresses and losses will be analyzed for different designs, temperatures and controlled conditions.

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Optimization of Power Converters In Portable Energy Sources

Nicholas Benavides with advisor P. L. Chapman

ABSTRACT

Portable electronic devices have grown in number and complexity. Powering these devices with lightweight sources is a major research focus. Advanced technology energy sources such as fuel cells and combustion-based microturbines seek to supplant chemical batteries due to their theoretically high energy density. These sources typically do not have directly useful output, and are most efficient when used at a constant power level. This requires complex power conversion and secondary energy storage to meet changing load demand. Our work focuses on optimizing the tradeoff between mission length and optimal converter efficiency. A short mission time can use a light-weight, inefficient converter by adding a small amount of fuel. Conversely on a long mission, the fuel is the most significant mass in the system, and any drop in efficiency has a larger effect on the net mass. As the mission lengths approach 1000 hrs, the maximum possible efficiency is desired, even if the optimum results in a heavier converter.

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Analysis and System-On-Chip Implementation of Digitally Controlled Multi-Port DC-DC Converters

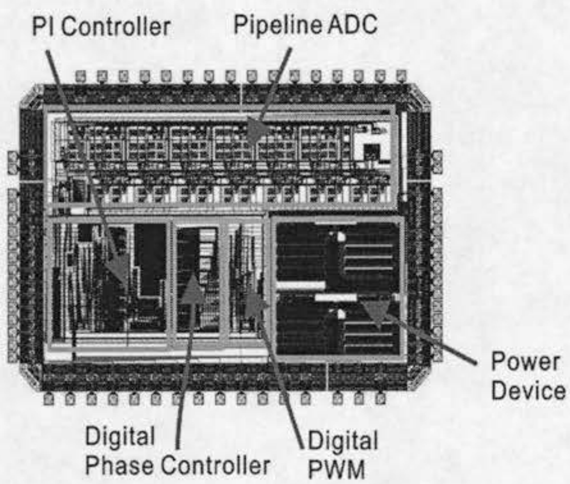
Jaesoo Byoun with advisor Prof. Patrick Chapman

Supported by Grainger Endowments

ABSTRACT

A proposed power management architecture that uses digital phase control to maximize the advantages of digital control in the low-voltage power electronics field. The implemented architecture consists of 7-bit Pipelined ADC, PI digital controller, Digital Phase Controller, Digital PWM and CMOS Power Device. The implemented architecture design is submitted for fabrication to MOSIS.

The proposed architecture is to stabilize the feedback loop without a current sensor from full load to no load conditions by using digital phase controller. The architecture also has multi-input multi-output functionality and sets not only the sequence of on-and-off of the dc-dc converters but also the device itching command signal.



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Passive Components for On-Chip DC-DC Power Converters

Daisy Chen with advisor Prof. Patrick L. Chapman

Supported by the Grainger CEME

ABSTRACT

The use of integrated passive devices on ICs is an increasing field of research as devices become smaller and package size becomes an issue. Hybrid passive devices are devices that will combine capacitive and inductive behavior in one device and could be used for applications such as filtering.

A preliminary hybrid passive device design was laid out and masks were made. The layout includes hybrid passive devices as well as simple metal insulator metal capacitors. The hybrid passive devices and capacitors are composed of two copper layers with titanium dioxide as a dielectric plus additional layers for contacts. It is currently being fabricated on 2" silicon wafers. After completion, there will be five layers, alternating between metal and insulator layers.

After the fabrication of the preliminary hybrid passive devices, they will be tested to obtain information about their properties and behavior. The capacitors will be tested to obtain information about the dielectric. Future work will include a more advanced design building upon the results of the first design, testing, and possible implementation in a converter.

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Dynamic Modeling of Multiple-Input Power Converters

Yongxiang Chen with advisor P. L. Chapman

ABSTRACT

Multiple input power converters are used to supply energy to systems that have multiple energy sources. For example, a solar vehicle that is powered by a solar panel and a battery can use a two-input dc-dc converter, which can be controlled to provides maximum power point tracking of the solar panel and steady output power to the motor simultaneously. An example of a two-input dc-dc converter is shown.

The design and analysis of a multiple-input power converter traditionally uses either switched or average value models. The switched model provides the most detailed and accurate results but requires significant computational effort. The averaged-value model is easier to compute but accuracy is reduced and most switching details are omitted. In this study, a multi-frequency dynamic model is being developed. It allows the user to trade off between accuracy and computational effort, which benefits the design process as well as overall system analysis. A sample comparison of the results from the three different models is shown.

Xu Cheng

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Slack-independent LMP decomposition

Xu Cheng with advisor T.J. Overbye

Supported by Grainger Endowments

ABSTRACT

The purpose of the study is to propose a slack-independent model for LMP decomposition. A new LMP decomposition model using AC OPF model is proposed to overcome the slack-dependent disadvantage of the conventional ones. The actual effect of marginal variation of generator with respect to load variation is studied as the basis of the decomposition model. Theoretical derivation and proof are given. The new model achieves a set of reference energy price independent results. A tutorial example is presented to compare the new model and the conventional one.

Bryan J. Cooper

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Optimal Power Plan Required to Sustain Temporary Operations as applied to Expeditionary Power Generation

Bryan J. Cooper with advisor P. W. Sauer

Pending Approval by the United States Air Force

ABSTRACT

The Armed Forces often deploys to austere locations where they must setup their base camp and sustain operations for an indefinite amount of time. Several things are desirable when choosing a location, such as isolation for security reasons, a water source to make potable water for drinking and sanitation, and electricity. More often than not, the electricity available, if available, is not reliable. Both the Army and the Air Force have prepackaged kits that they each use to provide adequate and reliable power to successfully accomplish their mission objectives.

This research will analyze several different population/land scenarios of typical base camps and develop an algorithm engineers can use to optimize their electrical service in terms of reliability, security, maintenance, resource availability, and cost. It will also examine and, possibly modify, each of the existing prepackaged kits.

Charles M. Davis

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Cyber Security and the Power System

C. M. Davis with advisor T. J. Overbye

ABSTRACT

The cyber security of the electric transmission system is of increasing concern. To study potential problems and solutions, the NSF has established an NSF Cyber Trust Center was created in August 2005. Working with this center, a power system SCADA client has been developed to model the workings of a control center. The SCADA client communicates using a custom protocol to PowerWorld Simulator. It has the ability to both receive data and send commands. A protocol translator is being developed that will translate between the custom PowerWorld protocol real SCADA protocols. A SCADA test bed is also being developed. This system integrates hardware and software. Real relays and RTUs are used with PowerWorld Simulator acting as the power system through a converter. This system will allow the modeling of various kinds of cyber attacks.

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Model Order Reduction of Highly Accurate Power Electronics and Electromechanical Systems

Ali Davoudi with advisor Patrick L. Chapman

ABSTRACT

Analysis of power electronics and electromechanical systems are faced with many compromises in simulation. Inevitably, highly accurate physics-based methods are of high computational intensity. In power electronics and electromechanical systems, these high-order models are obtained from finite-element analysis (FEA) or magnetic equivalent circuit (MEC) approaches. Model order reduction (MOR) techniques break these compromises and provide analysts with accurate, physics-based models that have low order and fast execution time. High-order physics-based MEC/FEA models are developed using decomposed uniform grids and/or high-fidelity MEC models that account for saturation, eddy, lamination, 3-D, corner effects, and motion. These models are later preceded with mathematically rigorous reduction techniques to a lower order model that includes only the dominant states.

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2007 Solar Decathlon

Trishan Esram with advisor P. L. Chapman

Supported by the Illinois Clean Energy Community Foundation

ABSTRACT

The 2007 Solar Decathlon, organized by the Department of Energy, consists of twenty teams of students, coming from national and international colleges and universities, competing to construct the most aesthetically appealing and energy-efficient house that solely uses solar energy. Our group in the Electrical and Computer Engineering department and groups from other departments make up the team for University of Illinois at Urbana-Champaign.

The focus of our group is to maximize and efficiently distribute the power coming from the solar modules, the only power source for the house. Our tasks started by determining the power requirement of the house, designing and building an effective electrical system, and trading off between costs and efficiency, when choosing electrical components and appliances.

The electrical system design has been completed and the house is currently under construction. In the meantime, the electrical components are being tested in our laboratories. Once the construction ends, all the components will be put together in the house. More testing will then be done under real weather conditions, throughout the summer until the 2007 Solar Decathlon competition, which will take place in October 2007 on the National Mall of Washington D.C.

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Switching Signal Spectrum Management

Xin Geng with advisor P. T. Krein

Supported by the Grainger CEME and by the

Motorola-UIUC Center for Communications

ABSTRACT

Switching power converters are designed to convert electrical power from one form to another at high efficiency. The control of switching converters relies on appropriate modulation of the switches. Pulse-width modulation (PWM) technique becomes the primary control scheme due to its simplicity and effectiveness. However, switching signals generated by original PWM method generally contain rich harmonics which have detrimental effects to the converter working environments. For instance, unpleasant acoustic noise, mechanical resonance and electromagnetic interference (EMI) are all caused by the harmonic components existing in the power conversion devices.

The main objects of this project is to address above issues which requires *spectrum shaping*, the technology to modify harmonic characteristics of switching signals without sacrificing signal-band integrity. Two directions are attempted. First, a modulating-function based approach is studied based on previous work on multi-carrier and multi-signal PWM architectures. Predistortion signals are added into the modulating function to change the characteristics of the switching signal spectrum. Second, a carrier-based approach is proposed in which the carrier waveform is altered either in a random fashion or a deterministic way. Both methods show potentials to reshape the signal spectrum. Further research on systematic design criteria and digital implementation are being conducted.

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Advanced Electric Machine Controls

Brian H. Green with advisor P.W. Sauer

Supported by the Grainger Endowments

ABSTRACT

A single inverter is often used to drive parallel-connected induction machines in applications such as locomotives and steel processing. This configuration can be simpler and more compact than the multi-inverter arrangement. The objective of this work is to develop a field oriented strategy that gives dynamic control over maximum flux magnitude and mechanical output power of the machines. This control assumes n machines with matched parameters, but accounts for differences in rotor mechanical speeds which lead to unbalanced loading. Controlling the maximum flux magnitude can ensure that no machine operates in the saturation region. Control of the output mechanical power can be desirable because of the mechanical coupling of the system. This control is well suited for locomotive applications where the induction machines drive parallel axles and where wheel diameters are not perfectly matched.

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Electricity Markets and System Reliability

Teoman Güler with advisor G. Gross

ABSTRACT

In the restructured electricity systems, market forces induce system operators to drive the system to operate near or at the limits of operational reliability. Under such conditions, the maintenance of system security is of paramount importance for ensuring effective and efficient market operations. The objective of this study is to exploit the impacts of the system security criteria on market operations. We analyze the extensive test results on various systems in terms of different criteria including costs, reliability performance and benefits. The work also assesses the additional opportunities for strategic behavior by sellers and the effects of spatially distributed generation reserves under different security criteria. We are also undertaking some analytical tool development to predict the impacts of changing the security criterion.

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Power System Level Impacts of Plug-In Hybrid Vehicles

Steven Judd with advisor T. Overbye
Supported by PSERC

ABSTRACT

At present, the U.S. is importing crude oil at the rate of 9.8 Mb/day. In addition, approximately 5.4 Mb/day of crude oil are produced domestically. Two-thirds of this oil is refined into gasoline and diesel fuel to power U.S. passenger vehicles and trucks. The political and economic effect of this "addiction to oil", particularly imported oil, is well documented, and is recognized as a serious national problem. With a growing world-wide demand for crude oil, and OPEC cartel controlling a large portion of its supply, there has been a significant rate-of-change in its market price now standing at $65 per barrel. Also the burning of petroleum fuel emits CO_2 gas, the most serious greenhouse gas, into the atmosphere at levels now believed to be causing a global warming effect with very serious changes in global weather patterns. There is a real national need to reduce consumption of crude oil, particularly imported oil.

A number of solutions have been proposed for this problem, including finding more oil, increasing fuel economy, the use of ethanol, and the use of conventional hybrid electric vehicles (HEVs). While all of these solutions have merit, we believe another solution exists that could be extremely attractive to the electric utility industry – the Plug-In HEV (PHEV). USA driving pattern studies have shown that on average half the vehicles drive 25 miles or less each day, and 78% drive 45 miles or less each day. The PHEV is an evolutionary change from the current HEVs now commercially available. By increasing the battery capacity, the PHEV becomes a dual-fuel vehicle in which electric utility supplied primarily off-peak energy, could be used to replace much of the gasoline energy now used in conventional vehicles.

From an electric utility point of view the use of PHEVs could also be quite attractive. At a minimum they represent new, primarily off-peak users of (in aggregate) substantial amounts of electric energy. To gauge the potential market, consider that in the U.S. we currently use about 500 million gallons of gasoline a day. To meet this energy requirement completely with electric energy (assuming 70% efficiency in PHEV and 12.5% efficiency in combustion engines) would require and additional 3.3 million MWh per day, a value on par with our current daily electric usage of 10 million MWh. In addition to PHEVs being energy users, in aggregate they could also provide large amounts of potentially controllable stored energy. For example, if a single PHEV has an energy storage of 15 kWhr, one million vehicles could provide 15,000 MWh of energy storage capability. Since many of these vehicles will be driven into the downtown areas during the day, they could represent potential emergency energy reserves, often in the locations on the grid where they are needed most. An infrastructure would be needed to access this energy including plug-ins and wireless communication to know customer intentions and when to draw stored energy. With such a network the stored energy in the PHEVs and their energy storage capacity could become a highly controllable, system-level resource. Potential applications include the ability to greatly reduce spinning generation reserves, the ability to increase transmission system capacity by providing a responsive post-contingent control, and the ability to mitigate LMP market volatility. For example, the energy in the PHEVs in the above example could be quickly made available to temporarily replace the energy lost during the unexpected outage of a large generator.

Anupama Kowli

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Power Systems and Control

Anupama Kowli with advisor P. W. Sauer
Supported by the Grainger Endowments

ABSTRACT

Power systems are highly nonlinear in nature. But the techniques currently being employed for observability analysis and state estimation for the same are developed for a model obtained after linearizing the system about an operating point. Many such algorithms have been developed over the years and these can be broadly categorized into the following classes: topological, numerical or a combination of both.

- Topological algorithms check the system observability by constructing a *spanning tree* and checking its rank (full rank = system observable). Work has been undertaken to construct algorithms in case of measurement deficiency (in this case, maximum observable subnetworks can be determined). The system can be made observable by appropriate pseudo measurements.
- Numerical algorithms use iterative schemes to determine maximum observable islands by investigating the zero pivots that occur during the triangular factorization. Several extensions have been made to the same.
- Hybrid algorithms are a mixed topological-numerical approach.

The goal of this project is to exploit the nonlinearities of the power network and subsequently develop algorithms which incorporate system dynamics during observability analysis and state estimation. Work that has been done so far includes review of the previous techniques being used and a formulation for investigating observability for a nonlinear power system model. In the future, development of a nonlinear observer for the same can be undertaken. We shall then apply nonlinear control to the power system.

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DC-DC Converter Design and Integrated Circuit Implementation

Yingying Kuai with advisor P. L. Chapman

Supported by the Power Affiliates Program and Grainger CEME

ABSTRACT

Integrated Circuit (IC) implementation of dc-dc converters is popular in portable electronic systems, as it is the most cost-effective approach to design a complex electronic system. This project deals with the design and implementation of a dc-dc converter using IC technology and digital control.

Layout issues such as determining the optimal size of power devices and ground isolation will be addressed. In addition, novel design and optimization approaches to achieve high-efficiency and high energy density will also be explored. Further effort will be put into digital control aspects for dc-dc converters. Digital control promises significant system performance gains resulting from complex control algorithms not available from analog control. This project will enable a shift from small-signal linearized approximate control techniques to advanced nonlinear digital controls that exploit the fundamental structure of power converters. Continuing improvements in digital circuits, relative to analog, enable much more advanced control techniques. Particularly, focus will be on the development of advanced nonlinear large-signal digital control methods to supplant linear small-signal analog controllers in dc-dc power converters.

Alexis Kwasinski

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Direct Current Distributed Generation System Analysis Based on a Microgrid Telecom Power Plant

Alexis Kwasinski with advisor P. T. Krein

Supported by Grainger CEME

ABSTRACT

A *microgrid* is an independently controlled portion of an electrical grid. It comprises its own power sources, energy storage devices and loads, and is usually interconnected with a larger grid. A microgrid can achieve improved local reliability and high efficiency relative to the complete power grid. It also provides uninterruptible power supply functions. These characteristics makes microgrid based system specially suitable for telecom power systems. Since communications industry has a long experience in high power direct current (DC) local networks, this work explores general DC distributed generation systems using a microgrid-based telecom power plant with a modular distributed architecture as a basis for the analysis. The current study develops a systematic approach to determine the most suitable configuration of a microgrid-based telecom power system, and establish the possible basis for optimal design. The objective is to set the system's main bus voltage, the redundancy policy, the power converter topologies to apply, and the configuration of both the microsources and the energy storage devices. The analysis is done by comparing alternative configurations using a value function that considers the power plant's main characteristics: cost, availability, flexibility, technological development, potential for industry synergies and other extra advantages such as survivability in natural disasters. The next step in this work will be to construct a prototype with the system characteristics yielded by the comparative study. Future work will extend the analysis into other applications such as construction and transportation.

Alexis Kwasinski was awarded the 2005 Joseph Suozzi INTELEC Fellowship for this work.

Shanshan Liu

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The Development of Power System Load Models Using PMU Data

Shanshan Liu with advisor P. W. Sauer

Supported by the Grainger Foundation

ABSTRACT

The accuracy of system models are essential for system analysis, planning and design in electrical power systems. Having accurate load models can help to understand the dynamic phenomena and design the control system. More important, load representation has a significant impact on system stability analysis.

While scientifically accurate and detailed models have been proposed for generators, lines, transformers and control devices, the same has not occurred for load models because of the random nature of a load composition. We can determine the aggregate load model parameters if the parameters of all separate loads are well known, which is often not available. In the absence of the precise information, one of the most reliable ways to obtain the trustable load model is to apply identification techniques. Now with the installation of PMU, it is possible to get the real-time data of the power system. Since the loads are actually evolving with time, it is more useful and also more challenging to update the load model timely to assure the best performance.

This project is to develop an automatic method for the determination of variable parameters of the dynamic load model under normal operation condition of power system

David Maggio

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Determining Transmission Corridors of National Significance Using Power Transfer Distribution Factors (PTDFs)

David Maggio with advisor T. Overbye

Supported by the Department of Energy

ABSTRACT

Subsection 1221(a) of the Energy Policy Act of 2005 calls for a study to determine national interest electric transmission corridors (NIETCs). These corridors are defined as "any geographic area experiencing electric energy transmission capacity constraints or congestion that adversely affects consumers." The issue then becomes how to search for these corridors, in a mathematical sense, in larger systems, such as the Eastern Interconnect. The method that is investigated suggests using the power transfer distribution factors (PTDFs) in order to determine the "direct flow" between two hubs. With these hubs properly defined, we hope to ascertain where these transmission corridors of national significance exist.

Merry Pullolickal Mani

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Stochastic Transmission Revenues

Merry Pullolickal Mani with advisor P.W. Sauer

ABSTRACT

This project studies the impacts of uncertainty in the load and the openings of transmission lines on the generated revenues from transmission tariffs. An IEEE 14-bus test system is used. The hourly revenues are computed in a Monte Carlo simulation using random samples drawn from a population with a specified distribution. The distributions of the hourly system revenues due to the uncertainty in the load forecast and the openings of lines are also computed analytically using linear power flow methods and distribution factors. This project presents a comparison of the solutions obtained through the analytical methods with the solutions generated by the Monte Carlo simulations.

Matthew Meinhart

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Microprocessor Implementation of Modulation-based Harmonic Elimination

Matthew J. Meinhart with advisor P. L. Chapman

ABSTRACT

Pulse-width modulation (PWM) methods used in dc-ac conversion have been well researched and their advantages in terms of control and implementation are well-known. A wide variety of techniques for eliminating harmonics through pulse-width modulation switching waveforms exist and the harmonic content of these signals plays a key role in the overall performance of the entire drive system. A judicious choice of PWM switching strategy can not only reduce unwanted harmonics, but also minimize computational effort, and allow implementation in cheap, low-end processors. A recently introduced PWM technique that uses a modified carrier waveform to eliminate harmonics will be reviewed. The effectiveness and "cost of implementation" of this modulation-based technique while implemented on a PIC microprocessor will be analyzed.

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Effect of Distributed Energy Storage in the Voltage Stability of an Island Power System

Linda Monge-Guerrero with advisor P. W. Sauer

ABSTRACT

This project studies the effect of energy storage systems (ESS) used as distributed reactive compensation for voltage stability of an island power system. The dynamic voltage behavior using four load models was studied for these scenarios. The system under study was closer to voltage instability when loads were modeled using static load models than with load models considering induction motors, being the constant power load model the most critical. Modal analysis was performed to determine the system's weakest buses. V-Q curves were plotted for these buses to determine their reactive power margin. For our ESS, we consider the use of superconducting magnetic energy storage (SMES) technology as well as battery energy storage systems (BESS) and assumed the availability of four 15 MVA ESS units for reactive compensation. Six reactive compensation cases considering the allocation of all four SMES units at a single bus and their allocation distributed at different buses were evaluated. Cases considering one-site ESS location were able to increase bus voltages at one weak area, while the distributed ESS schemes managed to increase critical bus voltages at more than one weak area.

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Integrated Electric Machine and Drive for Single-Phase Applications

Brett Nee with advisor P.L. Chapman

Supported by the National Science Foundation

Electric machines are a part of our everyday lives and are often taken for granted, but consume sixty percent of our nation's electricity. The majority of electric machines in use throughout the world are fractional-horsepower, single-phase induction motors. These machines are widely used for their reliability, mature manufacturing process, low cost, and nearly speed-independent torque. However, the single-phase machine has a significant flaw, low efficiency. Typical single-phase machines run with an efficiency of 30% at light load and 60% at full load. This inefficiency is not fundamental to induction machines, but is for all single-phase machines and traditional line-start induction motors. This waste of electricity can be reduced if they are replaced equally reliable and fundamentally more efficient three-phase (polyphase) electric machines. In a conventional design, the power conversion is a series string of power conversions, each focusing on an individual stage's function, such as regulating an output voltage, reference current, or speed.

A design from a system level perspective, which includes electrical and mechanical attributes, can decrease cost and volume as well as increase reliability. The system level design will result in an integrated drive that has all the beneficial characteristics in each power transfer stage. An example is to use the magnetic steel of the machine for an inductor in passive or active power factor correction. Another possibility is using the mechanical characteristics to filter an injected torque ripple in a permanent magnet synchronous machine (PMSM) to reduce the capacitor current ripple. The preliminary results present the advantages that an integrated drive design can achieve, lowering cost without sacrificing efficiency.

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Assessment of the 2006 Illinois Electricity Auction

Matias Negrete-Pincetic with advisor G. Gross

ABSTRACT

The restructured electricity industry aims to fully harness the benefits of competitive forces through the introduction of electricity markets. Both sellers and buyers of electricity face inherent uncertainties due to the nature of electricity and electricity markets. The principal sources of uncertainty include the volatility of the electricity prices, the dependence of the demands on weather conditions and the availability of the generating units. A key thrust in the effective management of these uncertainties is the implementation of forward contracts for capacity. There are many approaches to trade these contracts. We focus on one such approach, which is the *capacity auctions*, adopted in Illinois, Ohio, Maryland and New Jersey. In this work, we present a review and a critical analysis of the design of, and the results obtained in, the *reverse capacity auction* performed in Illinois in September 2006 for the two major distribution companies, ComEd and Ameren. Our work is from the vantage point of power system operations and economics and aims to assess how well the auction process was designed and performed.

Rajesh Nelli

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Demand Side Management in Power Systems

Rajesh Nelli with advisor G. Gross

ABSTRACT

Demand-side management (DSM) programs consist of the planning, implementing, and monitoring activities of electric utilities that are designed to encourage consumers to modify their level and pattern of electricity usage. Demand Response is a Demand Side Management solution that can be defined as the set of activities to reduce or shift electricity use to improve electric grid reliability, manage electricity costs, and ensure that customers receive signals that encourage load reduction during times when the electric grid is near its capacity. The two main drivers for widespread demand responsiveness are the prevention of future electricity crises and the reduction of electricity prices. Additional goals for price responsiveness include equity through cost of service pricing, and customer control of electricity usage and bills.

We can divide the existing demand response programs into two main categories: Incentive-based programs and Time-based programs. In incentive-based programs, payments are made to customers to reduce their electricity usage during periods of system need or stress. The customers who participate in such programs adjust their production process, shift their loads to off-peak periods, or run on-site generators to reduce their level of electricity demand; in return they get incentive payments based on the degree of their participation. Direct load control, Interruptible rates, Demand bidding, Ancillary-services market program are various examples. In time-based rate programs, currently a range of time-based tariffs are offered to retail customers, so as to promote demand response based on price signals. Time-of-use rates, Critical peak pricing, Real-time pricing are various types of Time based rate programs. But, residential customers are assigned flat rates which offer no price signals; this is the only option in the absence of advanced metering that can record time-differentiated usage.

The goal of this project is to conduct a thorough study of the demand side management program adopted by Independent System Operators and to evaluate the reliability effects including outage costs, the impacts on system-wide costs and benefits, and the uses of strategic behavior by market participants. Further, the goal of this project is to investigate the feasibility of various DSM techniques for use by utilities. The work that is underway concentrates on the economic impact of demand response on power system operations.

Penglin Niu

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Biomechanical Energy Conversion Technology

Penglin Niu with advisor P. L. Chapman

Supported by the Office of Navy Research

ABSTRACT

Traditionally, mobile electronic devices have the problem of changing batteries or recharging batteries often. This is sometimes troublesome, especially for military field operations. One possible solution is to convert the wasted biomechanical energy, the human body movement energy to the useful electrical energy for the electronic devices. This will require both high efficiency and low physical influence on the human movement. In this research, we have evaluated actuation methods, including magnetic, piezoelectric, electrostatic, and electrical polymers for various motions in terms of energy, power, mass, and cost. We also discuss the practical issues associated with each, especially in terms of the power electronics required to connect the biomechanical sources to useful loads.

Currently, we are working on three potential human motions for energy harvesting and design of one energy harvesting device for each motion. Arm swing, horizontal foot movement, and up-down center of gravity movement during walking are analyzed for energy harvesting. Given commonality among the three motions, a general linear moving coil magnetic generator model is proposed. Based on a linear motor finite-element model, prototype devices are designed and built for each motion to match their biomechanical characteristics. Based on the testing of the prototype devices, second stage devices have been built for better mechanical and electrical performance. A self-powered power electronic conditioning and filtering system with high efficiency is designed and built for the charging of the battery from the generator. In the future work, the relationships between the human motions and operations of the generators will be analyzed, and the generators for each motion will be optimized based on these relationships.

Tim O'Connell

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Electric Machine Slot Shape Optimization using Schwarz-Christoffel Maps

Timothy C. O'Connell with advisor P. T. Krein

ABSTRACT

Schwarz-Christoffel (SC) mapping can be used as an electromagnetic field solution method motivated by an analytical solution of the governing equations. The SC method is a complex analysis tool allowing one to circumvent certain difficulties associated with solving a boundary value problem on a complicated geometry. Using a complex conformal mapping from the machine's domain to a simpler domain, one can more easily solve the BVP, then map its solution back to the original geometry. Using a recently-developed free software package, accurate SC maps can be quickly and efficiently calculated automatically. Consequently, the SC method has become tractable for many practical field problems.

In this work, the SC method has been successfully implemented in a Monte Carlo electric machine slot shape search algorithm attempting to maximize the machine's average torque. A Monte Carlo search randomly generates machine designs using pre-defined probability distributions for each of the design parameters. By randomly exploring the full design space, a Monte Carlo search thus allows novel machine designs to be examined that the designer might not otherwise try. Also, the computational speed and accuracy gains afforded by the SC method are better realized in a large-scale search. By combining the SC method with a Monte Carlo search in this way, the SC method's usefulness in practical machine design is judged. A Monte Carlo search of 11,050 designs has been successfully carried out and a maximum force horizon curve deduced from the data. Using curves generated in this way, parameter tradeoffs can be examined quickly and efficiently. Having thus shown the utility of incorporating the SC method in machine design, we continue to further develop the models and techniques necessary to fully simulate a practical machine.

Grant Pitel

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Performance Limits of Dc-Dc Converters and Control

Grant Pitel with advisor P. T. Krein

Supported by the Grainger Endowments

ABSTRACT

Response times in switching mode power supplies are limited by their time-dependent states: inductor currents and capacitor voltages. These state values become critical in fast dynamic applications such as drives and source emulation. Traditional controllers (e.g., proportional-integral closed-loop controls) employ prior error information that can limit response times. However, when present and future information are included a controller can achieve system-limited response, a highpoint in performance. Such is possible using a method called boundary control, which directs states with a nonlinear switch action and a surface that is usually a first or second-degree polynomial. Recent advances in digital processing speed have enabled real-time calculation of even higher degree surfaces that approach a converter's system-limited performance, a benchmark for other control methods. Presently, surface construction algorithms for two different dc-dc converters are being devised for a DSP. Future work will address hardware implementation and surface approximations that reduce processor overhead.

Hector Pulgar

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Theoretical Conditions For Collapsing A Power System

Hector Pulgar with advisor P. W. Sauer

Supported by Fulbright Fellowship

The discovery of conditions for voltage collapse is a very iteresting issue basically due to the current power systems' stress and the recent blackouts experienced in several systems around the world. This study is based on the Ph.D. Thesis of Santiago Grijalva, former UIUC's student. In order to approach to this problem it is studied the structure of the Power Flow Jacobian matrix and its entries. Applications to a basic power system without any reactive power control are considered. The main result of this work is the identification of a necessary condition for collapse. In simply terms, this condition establishes that at least one transmission line would reach its STSL (Static Transfer Stability Limit) before the collapse is encountered. This work can bring promising ideas to the development of new techniques and monitoring systems to predict a power system's instability.

Liyan Qu

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Reduction of Dynamic Nonlinear Models of Magnetic Devices

Liyan Qu with advisor P. L. Chapman

ABSTRACT

Nonlinear model order reduction (MOR) methods for extracting low-order, dynamic models of nonlinear magnetic devices from a high-order physics-based (finite element) model are proposed. These methods use the piecewise linear approach, with the linear MOR methods. They enable physics-based models to be implemented without heuristic assumptions or excessive computation. These methods are demonstrated with an example inductor model and verified experimentally. Simulation results show that the original, nonlinear high-order system is well represented by a piecewise set of connected low-order, linear systems. Synthesis of these methods can be fully automated so the end user can rapidly model new devices without repeating sophisticated mathematics. This work provides a foundation for modeling more complicated magnetic devices, such as multiphase coupled inductors, actuators, and machines.

Brian Raczkowski

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Identification of Critical Cutsets for Static Collapse Analysis

Brian Raczkowski with advisor P. W. Sauer
Supported by the Grainger Endowments

ABSTRACT

This topic deals with Static Transfer Stability Limits (STSLs) of network branches, cutsets of network branches, and their relation to power flow Jacobian singularity. A minimal cutset is a grouping of system branches that – if removed from the system – separates the seller and buyer for a given transaction into two separate subsystems (islands) of the original network while containing no unnecessary branches in the grouping. We define a critical cutset as a minimal cutset of system branches that exactly reaches its own cutset STSL (CSTSL) at the instant of power flow Jacobian singularity. We propose a conjecture that at least one minimal cutset in a power system is the critical cutset for a given transfer. Based on the numerical examples, there is a strong motivation to pursue a theoretical result that proves the existence of a single critical cutest that could be used to predict and quantify the boundary of existence of a load flow solution.

Pablo Ariel Ruiz

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Pablo Ariel Ruiz with advisor P. W. Sauer

Supported by a Roberto Rocca Fellowship and by Grainger Endowments

ABSTRACTS

Voltage and Reactive Power Estimation for Contingency Analysis

Operational reliability is normally checked using contingency analysis, thus requiring the solution of the power flow problem under a wide variety of system conditions. As power flows are computationally expensive and approximate solutions are usually acceptable, fast estimation methods are used. Real power distribution factor methods provide a good trade-off between accuracy and speed. Reactive power and voltage sensitivities-based methods have not been as successful, partially because equipment limits are ignored. In this project we study the estimation of post-contingency voltages and reactive power generation and flows using sensitivities. Employing piecewise linear estimates, the effect of equipment limits on the estimates is effectively captured. Numerical results on the IEEE test systems show that VAr limits have a significant influence in post-contingency voltages and reactive outputs and flows.

Operating Reserve: Economic Value and Demand Functions

Operating reserve is idle capacity connected to the system with the purpose of ensuring reliable system operations in the case of equipment outages and unexpected load variations. The reserve has an economic value since it prevents load shedding. In several electricity markets, reserve demand functions have been implemented to take into account the value of reserve in the market clearing process. These often take the form of a step-down function at the reserve requirement level, and as such they may not appropriately represent the reserve value. The value of spinning contingency reserve is impacted by the reliability and dynamic characteristics of system components, the system operation policies, and the economic aspects such as the risk preferences of the demand. The objective of this project is to compute the reserve value explicitly taking into account all these aspects. The value of reserve is used to build reserve demand functions for electricity markets and to obtain improved reserve requirements for vertically integrated utilities. Numerical results show that the demand functions constructed satisfy the usual reliability criteria.

David Savageau

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North America Security Constrained Optimal Power Flow (SCOPF)Study

David Savageau with advisor T. J. Overbye

Supported by Grainger Endowments

ABSTRACT

The initial goal this project is to establish a security constrained optimal power flow (SCOPF) model of the entire North American transmission system. The starting point for this project is the development of an integrated transmission system model that includes reasonably accurate cost information for all of the generators in the system (> 50 MW).

Once a working model has been constructed, SCOPF studies will be run under a variety of different historical loading conditions dispatching the three major interconnects (Eastern, Western and ERCOT) as superareas. The purpose of this portion of the study is to benchmark the study results with results obtained from the actual grid, adjusting the model as necessary to duplicate (to a reasonable degree of accuracy) actual system results. The ultimate goal of this research is to use this model to study the impact of new transmission additions, such as the TransAmerica Grid Project (TAG).

Melanie Shelton

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A Magnetic Sensing Approach to Characterize Corrosion in Reinforced Concrete

Melanie Shelton with advisor P. L. Chapman

ABSTRACT

Damage caused by corrosion of reinforcing steel plagues civil infrastructure in the United States. Corrosion damage causes an estimated 6 to 10 billion dollars of damage per year to bridge decks alone. Despite this cost, no reliable non-destructive testing method exists to detect the presence of corrosion or the rate at which corrosion occurs. Existing methods, such as visual inspection and half-cell potential measurements, are unable to fully characterize damage. The goal of this project is to develop a new sensing technique based on magnetic field measurements that will accurately measure both the state and rate of corrosion in reinforcing steel.

Working jointly with a group in the Civil Engineering Department, the project seeks to employ giant magneto-resistive (GMR) sensors to measure the small magnetic field generated by electric currents caused by corrosion. Two types of detection will be studied. In the first sensing mode, the GMR sensors passively sense the magnetic field emitted by a corroding steel bar. These measurements allow the rate of corrosion in the steel bar to be determined. The second sensing mode will include an actively injected magnetic field. The sensors will then measure changes in the magnetic field as it interacts with the steel bar. After processing, these measurements can determine the thickness of corrosion products, such as rust, on the steel bar's surface. The thickness of the coating indicates the extent of corrosion damage. This type of testing is analogous to eddy current testing. The figure shows preliminary measurements taken with the GMR sensors in the passive sensing configuration. The results clearly show that a corroding steel bar emits a more intense magnetic field than a non-corroding, or passivated, steel bar.

Jeremiah Smith

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Algorithm to Determine Minimum Contingency Set In voltage Collapse Scenario

Jeremiah Smith with advisor P.W. Sauer

ABSTRACT

Voltage security is a major concern in today's transmission systems. With the steady increase of load across the system, threat of terrorism, and recent occurrences, voltage collapse can be a detrimental result of poor system planning and operation if it is not monitored. This investigation explores how many system elements must be outaged in order to cause system wide voltage collapse. It also examines principles in maximum transfer capability limits on transmission lines using the attached model, along with the effectiveness of shunt capacitor banks and synchronous condensers used as voltage control devices. The IEEE 118-bus case is used to conduct simulations which implement continuous steady-state load flows and power-voltage curves (also attached) as indicators. The results remain accurate in the base case by assuming constant power factor load throughout, and applying given generator capability curve data and automatic generation control data to each unit. Using the (n-1) contingency list, sensitivities are found for the system with respect to increased system load given a unique (n-1) topology. The minimum number of system elements can be found by systematically repeating this process while outaging the most sensitive element at each step. Large cases on the order of 10,000 buses are then analyzed to show faster computation time when compared to exhaustive studies, along with the realistic applications of such a method.

Zakdy Sorchini

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Analysis and Design of Vector Controllers for Induction Machines using Singular Perturbations

Zakdy Sorchini with advisor Philip T. Krein

Supported by the Power Affiliates Program

ABSTRACT

This project is aimed at improving the understanding and performance of induction motor drive systems. A framework for the analysis of established control techniques is proposed. This framework retains the physical significance of the system and can be used to establish links between the distinct control techniques. Additionally, new control techniques can be proposed based on a singular perturbation analysis. For analysis and design, the impact of machine characteristics, in particular the leakage factor, is explored.

Currently, alternative induction machine models have been proposed as a framework for the analysis and design of controllers. Based on this framework and using singular perturbation analysis, a sliding mode controller to achieve torque control has been proposed. It was shown that under certain restrictions and by explicitly considering the power electronics inverter, direct torque control (DTC) can be formally derived from this sliding mode controller. The derivation provides insight into the dynamic behavior and stability of this common technique. In addition to the analysis of established controllers, new controllers have been proposed. In particular, a controller based on stator flux has been shown to enclose the benefits of field oriented control (FOC) and DTC, while avoiding their limitations. Viability of this new controller has been confirmed experimentally. Implementation details are being refined to be able to verify the performance claims of the controller.

Zeb Tate

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Professional Interests: Power System simulation, visualization and operation

Current Research Topics:

- Event detection based on phasor measurement unit (PMU) data
- Reconciling PMU data with load flow and state estimator results
- Rapid visualization of power system information using graphics processing unit (GPU) programming techniques

Line Outage Detection with Phasor Measurement Units

Zeb Tate with Advisor T. Overbye

Supported by a NSF Graduate Research Fellowship

ABSTRACT

The deployment of phasor measurement units (PMUs) throughout the power grid has increased substantially in recent years, and this growth is expected to continue. With these new measurement devices, new techniques must be developed to take advantage of the wealth of information that they provide. In particular, the voltage and current phasor angles obtained from these PMUs should be used to increase the situational awareness of grid operators. In this paper, we discuss how line outages can be identified due to changes in phasor angles observed at a limited number of buses. Using these techniques, it should be possible to get early indicators of line outages anywhere in the grid.

Wayne Weaver

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Geometric and Game Theoretic Control of Energy Assets in Small–Scale Power Systems

Wayne Weaver with advisor P.T. Krein

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ABSTRACT

Power electronics are extensively deployed throughout the power system, including in many loads and renewable energy resources. Such widespread deployment represents both a curse and a blessing to the power system design engineer. The curse arises because power electronic loads can regulate energy intake so tightly that negative impedance instabilities and voltage collapse can result. The blessing is due to the ability to control the terminal characteristics at both load and source so as to have desirable attributes and manage local energy storage. In small power systems, such as those of vehicles and naval ships, power electronics constitute the dominant network interface element. In such systems, it is then advantageous to design the controls of the power electronics as well as any other network element to best utilize energy assets and to avoid system collapse. Many techniques to enhance power system stability are documented in the literature. Most deal with either source or load aspects, but to date there has not been a comprehensive control framework for all power system components. Such a framework must deal effectively with the interactions of multiple entities with conflicting interests and may be considered in a game theoretic context. This talk will discuss the representation of the interactions of multiple power system entities using a game theoretic setting in which "players" have to dynamically negotiate to achieve their desired goals. The controls of the individual loads are based on a geometric energy control method with the determination of the manifold based on the desired interaction. The potential research avenues stemming from this work will also be presented.

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Generalized Selective Harmonic Control

Jason Wells with advisor P. L. Chapman

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ABSTRACT

Pulse width modulation (PWM) techniques have been widely researched for more than 40 years. Researchers have identified a variety of switching methods suitable for dc-ac power conversion including voltage source inversion (VSI), natural PWM, uniform PWM, space vector PWM, programmed PWM, selective harmonic control (SHC) and direct modulation. Although much of this work is well established, modulation techniques are still an active area of research with ongoing developments in both theory and implementation. As new techniques are developed and the technology landscape evolves, it is particularly important to evaluate them in the context of established theory and to revisit statements of common wisdom. This work extends the theoretical framework of SHC and considers how these extensions, combined with advances in digital controllers, impact the broader topic of dc-ac inversion.

This work expands the mathematical theory of SHC by relaxing unnecessary constraints on the switching patterns that are implied in the traditional problem formulation. This generalization results in expansion of the solution space from a discrete set to a collection of continuous sets as described later in this document. The work continues by elucidating the nature of the solution space of this expanded problem. Specifically, it will establish why previous claims of techniques to obtain complete solution sets were incorrect in some senses but still useful in solving the generalized problem. If possible, a bound on the number of discrete solution sets will be established through analysis of the resulting system of polynomial equations. Ultimately, the expanded solution space will be analyzed for optimality similarly to previous work based on the traditional formulation.

Additionally, the project will examine two practical issues, acoustic signature and real-time implementation, which arise in the utilization of SHC in power electronic drives. Acoustic performance will be measured across the solution space to determine if there are discernible differences in sound intensity. The project will then examine real-time implementation issues of the expanded SHC problem. Particularly, this more general framework makes evident a connection between SHC and natural PWM methods. An approximation to SHC solutions can thus be obtained in real-time by proposing an appropriate frequency modulated carrier function to perform natural PWM.

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*dq*0 Phasor Calculation

Rodney Yeu with adviser P. W. Sauer
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ABSTRACT

Phasor Measurement Units (PMU) provide voltage and current phasors which are magnitude and angle measurements referenced to a synchronized clock over the whole power system. Measurement of the phase angle can help better analyze the power system such as improving state estimation and providing new method of analyzing stability of the power system. Currently, phasors are calculated by using the sampled voltage and current measurements to calculate the magnitude and phase of the fundamental frequency component of the signal. This process is subject to off nominal frequency error introduced by fixed sampling rate and needs to be compensated for at the output of the PMU.

If the sampled voltage and current measurements are transformed to the *dq*0 coordinates, the phasor value can be calculated without doing the discrete Fourier transformation calculation. The *dq*0 transformation is made on a reference frame that is rotating at a constant frequency of 60 Hz to utilize the fixed sampling rate and the phasor is a function of the transformed variables. The phasor calculation of a 60-Hz signal is straight forward but the phasor calculation of a non-60-Hz signal on a 60-Hz rotating reference frame is shown to have a phase angle error. This study will develop an algorithm to calculate the phasor from the *dq*0 variables that will compensate for this phase angle error.

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Investigation into Simplified Vector Controller of Induction Machines

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ABSTRACT

The project is to investigate the feasibility of a simplified vector controller for induction motors based on torque angle. A constant torque angle scheme is equivalent to constant slip control during the steady state. In such a mode, an induction motor can be operated at maximum efficiency, maximum power factor or maximum torque per ampere mode. Torque angle control is simpler than control of slip because it eliminates the need for exact knowledge of rotor time constant and maps the slip from a wide speed range into a limited angle range of 0 to 90 degrees.

At this stage, theoretical analysis has been carried out and simulation studies have been performed. It is predicted that under constant torque angle control with a proper start up scheme, an induction motor can achieve similar or better steady state performance as field oriented control in senses of efficiency and power factor. The dynamic response could be close to that of other vector control schemes. Constant torque angle needs only rotor resistance as the parameter input to the control system and can be carried out without a speed sensor.

7. LABORATORY FACILITIES

The Power Area has assembled some of the nation's finest facilities for experimental and computer-based research and teaching. Both undergraduate and graduate students can take advantage of these facilities. These laboratories have generated wide interest.

The Grainger Power Engineering Software Laboratory is located near the office areas on the third floor of Everitt Laboratory. The Laboratory has eleven advanced personal computers. All stations are connected to the campus network and Internet.

A major objective of the laboratory is to develop an extensive library of commercial software and large-scale databases for power area applications. Software is based on Windows XP. Some of the commercial software packages currently in use include:

Mathematica (an advanced symbolic mathematics package)
Matlab and Simulink
Mathcad
PSS/E (Power Technologies Inc. Software Package)
RISKSYM (Henwood package for energy market analysis)
PowerWorld
Power System Tool Box (PST Version 2.0)
Dymola (general-purpose simulation environment with hierarchy)
acslXtreme (general-purpose simulation environment)
ANSYS (finite element modeling)
Ansoft Maxwell and RMxprt (finite element modeling specific toelectromagnetics)
The software library is being expanded continually.

The **Grainger Electrical Machinery Laboratory** is located on the ground floor of Everitt Laboratory. This facility is primarily for undergraduate teaching, and is used for ECE 431, ECE 469, many ECE 445 projects, and student projects including the Future Energy Challenge. Ten self-contained machinery workstations are available. Each has an integral horsepower machine set with a servo-based dynamometer. Instrumentation includes digital wattmeters, oscilloscope, speed and torque displays, and other electronic support instruments. The equipment is suitable for the study of induction, synchronous, and dc machines. Small portable machine sets are used to introduce stepper motors and brushless dc machines. Transformers, resistor units, capacitors, SCR circuits, and power FET units are provided to support a full range of experiments in all aspects of power and power electronics. The facility has a dedicated 225 kVA three-phase supply and a 50 kW dc rectifier bank.

The **Advanced Power Applications Laboratory** is adjacent to the Grainger Electrical Machinery Laboratory. This laboratory serves as a general research facility for all hardware aspects of power electronics, machines, and power systems. The laboratory shares motor test sets with the Machinery Lab, with an additional precision dynamometer for more advanced studies. Additional equipment is available for the study of harmonic effects, high-performance switching converters, and digitally-controlled converters and drives. Computers are available throughout the laboratory for automation of experiments using LabView, Matlab, and other software environments. The Simulink Real-Time Toolbox is an important component. Additional laboratory space is available on the third floor of Everitt for low-power experiments.

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