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EIGHTEENTH ANNUAL REPORT OF THE POWER AFFILIATES PROGRAM

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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 for the calendar year 1996. 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. There are fourteen active affiliates associated with the PAP. They are:

Amoco Oil Company

Burns & McDonnell

Central Illinois Light Company

Central Illinois Public Service Company

Cinergy Corp.

Commonwealth Edison Company

Electrical Manufacturing & Coil Winding Association, Inc.

Illinois Power Company

MidAmerican Energy

S&C Electric Company

Sargent & Lundy

City Water, Light & Power, Springfield, IL

Union Electric Company

Wisconsin Power & Light Company

1996 was an active year for the PAP and the highlights are covered in this report. We acknowledge the valuable support of the Affiliates and are most thankful to these companies for their continued support.

George Gross
Stan Helm
Phil Krein
Tom Overbye
M. A. Pai
Pete Sauer
Bob Turnbull

1. INTRODUCTION AND SUMMARY

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

- bring focus to the power and energy systems area;
- provide financial assistance to students studying electric power engineering;
- increase university-industrial interaction at all levels of education and research in electric power engineering.

The program is described in considerable detail in Reference [1].

Throughout the past eighteen years, the Power Affiliates Program has maintained a stable base during times of rapid change. 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 crucial source of support.

This annual report is organized as follows. A financial statement for the calendar year 1996 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 specialization in this area by a group of faculty members and courses. Section 4 gives a brief description of the courses specializing in electric power and the latest enrollment figures. Included in this section is a historical record of the number of graduates who have taken three or more of these courses. The record shows that student interest has been maintained and even broadened in recent years. Section 5 lists the activities of both the students and faculty members during the 1996 calendar year. Section 6 provides a brief summary of research projects that are funded by other sources. Section 7 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/her research work. Since 1987, the power faculty members have focused on enhancing the laboratory aspects of the curriculum and research efforts. The Grainger Foundation has funded three major laboratories ranging from electric machinery to power engineering software. These facilities are discussed in Section 8.

2. FINANCIAL STATEMENT

The following tabulation of income and expenditures for the calendar year 1996 was prepared from a detailed University statement as of December 31, 1996, Reference [2].

Income carried over from the calendar year 1995	$ 6,262
Total income during calendar year 1996	$75,500
Total available income during calendar year 1996	$81,762

Expenditure Category	Expenditure Amount
Personnel and Services	$46,605
Materials/Supplies/Equipment	$ 9,738
Transportation	$ 8,610
Total	$64,953

Summary

Amount available during calendar year 1996	$81,762
Amount expended during calendar year 1996	-$64,953
Balance as of December 31, 1996	$16,809

3. THE POWER PROGRAM WITHIN THE DEPARTMENT

Electrical engineering 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 Reference [3]. All M.S.E.E. students are required to complete a minimum of 8 units (32 credit hours) and complete 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 Reference [4].

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

Bioengineering and Acoustics

Circuits and Signal Processing

Communication and Control

Computational Science and Engineering

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 eight 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 12% 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 1996 - 1997 academic year together with their general interests are:

G. Gross	(power system economics, planning and operations; electric regulatory policy; industry restructuring; competitive market mechanisms)
M. S. Helm, Emeritus	(power system analysis)
P. T. Krein	(power electronics, machines, electrostatics)
T. J. Overbye	(dynamics, stability and operations 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)
R. J. Turnbull	(energy and conversion technology, sensors)

A detailed summary of each faculty member's research activities is given in Reference [5].

Two of the primary responsibilities of the Power and Energy Systems Area Committee are to update and staff the courses assigned to the Power and Energy Systems Area. In 1996-1997 those courses were:

ECE270	Introduction to Circuit Analysis (Joint responsibility)
ECE330	Electromechanics
ECE333	Electric Machinery
ECE336	Advanced Electromechanical Energy Conversion
ECE364	Power Electronics
ECE369	Power Electronics Laboratory
ECE371GG	Techniques for Engineering Decisions
ECE371SUN	Solar Powered Vehicle
ECE376	Power System Analysis I
ECE378	Power System Analysis II
ECE452	Computer Methods in Electric Network Analysis (Joint responsibility)
ECE468	Modeling and Control of Electromechanical Systems
ECE473	Operation and Control of Power Systems
ECE476	Dynamics and Stability of Power Systems
ECE490	Power and Energy Systems Area Seminar
ECE497GG	Electric Resources Planning

The three-hundred level courses are advanced undergraduate or beginning graduate courses, while the four-hundred level courses are graduate. Of these courses, ECE336, ECE468, and ECE497GG were not taught during the 1996-1997 academic year. The Power and Energy Systems Area Committee continuously evaluates each course outline for possible revision in future semesters. A brief description of each of these courses, together with the enrollment of the past year, are included in the next section. In addition, Power Area faculty are active in ECE345, Design Projects. This is the capstone design course for our seniors.

4. COURSES AND ENROLLMENT

As one of eight major areas in Electrical and Computer Engineering, the Power and Energy Systems Area is responsible for a considerable number of courses. The current courses assigned to the power area are described briefly below. The total annual enrollment for the 1996-1997 academic year is also given for each course.

ECE270 Introduction to Circuit Analysis (Primary responsibility for this course is assigned to the circuits and signal processing area committee.)

ECE270 is the first course that all electrical engineering students must take after their math, physics and computer science requirements are completed. The course introduces elementary signal waveforms, electrical component models, and basic principles of circuit analysis including d-c, transient and sinusoidal steady-state analyses. The topical outline includes resistance, inductance, capacitance and source elements, Kirchhoff's laws, node and mesh equations, matrix methods, Thevenin and Norton equivalents, controlled sources, operational amplifiers, transient switching d-c analysis, impedance and transfer functions for steady state, frequency response, Bode plots, filters, mutual inductance, transformers and basic three-phase circuits. The recommended text was Electric Circuits, 5th edition by J. W. Nilsson. The total enrollment for academic year 1996-1997 was 361.

ECE330 Electromechanics

ECE330 is an introductory course in electromechanics, presenting both the electric and magnetic quasi-static fields for analysis of energy conversion devices. The origin of forces and torques, together with the full mechanical dynamics of Newton's Second Law (NSL), are discussed. The concepts of flux linkage, energy, co-energy and the resulting induced voltages are presented for their inclusion in Kirchhoff's Voltage Law (KVL). Conservation of power and energy is emphasized in energy balance analysis. An introduction to rotating machines is included with illustrative examples. Particular emphasis is given to the interaction between the electrical system (KVL) and the mechanical system (NSL). Notes by M. A. Pai were available for the course. The total enrollment for the academic year 1996-1997 was 129.

ECE333 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 Basic Electric Machines by Del Toro. The total enrollment for the academic year 1996-1997 was 29.

ECE336 Advanced Electromechanical Energy Conversion

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. Class notes are used. The course was not offered during the academic year 1996-1997.

ECE364 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 recommended text was Principles of Power Electronics by Kassakian, Schlecht and Verghese. The enrollment for academic year 1996-1997 was 54. The course has been produced on videotape.

ECE369 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 ECE364. A lab manual by P. Krein is available for the course. The total enrollment for the academic year 1996-1997 was 21.

ECE371GG Techniques for Engineering Decisions

This course is aimed at providing the skills and techniques for solving some typical problems faced in making engineering decisions in industry and government. The focus is on analytic schemes and systematic methodologies for making decisions with explicit consideration of the economic aspects. The course topics include time value of money, selection of alternatives, scheduling and inventory analysis and decision making under uncertainty. Several test cases will be covered. The required texts were: Modern Engineering Economy, 1993 edition, by D. Young and Operations Research, Principles and Practice, 1992 edition, by A. Ravindran, D. Phillips, and S. Solberg. The total enrollment for the academic year 1996-1997 was 26.

ECE371SUN/ME393 DRW Advanced Electric Vehicles (Solar Powered Vehicle)

During 1994, a new project to initiate the design of a solar-powered vehicle was the focus of the course. This is a project oriented course which involves the design and construction of a solar power car. On the electrical side there is an array of solar cells, d-c to d-c connected to charge batteries, and an electrical drive system including an induction motor. The course enrollment during the 1996-1997 academic year was 131.

ECE376 Power System Analysis I

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 in the academic year 1996-1997 was Power System Analysis and Design by Glover and Sarma. The enrollment was 24.

ECE378 Power System Analysis II

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 required text was Power Generation, Operation and Control, 2nd edition, by Wood and Wollenberg. The enrollment was 7 in the 1996-1997 academic year.

Graduate Courses:

ECE452 Computer Methods in Electric Circuit Analysis (Primary responsibility for this course is assigned to the circuits and signal processing area committee.)

ECE452 is a graduate course designed for both electric power and electronic students. The course presents the fundamental computer algorithms utilized to analyze scale circuits. Applications in both electronic circuit design and power system analysis are given. The following topics are presented: Network topology and circuit equations, branch constraints and problem formulation, solution of sparse linear algebraic equations, solution of nonlinear algebraic equations, power and electronic system applications, solution of piecewise linear algebraic equations, explicit and implicit numerical integration methods, transient analysis of power and electronic circuits, sensitivity analysis and decomposition. No text was required, classnotes were used. The total enrollment for the academic year 1996-1997 was 32.

ECE468 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. Internal notes by P. Krein are available for the course. The course was not taught during the 1996-1997 academic year. The course has been produced on video tape.

ECE473 Operation and Control of Power Systems

The course includes energy control center functions, power system operating states, supervisory control and data acquisition, state estimation, on-line load flow, security assessment, economic dispatch, automatic generation control, optimal power flow, security constrained economic dispatch, multistage rescheduling and equivalents. The course enrollment during the 1996-1997 academic year was 8.

ECE476 Dynamics and Stability of Power Systems

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 current course text is a set of notes prepared by P. W. Sauer and M. A. Pai. This course is available on video tape. The course enrollment during 1996-1997 was 7.

ECE490 Power and Energy Systems Area Seminar

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. The enrollment for 1996-1997 was 24.

ECE497GG Electric Resources Planning

This course provides coverage of the basic techniques in electric utility 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 course was not offered during the 1996-1997 academic year.

NUMBER OF ELECTRIC POWER AND ENERGY SYSTEM AREA GRADUATES FOR 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

1995-1996 Power Area Graduates

B.S.E.E. - 45
M.S.E.E. - 8
Ph.D. - 1

1996-1997 Power Area Graduates

B.S.E.E. - 43
M.S.E.E. - 9
Ph.D. - 2

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 1996. The major events are listed below:

- IEEE Power Engineering Society 1996 Winter Meeting
  - Tom Overbye presented a paper on Voltage Collapse and attended committee meetings.
  - Pete Sauer chaired the working group on Dynamic Security Assessment.
  - George Gross chaired the newly established Power System Analysis, Computing and Economics Committee meeting.
  - Stan Helm participated in committee meetings.
- IEEE Applied Power Electronics Conference
  - Phil Krein attended committee meeting.
- ECE333 and ECE378 student class trip to the Illinois Power Dispatch Center and Havanna Generating Station.
- Engineering Open House
  - ECE333 students presented machinery demonstrations.
  - George Gross acted as a Judge of the Engineering Open House activities/displays.
- American Power Conference
  - Stan Helm coordinated the UI participation in the sponsored student, sponsored faculty program.
  - Seven students and faculty sponsored by Central Illinois Public Service Co., Commonwealth Edison Co., Soyland Power Coop., Sargent & Lundy, Wisconsin Power and Light.
  - George Gross, Stan Helm and Pete Sauer attended.
  - George Gross chaired a session at the American Power Conference.
- 1996 University of Illinois Undergraduate Research Symposium
  - Andrew Dalton and Eugene Khutoryansky presented research summaries.
- IEEE Power Electronic Specialists Conference
  - Phil Krein chaired the Publications Committee, and served on the Power Electronics Society Ad Com.
  - Phil Krein presented a paper on the solar power processing technology.
  - Phil Krein was a panelist for a Rap Session on Education.

- IEEE Power Engineering Society 1996 Summer Meeting

  - Pete Sauer chaired the working group on Dynamic Security Assessment.
  - George Gross chaired the meeting and attended the PICA Board session.
  - George Gross chaired the Power System Analysis, Computing and Economics Committee meeting.
  - Stan Helm attended committee meetings.
  - Tom Overbye attended committee meetings and made a panel presentation.

- IEEE Workshop on Computers in Power Electronics

  - Luis Amaya presented a paper on his synthesis research.
  - Phil Krein was a panelist in the Benchmarks Panel Session.

- North American Power Symposium (NAPS)

  - Pete Sauer presented a paper on behalf of Stephen Fernandes on model data.
  - Ray Klump presented a paper on power system voltage stability.
  - M. A. Pai presented a paper on behalf of Ajit Kulkarni on dynamic simulation.

- IEEE Industry Applications Society Annual Meeting

  - Bob Turnbull became Chair of the Electrostatic Processes Committee.
  - Bob Turnbull participated in committee meetings.

- 1996 Electrical Manufacturers and Coil Winding Association and Conference Exposition

  - Pete Sauer and 10 undergrads participated. Two students presented papers.

- Wheeling and Dealing: Opportunities and Challenges in the *New* Electricity Industry Conference, Chicago, IL (April 25-26, 1996)

  - George Gross was the co-organizer of this national conference on regulatory issues in electricity.

- Power Systems Computation Conference (PSCC), Dresden, Germany (August 20-24)

  - Tom Overbye, George Gross and M. A. Pai presented papers.
  - George Gross chaired a session of the Conference.

- Hosted the following guest speakers:

  - Mark A. Harris, Naval Air Warfare Center, "The ONR PEBB Program Outline"
  - Ian Hiskens, University of Newcastle, Australia, "Energy Function Analysis of Systems With Dynamic Loads"
  - George V. Fantozzi, S&C Electric Company, "Selecting a Capacitor-Switching Overvoltage Control Method Effective in Preventing Nuisance Tripping of Adjustable-Speed Drives"

- John Endrenyi, Ontario Hydro Technology and the University of Toronto, "Reliability Models for Repairable Equipment With Preventive Maintenance"
- Wes Davis, Rockwell Automation/Allen Bradley, "Methods for Active Harmonic Cancellation in Power Systems"
- Alexandre Sanfelice Bazanella, Brazil, "Improving the Stability of Synchronous Machines With Nonlinear Control of Field Voltage (Concepts and Control Methods and Application and a Case Study)"
- A. Kuppurajulu, Indian Institute of Technology, "Closed Loop Reactive Power Rescheduling"
- Juan Perez-Ruiz, University of Malaga, Malaga, Spain, "Representation of Dispatch Constraints In Production Cost Models"
- Ljubomir Kojovic, Cooper Industries, "Simulation of Power Laboratory Tests and Electrical Apparatus Operations"
- Thomas Kay, Commonwealth Edison, "The Impacts of Industry Restructuring and Open Access On Power System Security"
- Sebastian Rios, Catholic University of Chile, "A Conceptual Framework of Quality of Electricity Service"
- Peter A. Frantz, Commonwealth Edison Company, "Power Marketing and Energy Trading"
- Jack Berlier, Indianapolis Power & Light Company, "A Pricing Model for Efficient Competition In Electric Power"
- James R. Collins, Illinois Power Company, "The Midwest Independent System Operator"
- James Evans, Detroit Edison Company, "Power System Monitoring and Control In the Advancing Utility Environment"

- Participated in multi-university seminar exchange over the internet for the following seminars:

  - Peter W. Sauer, University of Illinois, "Phasor Representations of Power System Transients"
  - Christopher L. DeMarco, University of Wisconsin-Madison, "The Potential for Malicious Control In A Competitive Power Systems Environment"
  - Robert J. Thomas, Cornell University, "PowerWeb" An Interactive Internet Game for Competitive Power System Operation
  - Steve Rovnyak, Cornell University, "Pattern Recognition for Real-Time Transient Stability Prediction and Control"
  - Pravin Varaiya, University of California at Berkeley, "Coordinated Multilateral Trades"
  - Hsiao-Dong Chiang, Cornell University, "BCU Classifiers for On-Line Dynamic Security Assessments of Large-Scale Power Systems"

- Presented the following seminars by UIUC faculty/students:

  - Ray Klump, "Assessment of Transmission System Capacity"
  - Philip Krein, "Introduction To Resonant Power Conversion"
  - Mark Laufenberg, "An Introduction to FACTS Controllers in Power Systems"
  - Eugene Khutoryansky, "Transformer Thermal Ratings"
  - Jamie Weber, "Implementation of an Optimal Power Flow Into A Power System Simulation Environment"
  - Peter Sauer, "Real-Time Control of Oscillations In Electric Power Systems"

- Shu Tao, "Development of a General Framework for Incorporating Demand-Side Bidding Into Competitive Electricity Markets"
- Cesar Pascual, "Switched Capacitor System for Automatic Series Battery Equalization"
- Yong Tian, "OASISNET: An Oasis Network Simulator"
- Matt Greuel, "Boundary Control Design Techniques for DC-DC Converters"

- Organized the 1996 Grainger Lecture Series on Power System Reliability

  - Invited a series of four lectures by Dr. John Endrenyi, Ontario Hydro Technology and the University of Toronto

- Energy Management Systems Short Course

  - George Gross directed this short course for training of ComEd technical personnel.

- Strategic and Planning Issues in Competitive Electricity Markets

  - George Gross directed and participated as part of the faculty for this short course given in Bergano, Italy in June 1996.

- Engineering Strategies for Open Access Transmission Short Course

  - George Gross organized and participated as part of this faculty for this new and timely short course given in San Francisco in December 1996.

- Edison Electric Institute Power System Planning and Operations School, Portland (September 4-8, 1996)

  - G. Gross is the director of this annual School administered with the support of the Office of Continuing Engineering Education at UIUC.
  - G. Gross is part of the faculty of the School.
  - Tom Overbye gave a presentation on the basics of power system operations.

- M. A. Pai is on the Editorial Board of *'Sadhana'* Journal of Engineering Sciences of the Indian Academy of Sciences, Bangalore, India.

- Profs. K. R. Padiyar and D. P. Sen Gupta visited the University of Illinois for three weeks under the Indo-US NSF cooperative science program. They gave lectures on subsynchronous resonance and power system stabilizers.

- R. J. Turnbull is the chairman of the Electrostatic Processes Committee of the IEEE Industry Applications Society.

- P. T. Krein presented a seminar on single-chip power conversion systems to Collins Division of Rockwell International.

- The solar power car was taken to a number of industries and meetings. Talks were given by the participating students.

- P. T. Krein presented a seminar on low-voltage dc systems to Intel Corporation.

- Tom Overbye gave a presentation on the basics of power system operation to the Oklahoma Corporation Commission.

- M. A. Pai visited the Indian Institute of Science, Bangalore, India, under the joint Indo-US Program sponsored by the National Science Foundation. He gave a seminar at IISc. He also visited the Central Power Research Institute.

- G. Gross and T. Overbye were invited lecturers at the Workshop on Modeling in Competitive Markets, California Energy Commission (May 1996).

- G. Gross was an invited lecturer in the "Revolution in the Electric Power Industry," series at the Carnegie Mellon University, Pittsburgh, PA, (February 1996).

6. RESEARCH FUNDED BY OTHER SOURCES

The Power Affiliates Program is a source of seed money which enables the faculty to obtain support from major funding agencies. The following pages summarize the projects which have been made possible through this growth.

Determination of Transmission Transfer Capability (ATC)

G. Gross

Grainger Foundation; Power Affiliates Program

In a restructured environment, electric utility consumers will eventually choose providers of electrical energy. Hence, there will be greater use of the system for transmission between various players and much higher level of power flowing through the power grid. This, in turn, will bring about the need to quantify the amount of transmission service that a network can provide. Our research aims to develop a consistent definition of transmission transfer capability and a general set of procedures for its evaluation. We will investigate the information requirements and the computational aspects and will study the use of a real-time information network as a medium for sharing the necessary information among various parties involved in the transmission of electricity. One particular area of focus is the quick updating of ATC values. By using a security-constrained optimal power flow formulation for ATC determination, a very large-scale nonlinear optimization problem results. By exploiting the structural characteristics of this formulation, we are investigating analytical approaches to determine fast update schemes of the ATC values.

Evaluation of the Automated Interchange Matching System (AIMS)

G. Gross, N. Mwase

Grainger Foundation; Power Affiliates Program

AIMS is a computerized hourly interchange matching system whose goal is to promote the maximum economic savings among all the participating players. This is accomplished by matching of bids to sell and offers to buy so that the sum of the savings for all the participants is maximized. We are evaluating the matching scheme from the point of view of the system, a buyer, and a seller. Our interest is to study the strategic behavior of players in formulating their bids to sell and offers to buy. We are investigating the truth revelation characteristics of the bids/offers, the role of transmission availability and the overall impact on system operations.

Multiarea Power System Production Costing

G. Gross

Grainger Foundation; Power Affiliates Program

The most challenging aspects of multiarea studies is to model realistically the loads and resources in each area and to construct computationally efficient schemes for their simulation. Typical applications are to interchange contract evaluation, geographically differentiated marginal costing studies, transmission service pricing, and strategic and resource planning. The multiarea production cost simulation model must correctly take into account the impacts of transmission constraints as well as interconnection operating policies. Our objective is to build a general model to simulate the operation of multiarea power systems under various operational policies, ranging from totally centralized dispatch to decentralized bidding dispatch.

Optimal Bidding Strategies in Competitive Electricity Markets

G. Gross, Shu Tao

Grainger Foundation; Power Affiliates Program

We have developed a general framework for the analysis of competitive electricity markets modeled after the so-called Poolco concept. Under the assumption of perfect competition, we formulated optimal bidding strategies for supply-side bidders. We are extending this framework to include the consideration of demand-side bidding in electricity markets. We are also investigating the incorporation of transmission constraints. One possible approach to this is the combination of Unit Commitment (UC) and Optimal Power Flow (OPF). The other topic of research work about the electricity market is the incorporation of financial contracts into the strategies of bidders.

Simulation of the Multinode, Open Access, Same-Time Information System

G. Gross, Y. Tian

Grainger Foundation, Power Affiliates Program

A Web-based simulator of the Federal Energy Regulatory Commission mandated Open Access Same-Time Information System (OASIS) network is being implemented. The purpose of the simulator is to provide a tool to study the various aspects of an OASIS network, to gain a strong intuitive feel for its operations, and to train users. For a specified time period, the OASISNET simulator reproduces an OASIS network of multiple nodes using the same communications medium as the actual system, the Internet, and with multiple players using the simulator simultaneously. Salient features of the simulator are its modular architecture, the ability to

simulate multinode OASIS network operations, and to accept simultaneous access from remote users through use of client/server technology. The simulation focuses on the dissemination and use of the available transmission capability information. Sample applications of the new simulator are investigated.

Structure Paradigms for Power System Restructuring

G. Gross

Grainger Foundation; Power Affiliates Programs

The entrenchment of competition, the drive for unbundling of services and products, and the new regulatory decisions are resulting in the development of new structures for power systems. A key consideration in the formulation of new structures is the need to have minimum requirements for coordination to ensure the integrity, reliability, and security of the system. This investigation is focusing on the economic efficiency, engineering/technical considerations/constraints, and critical informational aspects of various structural paradigms.

Computer-aided Design for Power Electronics

P. T. Krein, F. Najm, L. Amaya

Semiconductor Research Corp.; Power Affiliates Program

Power supplies and other electronic circuits for energy processing are usually designed on a case-by-case basis. In this project, a general framework leading to a step-by-step design process, suitable for automation, is being developed. A user would provide specifications, then select from alternatives presented by this CAD system. The system would establish a baseline design, then perform an optimization procedure to refine it and meet the user's specifications. The heart of this CAD system is a component selection algorithm that takes an alternative circuit and establishes component values needed to establish the baseline design.

Geometric Approaches for Control of Switching Power Converters

P. T. Krein, J. Kimball, R. Muyshondt, M. Greuel

Power Affiliates Program; Sandia National Laboratory

Power conversion circuits are large-signal nonlinear networks controlled exclusively through the action of switches. Several new approaches are being developed for power converter control. One approach expands on geometric methods, such as sliding mode control, used successfully in other nonlinear applications. In this boundary control approach, geometric structures in state space are used to control the evolution of converter voltages and currents. Methods such as boundary control offer precise, reliable converter operation with minimum influence by

unknown parameters and external noise.

Hybrid Electric Vehicle Systems

P. T. Krein, R. A. White (Mech. & Indus. Engr.), S. Splater, C. Hidrovo, D. Logue

National Renewable Energy Laboratory; Xantrex Technology, Inc.

(In conjunction with the Department of Mechanical and Industrial Engineering)

A complete hybrid electric car, combining an electric traction system with an engine-generator set, has been built and is now under study in the laboratory and on the highway. The car is designed to meet all performance, safety, and convenience characteristics of standard automobiles, while reducing exhaust emissions by as much as 90%. Objectives are to characterize major subsystems of a practical hybrid car in depth. Tests of efficiency, fuel economy, and emissions are being conducted. Parametric studies of subsystems are in progress. The data and information will assist industrial firms in the evaluation, design, and development of hybrid vehicle technology.

Low-Voltage Power Supplies – Operation and Control

P. T. Krein, L. Amaya, J. Kimball, M. Greuel

Power Affiliates Program

Modern microprocessors and both analog and digital circuits are being designed for lower voltages to support high densities and fast operation. This project considers solutions for power supplies operating in the range of 1 V to 3 V. Synchronous rectifiers and related techniques are being developed for this operating range. Control methods to minimize power loss and provide robust operation have been identified. A complete integrated circuit power converter for this range has been designed and fabricated in the MOSIS process. This converter will help support extensive experimental work.

Nonlinear Methods for Induction Motor Control

P. T. Krein, J. Locker, H. Maase

Grainger Fellowship; U.S. Army Construction Engineering Research Laboratories, DACA88-97-G001/DO 125

Field orientation is a widely used control method for ac induction motors. Recent results in nonlinear control theory, including feedback linearization and integrator backstepping, offer possible alternatives for ac servo systems. Observer techniques allow high performance without expensive sensors. This project examines the operating performance of new motor control alternatives. Methods are studied analytically, through detailed simulation, and experimentally.

A digital signal processing motor drive system has been designed and built for tests.

Parallel Inverters

P. Krein, L. Pairitz

Danfoss, Inc.

Pulse-width-modulated inverters are experiencing growing applications for control of ac motors. Modern systems support motors at power levels up to about 100 kW, although the cost increases rapidly above 20 kW or so. An alternative at high power levels is to use several inverters in parallel. To make such an arrangement reliable, tight coordination of individual inverters is necessary. The project is studying coordination techniques. Both device-level and system-level approaches are being examined through analysis, simulation, and experimental tests.

Simulation Methods for Power Electronics Analysis

P. T. Krein, D. Beck

Teltrend, Inc.

Comparisons are being made among various simulation approaches for switching power conversion systems. The switching nonlinearities of these systems are well suited to piecewise simulation approaches, but less well suited to conventional methods. The project compares SPICE-based circuit simulators and mathematical simulation methods such as MATLAB. The objective is to learn the considerations needed when preparing a simulation tool suitable for power electronics modeling and analysis.

Switched Capacitor System for Automatic Series Battery Equalization

P. T. Krein, C. Pascual

La Caixa de Pensions Fellowship

Rechargeable batteries are used in long series strings for many industrial applications. The recharge process is not uniform, and the weakest battery in the string limits the performance of the set. An equalization process is required to restore battery balance. In this project, a clocked switched-capacitor circuit has been developed to exchange charge between adjacent batteries in a series string. This exchange drives all batteries to identical voltages, without regard to component values, battery technology, or state of charge. This equalization process can proceed while the batteries are in use or under charge, or separately.

Analysis Methods for Real-Time Control of Dynamically Insecure Power Systems

T. J. Overbye, R. P. Klump

National Science Foundation, ECS 95-26146

As power systems become more heavily loaded, system operation will be increasingly constrained by contingent cases for which the power flow equations have no real solution. The goals of this project are to develop a measure to quantify the unsolvability of such cases and to determine the optimal controls to restore the case to solvability. A Euclidean norm is used in parameter space to measure the degree of unsolvability. The sensitivity of this measure to different system controls is then used to determine the best controls to restore the case to solvability. Both the static and dynamics aspects of the problem are considered.

Simulation Tools for Analysis of Alternative Paradigms for the New Electricity Business

T. J. Overbye, G. Gross, P. W. Sauer, J. Weber

Power Affiliates Program, American Public Power Assn.

In the restructuring of the electric power industry, a number of alternative paradigms for the future industry structure are under consideration. We are developing a modular simulation/visualization tool to effectively analyze and evaluate the effects these proposed paradigms will have on power system operations. Key research goals include methods to assess transmission system capacity, pricing of transmission capacity, and development of criteria for an equitable and consistent comparison alternative paradigm.

Dynamic Sensitivity Functions for Security Analysis In Power Systems

M. A. Pai, M. Laufenberg

National Science Foundation, ECS 95-22547; Grainger Foundation

In this research, we compute trajectory sensitivities of the post-fault system with respect to prefault loading conditions and for a given set of contingencies. From this we compute whether the system is stressed and, if so, identify the critical machines. Thus we develop an alternative to the transient energy function (TEF) method. Results on a 17-machine IEEE test system as well as systems described by differential-algebraic equations have been obtained. In view of the fast computing power available these days, sensitivity theory offers an alternative to existing techniques for security assessment and preventive control.

Hopf Bifurcation Analysis with FACTS Devices

M. A. Pai, M. Laufenberg

National Science Foundation, ECS95-22547; Grainger Foundation

In this research, we expand upon the MATLAB-based small-signal analysis formulation developed at the University of Illinois to include FACTS devices such as the Static Var Compensator (SVC) and Thyristor Controlled Series Capacitor (TCSC). In particular, we will focus on controlling Hopf bifurcation through proper placement of these devices. Auxiliary controllers are used when necessary to improve system damping.

Iterative Solvers for Fast Power System Simulation

M. A. Pai, P. W. Sauer, I. Hossain

National Science Foundation ECS 95-22547

Physically based preconditioners will be developed for fast nonlinear simulation of power systems using the general minimal residual (GMRES) iterative solver technique. It will be compared with the LU factorization method. Both will be developed on the MATLAB platform and integrated with the existing small-signal stability program and the transient energy function program. Ultimately, the idea is to develop a power system dynamics toolbox useful for R&D of small to medium sized systems.

Parallel Processing in Dynamic Simulation of Large-Scale Power Systems

M. A. Pai, A. Kulkarni

National Science Foundation, ECS 91-19428; Grainger Foundation

Parallel processing algorithms for dynamic response calculations of large power systems have been developed. The differential-algebraic system of equations of the power system are algebraized using the simultaneous-implicit method. The resulting system of linear equations at each time step are solved using the conjugate gradient method which belongs to the family of iterative solver techniques. Use of preconditioners such as the ILU(s) speeds up the convergence. Further enhancement in speed-up is obtained by using the preconditioner only when the number of iterations increase. The general minimal residual (GMRES) method suitable for matrices that are unsymmetric and not positive definite was found to be more robust than other iterative solver algorithms.

Robust Stability in Power Systems

M. A. Pai, C. D. Vournas (National Technical University, Greece)

National Science Foundation, ECS 93-19352

We used interval matrix theory to see if the linearized model of a power system is Hurwitz stable with respect to variations of the elements of the matrix in a given interval. The initial application has been with respect to Power System Stabilizer (PSS) parameter variation, which can be expressed in a matrix polytope form. Using interval matrix theory, we can plot the stability region in the parameter space with respect to uncertainties in the parameters. Multimachine application is now being done with loads being taken as perturbations.

Robust Stability of Power Systems Using Kharitonov's Theorem

M. A. Pai, E. Khutoryansky

National Science Foundation, ECS 93-19352

There is rich literature in control theory regarding Kharitonov's theorem and its extensions for robust stability. We plan to use it for power systems where load variations are considered as uncertainties. In particular we will focus on matrix equivalents of Kharitonov's theorem where parameters appear explicitly.

Small Signal Stability of Electric Power Systems

M. A. Pai, D. P. Sen Gupta and K. R. Padiyar, Indian Institute of Science, Bangalore, India

National Science Foundation, INT-93-02565

The purpose of this project under the Indo-U.S. Science Cooperative Program is to collaborate in the area of small signal analysis of large-scale power systems. Specifically, the topics to be addressed are the design of power system stabilizers, investigation of torsional oscillations, and computation of selected eigenvalues of the system. The goal of the project is to produce a research monograph in this area useful to the power engineering community. A preliminary set of lecture notes has been developed. Also some collaborative research work in the area of Flexible AC Transmission System (FACTS) controllers for system damping is being pursued.

Two Time-Scale Simulation of Power Systems

M. A. Pai, E. Khutoryansky

National Science Foundation, ECS 91-19428 (REU)

We used the asymptotic expansion theory for the "inner" and "outer" solutions of a singularly perturbed two time-scale system to systematically integrate the fast and slow subsystems in their respective time scales thus removing the "stiffness" of the original system. This is an alternative

to using the integral manifold theory. The two approaches are compared in terms of their computational speed and convenience for simulation using the example of a synchronous machine subjected to a disturbance.

Available Transfer Capability of Power Systems

P. W. Sauer, T. J. Overbye, M. A. Pai, G. Gross

National Science Foundation, EEC 96-15792

This project examines new approaches to the rapid computation of available transfer capability in electric power systems. It focuses on efficient techniques to simultaneously include thermal, voltage, voltage collapse, and transient stability margin constraints. New approaches to quantify the transmission reliability margin and capacity benefit margin are investigated.

Calibration of Data for Real-Time Control of Power Systems

P. W. Sauer, S. Fernandes

U. S. Department of Energy, 15X-ST131C

This project is investigating the importance of data accuracy in the real-time control of power systems. Sensitivities of static and dynamic response calculations to input data are being examined and related to results such as security margins, transfer capability, stability limits, and economic dispatch.

Control of Oscillations in Power Systems

P. W. Sauer, S. Fernandes

Empire State Electric Energy Research Corp.

This project is examining methods to eliminate sustained oscillations when they appear in power systems. An eigenvalue sensitivity approach is being tested to determine the effectiveness of operator controls which may eliminate oscillations. Effectiveness of discrete control actions, such as disabling a voltage regulator, is also being investigated.

Delivery of Electrical Energy to Railroad Freight Cars

R. J. Turnbull

Association of American Railroads

For improved braking and to detect problems, it is desirable that each car in a freight train have available a source of electrical energy. The goal of this project is to determine all the possible ways this energy can be supplied and to evaluate them. More detailed studies of the most promising schemes will be conducted.

Solar Electric Vehicle

R. A. White, P. T. Krein, R. J. Turnbull, A. Rockett, N. Kashhari, J. Locker, L. Bogusch, E. Weldy

University of Illinois; U.S. Department of Energy; various industrial sponsors

(In conjunction with the Department of Mechanical and Industrial Engineering)

A solar electrical car is being designed and constructed by students to compete in a cross-country solar car race (SunRayce 1997) held in June 1997. Mechanical engineering considerations include the minimization of drag coefficient, rolling resistance, and weight. Electrical engineering considerations include optimizing the amount of power transferred from a solar array to storage batteries and maximizing the efficiency of the drive motor and the inverter that supplies its energy. All this must be done while producing an operating vehicle that conforms to the rules of the competition. This project involves approximately 100 students.

7. 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:

Beatty, Shekita (M.S.)
Fernandes, Stephen (Ph.D.)
Greuel, Matt (M.S.)
Haidacher, Steffen (M.S.)
Hossain, Izzat (M.S.)
Khutoryansky, Eugene (M.S.)
Kimball, Jonathan (M.S.)
Klump, Ray (Ph.D.)
Kulkarni, Ajit (Ph.D.)
Laufenberg, Mark (Ph.D.)
Locker, Jonathan (Ph.D.)
Logue, Dan (M.S.)
Maase, Hannon (Ph.D.)
Muyshondt, Richard (Ph.D.)
Mwase, Naomi (M.S.)
Pascual, Cesar (M.S.)
Reppa, Robert (M.S.)
Splater, Scott (M.S.)
Tao, Shu (Ph.D.)
Tian, Yong (M.S.)
Tombuloglu, Burak (M.S.)
Troitskaia, Svetlana (M.S.)
Weber, Jamie (M.S.)

Shekita Beatty

Date of Birth: August 1, 1974

Place of Birth: Whiteville, NC

B.S.: December 1996, North Carolina A&T State University

M.S.: In progress

Professional Interests: Power Electronics, Power Systems Control

REAL-TIME OPTIMIZATION OF INDUCTION MOTOR OPERATING EFFICIENCY

Shekita Beatty with advisor R. Turnbull

Supported by Xantrex and the National Consortium for Graduate Degrees for Minorities in Engineering and Science, Inc.

ABSTRACT

Under normal operating conditions, induction motors perform at levels below their optimum efficiency. A control loop that includes a power electronics circuit drive and the induction motor can be developed to reduce power losses in the motor. By measuring the instantaneous power and voltage/frequency characteristics of the motor, a converter can be used to internally adjust the optimum voltage/frequency ratio. This ratio is defined as the ratio that uses minimum power for desired torques and speeds. The control loop will allow the converter to continuously monitor and adjust the motor's characteristics around an optimal operating point. Research will include theory, design, and implementation of the control technique mentioned above.

Stephen Fernandes

Date of Birth:	September 3, 1967
Place of Birth:	Rourkela, India
B.S.:	May 1989, Institute of Technology Varanasi, India
M.S.:	July 1992, Oregon State University

Real-Time Control of Oscillations of Electric Power Systems

Stephen Fernandes with advisor P. W. Sauer

Supported by Empire State Electric Energy Research Corp. (ESEERCO)

ABSTRACT

This project investigated methods to provide operator assistance to suppress sustained system oscillations and to monitor the closeness of the system to the onset of oscillations. The proposed methods for suppressing system oscillations were based on eigenvalue sensitivity techniques that can provide a ranking of various control options. A control's position in the ranking is based on its potential effectiveness in suppressing the oscillations. Initial results show that very complex eigenvalue behavior can occur as parameters are changed. Stephen Fernandes has recently withdrawn from the University. Work on this project will continue with a different student at a later date.

Matt Greuel

Date of Birth: April 5, 1972

Place of Birth: Effingham, IL

B.S.: December 1995, University of Illinois

M.S.: In progress

Professional Interest: dc-dc conversion.

A Comparison of Boundary Control with Conventional Control Methods in DC-DC Converters

Matt Greuel with advisor Philip T. Krein

Supported by Sandia National Laboratory

ABSTRACT

Boundary control techniques use state plane analysis to derive a control law in the form of a switching surface. These techniques appear very promising as a purely large signal tool for power converter design. This project develops design techniques using boundary control and compares these methods to conventional control methods. In addition, the use of estimators for state feedback is examined.

Steffen Haidacher

Date of Birth:	February 19, 1973
Place of Birth:	Munich, Germany
B.S.:	November 1995, Technical University, Munich, Germany
M.S.:	In progress
Professional Interests:	Power electronic applications for use in alternative energy projects.

System Control for Hybrid Electric Vehicle

Steffen Haidacher with advisor P. T. Krein

Supported by Xantrax, Technology Inc.

ABSTRACT

Air-pollution is a major concern in modern cities in particular, but also in the open countryside. One important cause for this are emissions from the increasing number of cars. One proposed way of facing that problem is a reduction in the emissions form individual cars. This goal can be achieved by a concept called hybrid-electric, which takes advantage of decoupling the processes of energy conversion in a standard combustion engine from the dynamics of vehicle propulsion. In the Hybrid Electric Vehicle of the University of Illinois, this separation consists of two systems linked electrically, with a battery pack as energy buffer. In this development, it is essential to control the combustion unit and the connected generator to ensure stable operation as well as to reduce emissions while maintaining the performance of a modern car. In contrast to large power systems, the operating conditions may alter drastically within a very short time due to the unpredictably changing environmental conditions and the varying power demand. Whereas the last two components of control deal with real time events, there is a need of a general system controller that adapts to long term processes and maintains the state of charge of the vehicle's batteries. This thesis is to propose a possible strategy for these controls. Secondly, the system's performance will be examined as a whole, which includes tests on fuel efficiency, emissions, electrical efficiency and other criteria.

Izzat Hossain

Date of Birth:	December 27, 1970
Place of Birth:	Dhaka, Bangladesh
B.S.:	May 1995, Bangladesh University of Engineering & Technology
M.S.:	In progress
Professional Interest:	Parallel computation and algorithms in power systems.

Nonlinear Simulation of Power Systems Using Iterative Solver Techniques

Izzat Hossain with advisor M. A. Pai and P. W. Sauer

Supported by the National Science Foundation

ABSTRACT

The purpose of this research is to investigate and compare different iterative solver techniques in the numerical solution of differential-algebraic systems such as the power system. The implicit method is used and the code is developed on the MATLAB platform. In particular, we will investigate physically based pre-conditioners to speed up the simulation. Currently the code has been tested in a serial mode.

Eugene Khutoryansky

Date of Birth: March 19, 1975

Place of Birth: U.S.S.R.

B.S.: May 1996, University of Illinois

M.S.: In progress

Professional Interests: Power and energy systems area of electrical engineering.

Application of Kharitonov's Theorem In The Stability Analysis of Power Systems

Eugene Khutoryansky with advisor M. A. Pai

Supported by the National Science Foundation

ABSTRACT

In this paper, we evaluate the region of stability in power systems by making use of the edge theorem and the segment Lemma. We explain the edge theorem and the segment Lemma, and we explain how they can be used to study power system robust stability. We apply these techniques to systems with uncertainty in the power system stabilizers and to systems with uncertainty in the operating point.

Jonathan Kimball

Date of Birth:	August 10, 1973
Place of Birth:	Pittsburgh, PA
B.S.:	May 1994, Carnegie Mellon University
M.S.:	August 1996, University of Illinois
Current Status:	Motorola, Inc. Phoenix, AZ

Application of Nonlinear Control Techniques in Low Voltage dc-dc Converters

Jonathan Kimball with advisor P. T. Krein

Supported by Grainger Endowment and Sandia National Laboratory

ABSTRACT

As output voltages are reduced, standard control techniques used in typical power converters are inadequate to achieve high efficiency and good performance. Since dc-dc converters are inherently nonlinear, nonlinear control techniques are required. Newly developed techniques can be used to maximize efficiency and greatly reduce voltage ripple. Issues being explored include stability and practical implementation of a next generation microprocessor power supply.

Ray Klump

Date of Birth: March 31, 1971
Place of Birth: Berwyn, IL
B.S.: May 1993, University of Illinois
M.S.: May 1995, University of Illinois
Ph.D.: In progress
Professional Interests: Power systems.

Assessment of Transmission System Capacity

Ray Klump with advisor T. J. Overbye

Supported by the National Science Foundation and the Grainger Foundation

ABSTRACT

The power industry is currently in the midst of a fundamental restructuring. The previous structure of vertically integrated utilities providing power at regulated rates is giving way to a more open marketplace with equal access to the transmission system for all wholesale buyers and sellers. Key to the development of such an open market is the ability to quantify and, hence, price, transmission system capacity in near real time. Transmission system capacity is limited by a number of factors, including thermal line limits, transient stability concerns, and the need to maintain voltage stability. All these issues must be addressed in the computation of transmission system capacity. This work focuses on quantifying transmission system capacity from the voltage stability viewpoint. In particular, it seeks a technique for identifying the limits placed by voltage stability requirements on energy transactions, as well as a scheme for pricing such limitations.

Ajit Kulkarni

Date of Birth:	April 10, 1967
Place of Birth:	Chicago, IL
B.S.:	May 1988, Arizona State University
M.S.:	January 1990, University of Illinois
Ph.D.:	October 1996, University of Illinois
Current status:	Henwood Energy Services, Inc. 2710 Gateway Oaks Dr., Suite 300 North Sacramento, CA 95833

Parallel Processing in Dynamic Simulation of Large Scale Power Systems

A. Kulkarni with advisor M. A. Pai

Supported by the National Science Foundation and the Grainger Foundation

ABSTRACT

The focus of this research was on the use of parallel processing in power system dynamic simulation. Efficient use of computer hardware of the supercomputer, such as the CONVEX machine SP-1200, Cray Y-MP and IBM RS6000, and research into better numerical algorithms that are parallelizable were investigated. Parallelizing the simultaneous implicit method using conjugate gradient style methods with suitable preconditioners was done on the Cray Y-MP, Convex, and IBM RS6000 for the 10-machine 39-bus system and the IEEE-50 machine system with detailed two-axis representation for each machine. Several iterative type Krylov subspace methods were investigated with different preconditioners for solving large sparse systems of the type Ax = b where A is non-symmetric. The best results were obtained using General Minimal Residual Method (GMRES) with incomplete LU factorization (ILU(s)) as the preconditioner and keeping the preconditioner the same till the number of iterations exceeded a certain threshold. This scheme is termed the dishonest preconditioning scheme. The technique has potential for solving very large scale systems quickly.

Mark Laufenberg

Date of Birth:	March 27, 1969
Place of Birth:	Dodgeville, WI
B.S.:	May 1992, University of Illinois
M.S.:	August 1993, University of Illinois
Ph.D.:	December 1996, University of Illinois
Current Status:	President of PowerWorld Corporation Urbana, IL Visiting Assistant Professor University of Illinois

Dynamic Sensitivity Analysis and Control of Power Systems with FACTS Devices

Mark Laufenberg with advisor M. A. Pai

Supported by the National Science Foundation, Power Affiliates Program
and the Grainger Foundation

ABSTRACT

Sensitivity theory as applied to a nonlinear dynamic system has been studied extensively in the automatic control literature both with respect to parameter variations and changes in initial conditions. Trajectory sensitivities, in particular, can be used in power systems to estimate system stability for a given contingency. They can provide an indication of the proximity of the state of the system to the stability boundary at the instant of fault clearing. Results on the 17-machine IEEE test system have been obtained. The technique can be used for real-time computation of stress levels in heavily loaded systems for different contingencies. Another part of the work deals with the small signal stability of power systems with FACTS devices. The SVC with auxiliary controllers has been added to the University of Illinois SSSP program. We plan to include TCSC, STATCON and UPFC controllers and examine their effect on transfer capability, voltage stability and steady state stability.

Jonathan Locker

Date of Birth: September 14, 1970

Place of Birth: Peoria, IL

B.S.: May 1992, Washington University

M.S.: January 1995, University of Illinois

Ph.D.: In progress

Professional Interests: Control systems for industrial applications.

Singular Perturbation Methods Applied to Induction Motor Control

Jonathan Locker with advisor P. T. Krein

Supported by the U.S. Army Construction Engineering Research Laboratory
and the Grainger Endowments

ABSTRACT

Advanced methods such as field-oriented control allow induction motors to be used in high-performance applications where quick position, speed, or torque response are desired. Although their benefits are well-known, many of the methods are difficult to tune or simply perform poorly when applied to high-quality, low-leakage motors. In some cases, this apparent contradiction can limit the use of induction motors for applications requiring both excellent control and high efficiency.

The goal of this project is to examine the induction motor model under a variety of singularity assumptions and to determine suitable control algorithms for each assumption. The algorithms are then to be implemented on a test bench such that we may compare and contrast their actual operating performances.

Daniel Logue

Date of Birth: July 28, 1970

Place of Birth: Pana, IL

B.S.: January 1996, University of Illinois

M.S.: In progress

Professional Interests: Power electronics and control systems.

Hybrid Electric Vehicle Control and Simulation

Daniel Logue with advisor P. T. Krein

Supported by Xantrex Technology, Inc.

ABSTRACT

In light of the recent concern over fossil fuel shortages and atmospheric pollution, there is an urgent need for an alternative to today's automobile. Specifically, there is a need for an automobile which has a much higher efficiency and a much reduced exhaust emission output. A prime candidate for this application is the hybrid electric vehicle. Improved efficiency and reduced emissions output is accomplished by requiring the on board internal combustion engine/generator pair to supply only the average demanded traction power. All transient behavior is handled by a battery pack buffer. This allows the internal combustion engine (ICE) to operate in steady state and also allows the ICE size to be reduced significantly since it is no longer responsible for acceleration transients. System simulation is being utilized to determine how the ICE/generator pair should be controlled to obtain optimum performance.

Hannon Maase

Date of Birth: June 13, 1967

Place of Birth: Urbana, IL

B.S.: May 1990, University of Illinois

M.S.: January 1992, University of Illinois

Ph.D.: In progress

Professional Interests: Rotating machines, power electronics, power quality and applications of advanced control techniques to ac motor drives.

Robust Simplified Control of ac Rotating Machines

Hannon Maase with advisor P. T. Krein

Supported by the U.S. Army Construction Engineering Research Laboratories

ABSTRACT

The objectives of this research project are to advance the understanding of the nonlinear operating characteristics of inverter-fed rotating machines, develop reduced-order drive models, and advance drive control algorithms. The approach will include the following: identifying and modeling machine operating characteristics through computer simulation and laboratory experimentation; exploring and developing novel ideas from control theory and observer theory; and developing and examining advanced drive control techniques. Reduced-order modeling techniques will be studied for developing improved drive models. Recent results in nonlinear, adaptive and robust control theory will be examined for developing control alternatives for ac drives. Observer ideas will be developed for reducing sensor dependency. The results from these efforts will then be used for developing robust, easy-to-implement control techniques for medium and high performance drive applications. These advanced techniques will be studied analytically, through computer simulation, and experimentally.

Richard Muyshondt

Date of Birth: December 12, 1969

Place of Birth: San Salvador, El Salvador

B.S.: May 1992, Texas Tech University

M.S.: December 1995, Texas Tech University

Ph.D.: In progress

Professional Interests: DC to DC conversion as well as analog, digital, and RF design.

Application and Design of DC-DC Converters with Boundary Control Methodologies

Richard Muyshondt with advisor P. T. Krein

Supported by Sandia National Laboratory

ABSTRACT

Boundary control is a geometrical design technique that uses the evolution of states in a system to derive an optimal control law. The purpose of this project is to develop a design methodology for DC-DC converters based on boundary control. In addition, the research will compare the boundary control methodology to conventional control methods such as PWM, current mode control, and others. This comparison will be based on theoretical, simulation, and hardware results. At this point, we have successfully implemented analog boundary controllers to optimize the performance of commercially available converter chip and are in the process of digitally implementing boundary controllers via a microcontroller.

Naomi Mwase

Date of Birth: June 3, 1966

Place of Birth: Ndola, Zambia

B.S.: January 1988, Polytechnic of the SouthBank, London

M.S.: In progress

Professional Interests: Power systems, control systems.

Evaluation of the Automated Interchange Matching System (AIMS)

Naomi Mwase with advisor George Gross

Supported by the Grainger Fellowship Foundation

ABSTRACT

AIMS (Automated Interchange Matching System) is a computerized hourly interchange matching system whose goal is to promote the maximum economic savings among all the participating players. This is accomplished by matching of bids to sell and offer to buy so that the sum of the savings for all the participants is maximized. We are evaluating the matching scheme from the point of view of the system, a buyer and a seller.

Our interest is to analyze the strategic behavior of sellers and buyers under AIMS. In particular, we are studying the strategies used by players in formulating their bids to sell and offers to buy. We are investigating the truth revelation characteristics of bids/offers, the role of transmission availability, and bottlenecks in the matching of the bids and offers.

Cesar Pascual

Date of Birth: June 15, 1968

Place of Birth: Teruel, Spain

B.S.: December 1992, Universitat Politecnica de Catalunya (UPC), Barcelona

M.S.: January 1997, University of Illinois

Current Status: Engineering position, Spain.

Battery Charge Equalization

Cesar Pascual with advisor P. T. Krein

Supported by a fellowship from the Spanish savings bank "la Caixa"

ABSTRACT

Charging a set of series-connected batteries with a single charger raises their voltages but does not guarantee that they will charge evenly. Initial differences tend to grow as the process is repeated. Over multiple charge cycles, battery performance reduces as the charging becomes more uneven. Batteries with the highest voltages become overcharged while those with the lowest values do not charge completely. The concept of battery charge equalization arises as a solution to this problem, and several alternatives for doing this are examined in this work. The conventional solution – forcible overcharging of the entire string until the lowest batteries are full – damages batteries and degrades their life. The goal of the work is to equalize individual battery voltages without requiring reconnection of the series string or overcharging of the highest batteries. An example approach is a multiple-output power converter for independent charging of all batteries in a string. Direct applications include electric vehicles and a variety of backup and energy storage systems. In these cases, a good equalization process would extend battery life and increase storage reliability.

Robert Reppa

Date of Birth: August 13, 1968

Place of Birth: Lansing, IL

B.S.: May 1990, United States Military Academy at West Point

M.S.: May 1996, University of Illinois

Current Status: Ford Motor Company
Sterling Heights, MI

Optimization of a Maximum Power Point Tracker

Robert Reppa with advisor R. J. Turnbull

Supported by the Department of Energy and the Power Affiliates Program

ABSTRACT

The amount of power derived from a solar module depends roughly on incident radiation and temperature. The module terminal characteristics will operate where the load line of the device to which it is connected intersects the module I-V curve. This intersection rarely matches the maximum power point of the module; hence, full use is not made of the available solar energy. A switching power converter that tracks the maximum power point of a solar module has been developed. This device has been optimized for efficiency and applied to the University of Illinois "Sunchief" solar car as a vehicle power management system.

Scott Splater

Date of Birth:	November 24, 1971
Place of Birth:	St. Louis, MO
B.S.:	May 1993, University of Illinois
M.S.:	January 1997, University of Illinois
Current Status:	Integrated Power Frederick, MD

Testing and Performance of a Practical Hybrid Electric Vehicle

Scott Splater with advisor P. T. Krein

Supported by the Power Affiliates Program and Teaching Assistantship

ABSTRACT

The University of Illinois has produced a fully operational series Hybrid Electric Vehicle (HEV) through the conversion of a production automobile, making it one of the first complete hybrid conversions. While it retains all of the passenger and trunk space of the original vehicle and performs comparably to many production vehicles, its true series hybrid nature makes significantly higher fuel mileage and lower emissions possible. It has won two national awards for Best Engineering Design and has been the top-performing series conversion vehicle at both the 1993 and 1994 Hybrid Electric Vehicle Challenge competitions; now it serves as a test bed for evaluation of models and analysis of design attributes for practical hybrid cars. Main topics of exploration included the identification and analysis of critical design factors and performance attributes relating to energy management in a hybrid vehicle, analysis of lead-acid battery maintenance issues and strategies in this setting, and determination and evaluation of detailed component models for all elements of a series hybrid car. Through simulation and actual road and lab driving tests, basic and advanced models of such elements and the larger systems were validated.

Shu Tao

Date of Birth: March 19, 1969

Place of Birth: Changchun, China

B.S.: July 1992, Tsinghua University

M.S.: July 1995, Tsinghua University

Ph.D.: In progress

Professional Interests: Power system operation and control

Optimal Bidding Strategies in Competitive Electricity Markets

Shu Tao with advisor George Gross

Supported by the Grainger Fellowship

ABSTRACT

The U.S. electricity industry is experiencing the most dramatic changes in its history. The increasing importance of the competitive electricity market is the primal driver of these changes. We have developed a general framework for the analysis of competitive electricity markets such as those in the England and Wales Power Pool. Under the assumption of perfect competition, we derived the formulation of optimal bidding strategies. Using this framework and analytical results to date we are investigating the consideration of demand-side bidding in the electricity markets are under investigation. A second area of study is the relaxation of the perfect competition assumption and the study of market power concentration in the hands of a few players. The application of game theoretic tools will be explored. A third area is the incorporation of financial contracts into the strategies of bidders. In addition, this research will investigate the incorporation of transmission considerations and constraints in to the electricity markets.

Yong Tian

Date of Birth: November 16, 1974

Place of Birth: Sichuan, China

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OASISNET: An OASIS Network Simulator

Yong Tian with advisor George Gross

Supported by the Grainger Fellowship

ABSTRACT

This describes a Web-based simulator of the Federal Energy Regulatory Commission (FERC) mandated Open Access Same-Time Information System (OASIS) network. OASIS is the real-time information network/electronic bulletin board whose specification are spelled out in FERC Order 889. The purpose of the simulator is to provide a tool for study of the various aspects of a multi-node OASIS network and to gain a strong intuitive feel for its operations. For a specified simulation period, the OASISNET simulator reproduces the behavior of an OASIS network using the same communications medium as the actual system, the Internet, and with multiple players using the simulator simultaneously. Users dynamically interact with the simulator through World Wide Web (WWW) browsers. Salient features of the simulator are its modular architecture, the ability to simulate multi-node OASIS network operations and to accept simultaneous access from remote users through the use of client/server technology. The simulation focuses on the dissemination and use of the available transmission capability information. Sample applications of the new simulator are discussed. These include the study of effects of delay in information transmission, the illustration of the uses of ATC information by a broker for undertaking transactions, and a case study to show the difference between recallable and non-recallable transmission service.

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Electric Utilities as Telecommunications Providers for the National Information Infrastructure

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Supported by the Power Affiliates Program and Grainger Foundation

ABSTRACT

This research is a multidisciplinary look at what role an electric utility can play in the proposed NII or "Information Superhighway." Electric utilities are uniquely situated as players in the NII by virtue of the existing rights of way they possess as well as the extensive telecommunication networks they maintain. The goal of this work is to develop a strategic plan for an electric utility to enter into this arena and cooperate with other carriers to provide a unified local telecommunication network. Economic and regulatory issues are being explored as well as the information and architecture issues of a transmission service information network.

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Optimization of Induction Motor Powered by Variable Speed Drive

Svetlana Troitskaia with advisor R. Turnbull

Supported by the Power Affiliates Program

ABSTRACT

Motors with varying shaft speed are used in many applications, but most of up-to-date research is concerned only with high motor efficiency at constant speed. The goal of this research is to minimize energy losses in an induction motor for an operating cycle which consists of varying speeds and loads. It will be assumed that the input voltage and frequency can be varied to match the motor parameters. The motor will not be required to start with line frequency.

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Simulation of Electric Power Systems

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ABSTRACT

Changes in the regulation of the electric power industry throughout the world have created new problems concerning economics and engineering of the electric power system. To tackle these problems, new tools as well as new ways of looking at the problems need to be developed.

An Optimal Power Flow (OPF) has been developed to help with the simulation of power markets. Using the OPF software, electricity spot markets can be simulated with unique prices at each bus reflecting the real cost of service at that bus. This includes the simulation of electric power spot markets as well as reactive power spot markets. Another interesting enhancement is the modeling of price dependent load models. Using this model, price-sensitive consumers can be simulated.

8. 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. They contribute significantly to growth in the Area.

The Grainger Power Engineering Software Laboratory was established in 1988 with funds from the Grainger Endowment. It is located near the office areas on the third floor of Everitt Laboratory. The Laboratory has three IBM RS6000s and four advanced personal computers. A laser printer serves the computers. All stations are connected to the campus network, which, in turn, provides access to major international networks via Internet.

A major objective of the laboratory is to develop an extensive library of commercial software and large-scale data bases for power area applications. Software is based on the Unix operating system and on MS-DOS. Some of the commercial software packages currently in use include:

Mathematica (an advanced symbolic mathematics package)
ETMSP (EPRI Extended Transient Midterm Stability Program)
ATP (Alternate electromagnetics Transients Program)
MatrixX (system analysis software)
SYMNON (system analysis and design software)
IPFLOW (Interactive Power Flow)
SSSP (Small Signal Stability Analysis)
INSITE (Interactive Nonlinear Systems Investigative Toolkit for Everyone)
MatLab
PSS/E (Power Technologies Inc. Software Package)
PowerWorld

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 333, ECE 369, and the Advanced Electric Vehicle Program. Ten self-contained machinery workstations are available. Each has an integral horsepower machine set, digital watt meters, oscilloscope, optical tachometer, torque sensor, and electronic support instruments. Transformers, resistor units, capacitors, SCR circuits, and power FET units are provided in support of the full range of experiments in all aspects of power. The facility has a dedicated 225 KVA three-phase supply and a 50 kw d-c rectifier bank.

The laboratory has generated a considerable of interest among students and other universities.

Student participation continues to grow. The equipment allows experimental work to be more complete without sacrifice of hands-on experience for students.

The Advanced Power Applications Laboratory is located 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 lab shares motor test sets with the Machinery Lab. Additional equipment is available for the study of harmonic effects, high-performance switching converters, and digitally controlled drives. This laboratory has extensive computer facilities, which communicate with the Grainger Power Engineering Software Laboratory through the building network. Current projects include harmonic effects in uninterruptible power systems, high-performance distributed power supplies, advanced ac motor controllers, and electric vehicle drives.

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