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TWENTY-FIRST 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 1999. 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 ten active affiliates associated with the PAP. They are:

Ameren - UE
BP Amoco
Burns & McDonnell
Central Illinois Light Company
City Water, Light & Power
ComEd
Electrical Manufacturing & Coil Winding Association, Inc.
MidAmerican Energy
PowerWorld Corporation
S&C Electric Company

1999 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
Ian Hiskens
Phil Krein
Tom Overbye
M. A. Pai
Pete Sauer

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-industry 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 1999 under the PAP umbrella clearly were in support of these objectives. The program is described in considerable detail in Reference [1].

Throughout the past twenty-one 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 critically important source of support.

This annual report is organized as follows. A financial statement for the calendar year 1999 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 an 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 1999 calendar year. Section 6 provides a brief summary of research projects that are funded by various 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 or her research work. Laboratories and other facilities of the power area are discussed in Section 8.

2. FINANCIAL STATEMENT

The following tabulation of income and expenditures for the calendar year 1999 was prepared from a detailed University statement as of December 31, 1999, Reference [2].

Income carried over from the calendar year 1998	$ 5,467
Total income during calendar year 1999	41,183
Total available income during calendar year 1999	$46,650

Expenditure	Expenditure Amount
Personnel and Services	$37,212
Materials/Supplies/Equipment	7,251
Transportation/Travel	5,846
Total expenditures	$50,309

Summary	
Amount of funds available during calendar year 1999	$46,650
Amount of expenses during calendar year 1999	-50,309
Balance as of December 31, 1999	$-3,659

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 Reference [3]. All M.S.E.E. students are required to complete a minimum of 8 units (32 credit hours) 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 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 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 1999 - 2000 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)
I. A. Hiskens	(power system dynamics)
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)

A detailed summary of each faculty member's research activities in 1999 is given in [5].

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 1998-1999 those courses were

ECE 330	Power Circuits and Electromechanics
ECE 333	Electric Machinery (with laboratory)
ECE 336	Advanced Electromechanical Energy Conversion
ECE 364	Power Electronics
ECE 369	Power Electronics Laboratory
ECE 371AHV	Advanced Hybrid Automotive Systems
ECE 371GG	Engineering Decision Techniques
ECE 371HEV	Hybrid and Electric Automotive Systems
ECE 376	Power System Analysis I
ECE 378	Power System Analysis II
ECE 468	Modeling and Control of Electromechanical Systems
ECE 473	Operation and Control of Power Systems
ECE 476	Dynamics and Stability of Power Systems
ECE 488	Electricity Resource Planning
ECE 490I	Power and Energy Systems Area Seminar
ECE 497PH	Hybrid Systems Analysis of Power System Dynamics
ECE 497PWR	Power System Modeling and Analysis

The three hundred level courses are advanced undergraduate or beginning graduate courses, while the four hundred level courses are graduate. Of these courses, ECE336, ECE371GG, ECE378, ECE468, ECE473, ECE476, ECE488 and ECE497PWR were not taught during the 1999-2000 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 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 1999-2000 academic year is also given for each course.

ECE 330 Power Circuits and Electromechanics

ECE 330 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 Foundations of Electric Power by I. R. Cogdell. The total enrollment for the academic year 1999-2000 was 147.

ECE 333 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 Fundamentals, 3rd edition, by S. J. Chapman. The total enrollment for the academic year 1999-2000 was 36.

ECE 336 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 1999-2000.

ECE 364 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 1999-2000 was 18. The course has been produced on videotape.

ECE 369 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 1999-2000 was 11.

ECE 371GG Engineering Decision Techniques

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 course was not offered during the academic year 1999-2000.

ECE 371HEV/ME 393DRW Hybrid and Electric Automotive Systems

This four-hour course is a large-team design program directed at advanced vehicle technology and automotive electronics. A multidisciplinary team addresses all the design, implementation, and operating issues for a high-performance practical hybrid automobile. Students learn about physical and engineering considerations in battery systems, electric traction, engines, emission controls, and other automotive system issues. The total enrollment for the academic year 1999-2000 was 32.

ECE 371AHV/ME 393AHV Advanced Hybrid and Automotive Systems

Design, operation, and systems issues associated with automobiles that combine a combustion engine with an electrical system. Major sub-systems including engine and emission controls, inverters and electric machines, batteries and energy management, dynamic operation, and structural considerations. In this course, students are expected to build and operate working subsystems. There is emphasis on testing, data analysis, and modifications to achieve defined engineering objectives. Laboratory work involves parametric studies and experiments with vehicle sub-systems and complete vehicles. The total enrollment for the academic year 1999-2000 was 11.

ECE 376 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 1999-2000 was Power System Analysis, 2nd edition, by Bergen and Vittal. The total enrollment for the academic year 1999-2000 was 20.

ECE 378 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 recommended text is Power Generation, Operation and Control, 2nd edition, by Wood and Wollenberg. The course was not offered during the academic year 1999-2000.

Graduate Courses:

ECE 468 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 offered during the 1999-2000 academic year. The course has been produced on videotape.

ECE 473 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 was not offered during the 1999-2000 academic year.

ECE 476 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 the book "Power Systems Dynamics and Stability" (Prentice Hall 1998) by P. W. Sauer and M. A. Pai. The course was not offered during the 1999-2000 academic year.

ECE 488 Electricity Resource 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 academic year 1999-2000.

ECE 490I 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 course had an enrollment of 20 for the 1999-2000 academic year.

ECE 497PH 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. The course had an enrollment of 9 during the 1999-2000 academic year.

ECE 497PWR Power System Modeling and Analysis

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. The course uses the notes of George Gross for a text. The course was not offered during the 1999-2000 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

1995-2000 Annual Average Power Area Graduates

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

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 1999. The major events are listed below:

- HCCSS on System Sciences, Maui, HI, January 1999
  - Tom Overbye and Pete Sauer presented papers.
- Phil Krein attended a review meeting of MIT Industry Consortium on Advanced Automotive Electronics in Birmingham, Alabama, January 1999.
- Phil Krein attended an IEEE Technical Activities Board Meeting in Hilton Head, South Carolina, February 1999.
- Phil Krein attended the IEEE Applied Power Electronics Conference and chaired the PE AdCom Meeting, Dallas, Texas, March 1999.
- IEEE Power Engineering Society 1999 Winter Meeting, New York
  - Tom Overbye presented papers and attended committee meetings.
  - Pete Sauer, George Gross and Stan Helm participated in committee meetings.
- Engineering Open House
  - ECE333 students presented machinery demonstrations.
- ECE 333 and ECE 378 student class trip to the Illinois Power control center and Vermillion generating station.
- 1999 American Power Conference
  - Stan Helm coordinated the UI participation in the sponsored student, sponsored faculty program.
  - Eleven students and faculty were sponsored by ComEd, Doyen and Associates, Inc., MidAmerican Energy, Sargent and Lundy, Soyland Power Cooperative.
  - The faculty were represented by Stan Helm, Pete Sauer and George Gross.
- American Association of Petroleum Geologists, San Antonio, TX, April 1999
  - Tom Overbye gave a presentation on how the electric grid operates.
- The 1999 Grainger Awards were presented to 20 graduating BS, MS and Ph.D. students in power
- Illinois Electric Council, Springfield, IL, April 1999
  - Tom Overbye gave a presentation on the causes of the June 1998 Midwest Price Spike.
- George Gross participated in the CIGRE main meeting in Paris, France, April 1999.
- Phil Krein presented a paper and participated in an NSF USA/Jordan Workshop on Power Electronics Education, Ammar, Jordan, May 1999.
- Phil Krein presented a paper at the 1999 ISCAS Meeting in Orlando, Florida, May 1999.

- Phil Krein served as faculty advisor to the student team at the DOE Future Car Challenge competition in Arlington, Virginia, June 1999.
- IEEE Power Electronic Specialists Conference.
  - Phil Krein participated in the 1999 conference in Charleston, SC, and had two papers there.
- IEEE Power Engineering Society 1999 Summer Meeting.
  - Tom Overbye presented a paper, co-taught a short course and attended committee meetings.
  - Pete Sauer, Stan Helm and George Gross participated in committee meetings.
- Pete Sauer and George Gross participated in the PSERC retreat in Banff, Alberta, July 1999.
- Power Systems Computation Conference (PSCC), Trondheim, Norway, July 1999.
  - George Gross, Ian Hiskens and Tom Overbye presented papers.
- U.S. Department of Justice, U.S. Energy Information Administration, Washington DC, August 1999.
  - Tom Overbye presented a paper, co-taught a short course and attended committee meetings.
- U.S. Department of Energy Power Outage Study Team, Fall 1999.
  - Ian Hiskens and Tom Overbye participated as members of the DOE team investigating the cause of the power outages during summer of 1999
- George Gross presented a white paper on real-time control at an NSF Workshop in Washington DC, September 1999.
- Phil Krein presented seminars at GM, September 1999.
- Phil Krein chaired the PE AdCom Meeting and attended the 1999 Industry Applications Conference in Phoenix, Arizona, October 1999.
- National Academy of Engineering's Frontiers of Engineering Symposium, Irvine, CA, October 1999
  - Tom Overbye participated as an invited speaker.
- 1999 Electrical Manufacturers and Coil Winding Association and Conference Exposition
  - Pete Sauer and 11 undergrads participated; one student presented a paper.
- North American Power Symposium (NAPS), October 1999
  - Pete Sauer, Trong Nguyen and Dimitrios Chaniotis attended and presented papers.
- Phil Krein attended an IEEE IAB in Salt Lake, Utah, November 1999.
- Hosted the following guest speakers
  - Prof. Tom Sparrow and David Lusan, Purdue University, "Electricity Prices in Imperfect Markets"
  - Alex M. Stankovic, Northeastern University, "Dynamic Phasors in Modeling, Analysis and Control of Energy Processing Systems"
  - Howard F. Illian, Energy Mark, Inc., "Recent Progress in Interconnection Frequency Control"

- Dr. Gianfranco Chicco, Politecnico di Torino, "The Acquisition of the Regulation and Reserve Ancillary Services in a Competitive Electricity Market"
- Dr. Ettore Bompard, Politecnico di Torino, "Optimal Power Flow In Unbundled Electricity Markets"
- Mikael Amelin, Royal Institute of Technology, "Monte Carlo Simulation of Economics and Reliability Effects of Multi-Area Electricity Markets"
- Prof. Elsie Yi Ni, University of Hong Kong, "Power Tracing and Total Transfer Capability Evaluation"
- Harry Stoller, Illinois Commerce Commission, "Evolution of Electric Utility Regulation"
- Prof. D. Thukaram, Asian Institute of Technology, "Optimum Reactive Power Dispatch for Voltage Stability Improvement"

- Presented the following seminars by UIUC faculty and students:
  - Dan Logue, "Power Buffering: An Example of a PEBB Application"
  - Trong Nguyen, "Dynamic Contingency Analysis Studies for Inter-Area Transfers"
  - Peter Sauer, "Research Directions In Power Engineering"
  - Thomas Overbye, "Visualization of Flows and Transfer Capability in Electric Networks"
  - Phil Krein, "Research Activities and Opportunities in Power Electronics and Automotive Electronics"
  - James Weber, "A Nested Optimization Problem for Analysis of Market Bidding Strategies"
  - Jeong Wood Lee, "The Regulation and Load Following Ancillary Services"
  - Sean West, "The University of Illinois FutureCar"
  - George Gross, "The June 1998 Midwest Electricity Price Spike"
  - Pedro Correia, "An Overview of the "Contract Network" Concept"
  - James Weber, "Modeling An Electricity Market Using the Optimal Power Flow"
  - Yiqing Zhu, "Evaluation of the Reactive Market Power"
  - Trong Nguyen, "Dynamic Sensitivities of Power Systems Using Facts Devices"
  - Shu Tao, "Reactive Support Service Key Characteristics and Dominant Cost Component"
  - Eric Thomas, "Engine Simulation Control of an Induction Motor"
  - Christian Murphy, "Converter Efficiency Evaluation for Plasma Display Panel Powering"
  - Santiago Grijalva, "Ideas for a More Consistent ATC Framework"
  - P. R. Kumar, "Wireless Networks: Problems and Prospects"
  - Karl Reinhard, "Electromagnetic Launchers (EMLs)"
  - Pedro Correia, "Transmission Congestion Management Schemes: A Comparative Analysis Under a Unified Framework"
- The hybrid car student team and faculty (P. Krein and R. White) participated in the 1999 Future Car Competition in Oakland, MI and Washington DC.
- The hybrid car was displayed at the Chicago Auto Show.

- M. A. Pai is the series Editor for the research monograph series in Power Electronics and Power Systems for Kluwer Publishers
- Bob Turnbull is the vice chairman of the Manufacturing Systems Department IEEE Industry Applications Society
- Phil Krein is President of the IEEE Power Electronics Society.
- CIGRE
  - George Gross is a member of the Executive Committee of the U.S. National Committee of CIGRE with responsibility for strategic planning.
  - George Gross is an Expert Advisor to the U.S. Representation for CIGRE Technical Committee number 39
  - George Gross was appointed Vice Chairman of ACCOPE, the Committee changed with assessing the future publication policies of CIGRE, the international council on high voltage networks.
- Edison Electric Institute Power System Planning and Operations School
  - Pete Sauer gave a presentation, Seattle, WA, March 1999.
  - Tom Overbye gave a presentation, Chicago, IL, October 1999.
  - George Gross is part of the faculty of the School.

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.

Analysis and Evaluation of VAr Support as an Ancillary Service

G. Gross,* S. Tao

Power Engineering Research Center through Cornell University

The unbundling of electricity services has brought about the need to evaluate and quantify the various services. VAr support is one such service. We have analyzed the principal attributes of this service and identified the dominant cost component. We are developing an analytic basis for the evaluation of the VAr support needs associated with transactions. The objective is to develop an allocation mechanism for VAr support among the transactions on the system.

Analysis of Market Power in Reactive Power Electricity Markets

T.J. Overbye,* Yiqing Zhu

Power Affiliates Program

This project investigates the market power aspects of reactive power. Because of the localized nature of reactive power, most providers of this service operate in rather narrow "markets", with few opportunities for others to "compete" on the provision of reactive power itself. However the inability to effectively transport reactive power through an electrical network results in significant opportunities of suppliers of reactive power to exercise market power. This project explores two such aspects of market power induced by reactive power considerations. First, owners of reactive power facilities can have a direct effect on their degree of market power in real power markets, depending on how they use their reactive power resources. Second, owners of reactive power facilities can induce market power in other nearby regions of the system, not necessarily on their own node or for their own benefit.

Analysis of the Bilateral Transaction Paradigm for Electricity Markets

George Gross,* Jeong W. Lee, Pedro Correia

Grainger Foundation; Power Affiliates Program

We are investigating the structure and functioning of the bilateral-transaction-based electricity markets such as those created by the restructuring in Norway and Sweden. The objective is to analyze the salient characteristics of the Nord Pool market and to perform a side-by-side comparison

with the England and Wales Electricity Pool. The focus is on the assessment of congestion management and pricing. The development of a mathematical model representing the market structure and rules governing the operation of the Nord Pool market has been developed. The study will assess the functioning of the Independent Grid Operator and the critical role of transmission services.

Analysis of Uncertainties in Power system Simulation

Ian Hiskens,* M. Pai, P. Sauer, T. Nguyen

EPRI/DoD

Parameters of power system models can never be known exactly. Yet dynamic security assessment relies upon the simulations derived from those uncertain models. This project is exploring ways to quantifying the uncertainty in simulations of power system dynamic behaviour. Trajectory sensitivities can be used to generate an accurate first order approximation of the trajectory corresponding to a perturbed parameter set. Therefore it is feasible to quickly generate many approximate trajectories from a single nominal case. To quantify the effect of parameter uncertainty on the nominal case, parameter sets can be randomly generated according to their underlying statistical distribution.

Congestion Management Scheme for Multi-Transaction Systems

G. Gross,* S. Tao

ARO-DoD; EPRI

We are investigating the allocation of charges for congestion management (CM) in multiple transaction networks. The problem is formulated in two stages -- congestion allocation stage and congestion relief. In the congestion allocation stage, the operator determines the congestion burden attributable to each individual transaction. In the congestion relief stage, the operator used an adjustment bidding to determine the congestion relief actions. The allocation scheme is being tested on several systems.

Development of an Analytical Framework for Dispersed Generation

G. Gross,* Y. Lin

Grainger Foundation; Power Affiliates Program

Increased competition in the electricity supply industry, increasing costs of transmission and distribution upgrades, greater pressures on cleaner environment, higher energy efficiency and decreasing marginal costs of new and smaller generation technologies are some of the facts that are

going to impact on alternatives for adding electricity supplies. The principal objective is to formulate a comprehensive analytical framework for dispersed generation within which the economic, technological, environmental and reliability aspects can be studied. Simulation of systems with transmission constrained load pockets and dispersed generation expansion alternatives are being performed.

Development of a Path-Independent Power System Voltage Stability Analysis Tool

T.J. Overbye,* Ray Klump

National Science Foundation, 9860977

Deregulation and restructuring in the electric power industry is resulting in many new players attempting to utilize the high voltage electric transmission system. Transmission system capacity is limited due to a number of different mechanisms including: (1) transmission line thermal limits; (2) bus voltage limits; (3) transient stability constraints; and (4) the need to maintain system voltage stability. The purpose of this project is to develop new algorithm utilizing a path independent model for voltage stability assessment using energy method approach. Advantages of energy methods include path independence, ability to provide measures of voltage stability in particular regions and potential for relatively low computational requirements.

Dynamic Available Transfer Capability Computations

M. A. Pai,* P. W. Sauer, T. Nguyen, I. A. Hiskens (University of New Castle, Australia)

National Science Foundation, ECS98-03055; Grainger Foundation

Stability limits place restrictions on the available transfer capability (ATC) of power systems. Calculation of these limits is therefore very important, but has traditionally been quite difficult. This research proposes an iterative algorithm for determining parameter values, which result in marginal stability of a system. (A system is marginally stable for a particular disturbance if the post-disturbance trajectory lies on the stability boundary.) A knowledge of the critical parameter values allows the dynamic ATC to be determined. The algorithm is based on the Gauss-Newton solution of a nonlinear least-squares problem. This solution process uses trajectory sensitivities. The method has been validated on a small system and is being extended to larger systems.

Dynamic Security Boundary Computations for Inter-area Transfers

M. A. Pai,* T. Nguyen, I. A. Hiskens (University of New Castle, Australia)

National Science Foundation, ECS 98-03055

In this research we apply the trajectory sensitivities to compute critical clearing times directly as well as the impact of contingencies on inter-area transfers in a multi-area system. Analytical sensitivities are used to compute these quantities. Results on a 10-machine system have been completed. To compute critical clearing time directly, two points which have clearing times less than t_{cr} but in the vicinity of t_{cr} are needed. The sensitivities are linear only near t_{cr}. The advantage of this approach lies in not having to compute the critical energy. As part of this work we are also investigating the effect of uncertainties on power system dynamic simulations.

Effective Deployment of Financial Instruments in Competitive Electricity Markets

G. Gross,* S. Tao

Grainger Foundation; Power Affiliates Program

With the recent emergence of the well defined electricity spot markets and the establishment of the trading of electricity futures on specific exchanges, the application of financial instruments such as options, futures and forwards provides significant new tools to players in electricity. Such instruments can be used for risk management as well as speculation. Our focus is on the effective incorporation of these instruments in the operation of electricity trading. We will investigate certain design and definitional issues in the deployment of financial derivative concepts to electricity markets. Of particular interest is the evaluation of the risk mitigation capabilities provided by these instruments for the trading of electricity and their impacts on the spot markets. In this research project, we will investigate the salient uniqueness of electricity derivative contracts due to the physical power system. We will investigate the possibility of developing new financial instruments and strategies to accommodate the different risk preference of various participants in the spot electricity market. Moreover, we will study the impact of financial derivatives on various players of the market.

High Speed Dynamic Simulation Using Krylov Subspace Method

M. A. Pai,* D. Chaniotis

National Science Foundation, ECS 98-03055; Grainger Foundation

The differential-algebraic system of equations of the power system are algebraized using the simultaneous-implicit method. The resulting system of linear 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 generalized minimal residual (GMRES) method which belongs to the family of iterative solver techniques. In the previous research the use of preconditioners such as the ILU(s) was found to speed up the convergence. Further enhancement in speed-up was obtained by using the preconditioner only when the number of iterations increase. The GMRES method was found to be more robust than other iterative solver algorithms. Proposed improvements include investigating GMRES (*m*) method where the method is restarted after *m* iterations. Retention of eigenvector information before restart improves the convergence. Combined with suitable preconditioners we expect the method to be faster than current techniques for dynamic simulation.

Loss Allocation Scheme for Multi-Transaction Systems

G. Gross,* S. Tao

Grainger Foundation; Power Affiliates Program

We are studying the allocation of losses as a function of physical power flows in multi-transaction systems. We have recast the power flow problem in a transaction-based network and are studying the issue of appropriately allocating losses on the basis of the flows that the transactions bring about. Extensive tests of the approach are being carried out on systems of varying size. A mechanism for loss compensation has been developed to provide choice to transacting entities.

Metering Requirements and Metering Data Applications in Open Access Bulk Electricity Systems

G. Gross,* J. W. Lee

Power Engineering Research Center through Cornell University; Grainger Foundation

The FERC Order No. 888 specified six unbundled ancillary services that may be provided to transmission customers. The NERC has developed a classification of twelve separate interconnected operations services. The unbundling of the services accompanied by the disintegration of the vertical structure of the electricity business have set up new requirements for information acquisition, metering and the communications. This project will examine the communication protocols and the data management aspects of the metering activities

New System Control Methodologies

M. A. Pai, Ian Hiskens, Vaibhav Donde (University of Illinois), C. L. DeMarco (University of Wisconsin)

PSERC Project

In this research we are looking at the effect of dynamic control in the new deregulated environment. More specifically we are looking at deregulated Automatic generation Control (AGC) system and the

notions of eigenvalue sensitivities and participation factors is being investigated. Under the restructured scenario distribution companies (DISCOS) in a control area can have bilateral transactions with generating companies (GENCOS) with another control area. The modeling and simulation of such transactions complete.

Optimal Bidding Strategies in Competitive Electricity Markets

G. Gross,* S. Tao

The Grainger Foundation Inc.; 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. Strategies for maximizing profits of demand-side bidders are studied. Additional areas of investigation are the relaxation of the perfect competition assumption, the study of market power, the impacts of transmission, and the incorporation of financial contracts into the strategies of bidders.

Power Electronic Building Blocks Interconnected Network

G. Gross,* P. Krein,* D. Logue

SRI International

Conceptually, Power Electronic Building Blocks (PEBBs) are smart power electronic modules that are superior to conventional power devices in that they have increased sensing, protection control and interfacing capability. This research is directed toward development of a conceptual framework for addressing analysis, design and control issues. The University of Illinois hybrid electric vehicle is intended to be used as a test bed for this framework and other conceptual developments.

Power System Parameter Estimation

Ian Hiskens*

EPRI/DoD

The nonlinear non-smooth nature of power system dynamics complicates the process of validating system models from disturbance measurements. This project is investigating algorithms for computing a set of model parameters that provide the best fit between measurements and model response. Trajectory sensitivities are used to identify parameters that can be reliably estimated from available measurements.

Real-time Security Monitoring and Control

G. Gross*

Power Engineering Research Center (CERTS)

We have prepared a white paper that outlines the scope of issues, challenges and opportunities in the area of real-time security monitoring and control (RTSMC) of power systems in the restructured electricity industry. The counterpart of power system reliability in real-time operations is *security* - the ability of the power system to withstand contingencies. This White Paper is part of a set of six papers on reliability aspects of the electric power system prepared for the U.S. Department of Energy by the Consortium of Electric Reliability Technology Solutions (CERTS).

The Load Frequency Control (LFC) Performance Assessment

G. Gross,* J. W. Lee

Grainger Foundation; Power Affiliates Program

Load frequency control is used to regulate the frequency of the power system to be within acceptable bounds around the synchronous value. We are constructing a framework for the evaluation of LFC performance assessment taking into account the random variations of the actual load over time. Appropriate metrics for the LFC performance assessment are constructed in the random process based framework. These metrics are used to formulate the criteria for LFC performance assessment. The effectiveness of industry criteria is assessed.

Trajectory Sensitivity Analysis of Hybrid Systems

M. A. Pai,* I. A. Hiskens (University of New Castle, Australia)

National Science Foundation, ECS 98-03055

The development of trajectory sensitivity analysis for hybrid systems, such as power systems, is the main focus of this research. Crucial to the analysis is the development of jump conditions describing the behavior of sensitivities at discrete events such as switching and state resetting. Sensitivity analysis provides a useful by product along with dynamic simulation and can be used in preventative mode in real time operation of power systems. The basic formulation has been completed and currently we are enhancing it with flexible AC transmission systems (FACTS) devices.

Transmission Congestion Management and Pricing

G. Gross,* P. Correia

Ministerio da Ciencia e Tecnologia, Portugal, Fellowship

A number of new transmission organizations has come to be established in the restructured electricity industry. These organizations have implemented different schemes for managing and pricing congestion. We have developed a unified model for various congestion management schemes. We are assessing their comparative performance using a set of criteria. Evaluation of the efficiency of each scheme and the ability to provide appropriate economic signals for the removal of congestion is assessed. The necessary modifications and a set of incentives will be proposed.

Visualization of Electrical Power System Transmission System Capacity

T.J. Overbye,* Craig Martini

National Science Foundation, EEC 9813305

One of the major goals associated with restructuring in the electrical power industry is to allow nondiscriminatory access to the high voltage transmission grid. However a key difficulty in achieving this goal has been the fact that the capacity of the transmission grid has a finite but not easily determined value. That is to say, the ability of the transmission system to support additional power transactions is limited by the need to maintain system security. The goal of this project is to develop and apply innovative visualization methods to aid market participants in determining this availability.

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:

Balog, Rob (M.S.)
Bartlett, Chris (M.S.)
Chaniotis, Dimitrios (Ph.D.)
Correia, Pedro (Ph.D.)
Donde, Vaibhov (M.S.)
Grijalva, Santiago (M.S.)
Klump, Ray (Ph.D.)
Kukovec, Mike (M.S.)
Lee, Jeong (Ph.D.)
Lin, Yan (M.S.)
Locker, Jonathan (Ph.D.)
Logue, Dan (Ph.D.)
Mak, Frankie (M.S.)
Martini, Craig (M.S.)
Mucha, Joe (M.S.)
Murphy, Christian (M.S.)
Nguyen, Trong (M.S.)
Papenfuss, Cory (M.S.)
Pascual, Cesar (Ph.D.)
Reinhard, Karl (Ph.D.)
Tao, Shu (Ph.D.)
Thomas, Eric (M.S.)
Troitskaia, Svetlana (M.S.)
Weber, Jamie (Ph.D.)
West, Sean (M.S.)
Zhu, Yiqing (M.S.)

Rob Balog

Date of Birth:	September 18, 1974
Place of Birth:	Edison, New Jersey
B.S.:	1996, Rutgens University
M.S.:	In progress
Professional Interests:	Power electronics, analog circuits, visual environment controls, building/home automation.

Coupled Magnetics Applications

Rob Balog with advisor P. T. Krein

Supported by Grainger CEME

ABSTRACT

Coupled magnetic components, including transformers, coupled inductors, and electromechanical devices, can be difficult to model and to apply in circuits. This project seeks to develop fundamental understanding of how coupled magnetic elements - especially coupled inductors - compare with uncoupled components in filter applications. We believe the results will give better guidance about models for parasitic capacitances and other nonlinear circuit effects in all types of magnetic components.

Chris Bartlett

Date of Birth:	December 13, 1970
Place of Birth:	Chicago, IL
B.S.:	1994, University of Illinois
M.S.:	In progress
Professional Interests:	Power systems and generation.

Saturation and Hysteresis Modeling

Chris Bartlett with advisor Peter Sauer

Supported by the Grainger Foundation Endowments

ABSTRACT

This project is investigating mathematical models for saturation and hysteresis. Analytical models are being sought that correctly capture the energy lost due to hysteresis while maintaing proper energy conversion equations. Initial work is focusing on transformers, using piecewise linear methods.

Dimitrios Chaniotis

Date of Birth:	October 31, 1973
Place of Birth:	Athens, Greece
B.S.:	October 1996, National Technical University of Athens
M.S.:	August 1998, University of Illinois
Ph.D.:	In progress
Professional Interests:	Power systems, automatic control and computer engineering.

Iterative Solver Techniques In High Speed Calculations of Power Systems

Dimitrios Chaniotis with advisor M. A. Pai

Supported by the National Science Foundation Grant NSF ECS 93-19352
and Grainger Foundation

ABSTRACT

The Generalized Minimal Residual (GMRES) method is an alternative way to solve large sparse systems of the form Ax = b. In this research we seek to implement recent modifications/improvements in this technique to the power system problems to improve performance and robustness. We target three areas of application. The first one is the fast computation of P-V curves for normal as well as contingency cases. New pre-conditioners as well as an improvement to current methods have been tested with good results on systems of 4000 buses. The second area under investigation is dynamic simulation, which will be helpful in a fast dynamic security assessment (DSA) framework. Finally applications for model reduction of large systems will be investigated.

Pedro Correia

Date of Birth:	July 29, 1969
Place of Birth:	Lisbon, Portugal
B.S.:	July 1993, Instituto Superior Tecnico
M.S.:	May 1996, Instituto Superior Tecnico
Ph.D.:	In progress
Professional Interests:	Power system analysis; competitive electricity markets; system protection.

Transmission Congestion Management Schemes: A Comparative Analysis Under A Unified Framework

Pedro Correia with advisor G. Gross

Supported by Foundation for Science and Technology
of the Ministry of Science and Technology, Portugal

ABSTRACT

The restructuring of the electricity industry has spawned the introduction of new independent grid operators or IGOs in various parts of the world. An important task of an IGO is congestion management (CM) and pricing. This activity has significant economic implications on every market participant in the IGO's region. The work focuses on the congestion management schemes used by the IGOs in four representative systems selected to illustrate the various CM schemes in use: PJM, England and Wales, Norway and Sweden, and California. We develop a unified framework for the mathematical representation of the market dispatch and re-dispatch problems that the IGO must solve in CM in these various jurisdictions. These schemes and the pricing mechanisms are compared on a simple test system to assess their salient characteristics. The economic performance is evaluated using several criteria including efficiency and market signals given to the participants. Conclusions are drawn about the impacts of the various CM schemes and associated rules.

Vaibhav Donde

Date of Birth:	July 17, 1977
Place of Birth:	Thane (Maharashtra), India
B.S.:	June 1998, V.J.T.I., Mumbai, India
M.S.:	In progress
Professional Interests:	Power systems, control systems

Sensitivity Studies of Automatic Generation Control System In A Restructured Environment

Vaibhav Donde with advisors M. A. Pai and I. H. Hiskens

Supported by PSERC

ABSTRACT

Consequent to deregulation of the power industry, the automatic generation control system will have a different role to play. In this work we initially perform trajectory sensitivity studies for a two area system in a Vertically Integrated Utility (VIU). Trajectories sensitivities with respect to the gain of ACE controller (K) and the frequency bias (B) are examined which are then used to get an optimum of the performance index. In a deregulated environment the structure of the AGC is different. We plan to develop a similar two area model incorporating the measurements among the DISCOs and GENCOs in addition to the area control errors.

Santiago Grijalva

Date of Birth:	November 25, 1970
Place of Birth:	Quito-Ecuador
B.S.:	1994, National Polytechnic University - Ecuador
M.S.:	August 1999, University of Illinois
Ph.D.:	In progress
Professional Interest:	Real-time control of power systems, power system economics, information systems

Computation of Available Transfer Capability In Power Systems

Santiago Grijalva with advisor P. W. Sauer

Supported by Power Affiliates Program

ABSTRACT

The project is investigating enhancements to current methods for computing Available Transfer Capability (ATC). New algorithms to incorporate the reactive power and voltage effect in large transactions are studied. The work is focusing on power flow sensitivities, reactive power flow and estimation of maximum loadability.

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.

Path-Independent Power System Voltage Stability Analysis

Ray Klump with advisor T. J. Overbye

Supported by PowerWorld Corporation

ABSTRACT

The overall goal of this project is the development of a computationally efficient method for power system voltage stability assessment. The approach is to use energy methods for path independent assessment. The key computational challenge in this approach is determining the appropriate low voltage solutions. This challenge arises because for an n bus power system there can be up to a maximum of 2^{n-1} separate power flow solutions. Fortunately, only at most the n-1 type-one solutions need to be determined. Each of these solutions, if it exists, can usually be found with a low initial voltage guess at a particular bus i; the solution found with a low voltage guess at bus i will therefore be referred to as the bus i solution. The percent loading associated with the bus i energy measure then provides measure of the voltage stability in the region about bus i. Nevertheless, calculating all of these n-1 solution would still require computation equivalent to approximately n-1 power flow solutions, which would clearly be computationally unacceptable. Research is therefore focused on computationally efficient methods for determining these solutions.

Mike Kukovec

Date of Birth:	August 18, 1971
Place of Birth:	Winfield, IL
B.S.:	May 1999, University of Illinois
M.S.:	In progress
Professional Interests:	Consulting engineering for power generation, transmission, distribution.

Power Transmission Line Equivalent Circuit Models In Transient Analysis

Mike Kukovec with advisor P. W. Sauer

Supported Grainger CEME and the Electrical and Computer Engineering Department

ABSTRACT

Transient analysis techniques of power transmission line events lack a simple model that will adequately represent a real, lossy system. While models do exist that can accurately predict transient behavior, they are valid only for lossless cases. Other models exist that take losses into consideration and provide accurate steady state analysis, but are not valid for transient study.

By comparing several equivalent circuit models of power transmission lines for both lossless and lossy cases, possible techniques for accurate transient and steady state analysis will be discussed. Equivalent circuit models include the "PI", "T", "Inverted-L" and "Backwards-Inverted-L." The discussion will also focus on the number of segments used in the circuit models in relation to solution accuracy, and examination of system eigenvalues and their relationship to simulation results.

Jeong Lee

Date of Birth:	December 14, 1970
Place of Birth:	Seoul, Korea
B.S.:	1994, Seoul National University, Seoul, Korea
M.S.:	1996, Seoul National University, Seoul, Korea
Current Status:	Changed areas in ECE

Analysis of Load Frequency Control Performance Assessment Criteria

Jeong Lee with advisor G. Gross

Supported by the Grainger Foundation

ABSTRACT

This work focuses on the development and application of an analytic framework for the formulation and evaluation of control performance criteria in load frequency control (LFC). The framework is constructed so as to explicitly represent the uncertainty in the measured variables in LFC and to use metrics that are meaningful for the structure of the problem. The framework makes effective use of probability and random processes concepts to develop rather general criteria for LFC performance assessment. In fact, the NERC criteria ***CPS1*** and ***CPS2*** are special cases of the criteria of the framework. The paper thus provides an analytic rationale for the NERC control performance criteria. Analysis of the ***CPS1*** and ***CPS2*** criteria shows that, under conditions that are typically in effect in North American interconnections, the two criteria are redundant. Consequently, there is good analytical basis for not requiring the application of ***CPS2*** once ***CPS1*** is satisfied. Numerical results with four interconnections are used to illustrate the analytic results. The framework is a powerful construct that may be used to construct new criteria for LFC performance assessment.

Yan Lin

Date of Birth:	February 7, 1968
Place of Birth:	Yangon, Myanmar
B.S.:	August 1993, Yangon Institute of Technology
M.S.:	August 1997, Asian Institute of Technology
M.S.:	January 1999, University of Illinois
Current Status:	MAIN 939 Parkview Blvd. Lombard, IL

Evaluation of Dispersed Generation Options In Transmission-Constrained Load Pockets of an Interconnected System

Yan Lin with advisor G. Gross

Supported by the Grainger Foundation and Power Affiliates Program

ABSTRACT

This project considers a two-area system with a load pocket problem. The problem concerns a system with a larger area and a smaller area connected by tie lines whose transfer capability is severely limited. The focus of the study is on meeting the markedly higher forecasted load growth of the smaller area. Due to a variety of factors, the expansion of the transmission system is virtually impossible. As such the only practical means of meeting the load growth in the smaller area is by installing additional generating capacity in the area. We developed various expansion plans, whose variable economic aspects are evaluated and compared on a consistent basis. The modeling of the two-area system for performing probabilistic simulation to evaluate the production and marginal energy costs is described. In addition, the representation of photovoltaic (PV) generation is discussed. The set of expansion alternatives constructed makes use of both conventional and dispersed generation (DG) technologies. The key focus of the study is the analysis of the variable aspects of the expansion alternatives. The metrics used are the expected production costs and the short run marginal energy costs over a 10-year planning horizon. The economics of DG are investigated and compared to those of conventional resources. The reference expansion case is constructed using combined-cycle units only. The alternative expansion cases use three types of DG resources - PV, fuel cells, and microturbines. A wide range of sensitivity studies was performed to assess the impacts of several key parameters including load growth, fuel cost, PV penetration, and insolation availability. The results of these studies are summarized and the conclusions reached are discussed.

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.:	October 1997, University of Illinois
Ph.D.:	In progress
Professional Interests:	Control and simulation of power electronic systems and electrical drives.

Power Electronic Building Blocks: Concept Definition, Simulation and Application

Daniel Logue with advisor P. T. Krein

Supported by SRI International and DOE

ABSTRACT

The Power Electronic Building Block (PEBB) concept involves the control and interfacing of intelligent power electronic modules. Examples of PEBB modules include rectifiers, inverters and dc-dc converters. Local control exists to provide module functionality and to deal with fast local contingencies such as faults. A networked system of PEBB modules is termed PEBB*NET*. In addition to the local control provided by each PEBB module, the PEBB*NET* is managed by a centralized controller labeled the Coordinator. The Coordinator's job is to create a synergism between the various PEBB modules within the network to enhance or maintain global operating characteristics such as overall efficiency and performance, and system-wide stability.

Frankie Mak

Date of Birth:	February 2, 1974
Place of Birth:	Hong Kong
B.S.:	May 1997, University of Illinois
M.S.:	December 1999, University of Illinois
Professional Interests:	Electric power.

Modeling Frequency During Power System Transient

Frankie Mak with advisor P. W. Sauer

Supported by the University of Illinois

ABSTRACT

This project is investigating the various definitions for frequency during power system transients. Using a quasi-steady-state dynamic model of the electrical system the frequency can be defined as nominal plus the time derivation of the "phase angles" of voltages and currents. These are "local" frequencies. In addition, the center-of-inertia speed definition gives a "system" value for frequency. The distribution of power and energy during a unit outage is being examined to determine methods to allocate reimbursement for energy served.

Craig Martini

Date of Birth:	December 26, 1976
Place of Birth:	Middletown, Ohio
B.S.:	May 1999, Rose-Hulman Institute of Technology, Terre Haute, IN
M.S.:	In progress
Professional Interests:	Power and control systems.

Virtual Reality and Two-dimensional Visualization Methods Applied to Power Systems

Craig Martini with advisor T. J. Overbye

Supported by the National Science Foundation and Grainger Foundation

ABSTRACT

Displaying power system information in an effective manner can be difficult because of the complexity of power systems. As the electricity industry becomes increasingly competitive, information concerning electric system capacity and constraints is a valuable commodity. The goal of this work is to develop new methods of visualization using two-dimensional displays and a three-dimensional virtual environment to assist players in the electricity industry in extracting this knowledge from a large set of power system data.

Joe Mucha

Date of Birth:	January 29, 1975
Place of Birth:	West Berlin, Germany
B.S.:	December 1998, Andrews University
M.S.:	In progress
Professional Interests:	Automotive engineering

Control Strategy of Series Hybrid Electric Vehicles

Joe Mucha with advisor P. T. Krein

Supported by the Grainger Center for Electric Machinery and Electromechanics

ABSTRACT

Air pollution in major cities has led to the need for vehicles that produce fewer emissions. On alternative to conventional vehicles is the hybrid electric vehicle. Hybrid vehicles use energy in both fuel and electric form. The University of Illinois has developed a series hybrid electric vehicle that is essentially an electric car with an onboard engine and generator set to recharge the batteries. The goal of the project is to develop a highly efficient full size sedan that is capable of achieving a fuel economy of 70 miles per gallon with low exhaust emissions. The total efficiency of the vehicle is the product of the efficiencies of all the components in the system. Most of the efficiencies cannot be easily altered. However the engine efficiency varies from 10%-40% and the battery pack efficiency varies from 25%-90% depending on use. We are studying different techniques to determine the tradeoffs between the engine and batteries in order to maximize the product of their efficiencies. This research will be used to develop a control strategy for the engine and generator set. Computer simulations, chassis dynamometer tests, and on-road tests will be used to verify the performance of the selected control strategy for the vehicle.

Christian Murphy

Date of Birth:	March 11, 1976
Place of Birth:	Chicago, IL
B.S.:	June 1998, Williams College
M.S.:	In progress
Professional Interests:	Power conversion, devices, low power conversion, alternative energies and power storage.

Evaluation of a Resonant Converter for Plasma Display Panel Powering

Christian Murphy with advisor P. T. Krein

Supported by LG Electronics

ABSTRACT

Plasma display panels (PDPs) are beginning to replace the currently used bulky television and computer displays with a much thinner flat-panel alternative. A PDP acts as a capacitive load that requires a pulsed dc driving waveform with a magnitude of around 250 V at a frequency of up to 100 kHz. With a capacitive load, a significant portion of the driving energy is recoverable. A resonant converter is used to supply and recover the energy to the PDP. A recovery efficiency is defined as the ratio of the energy supplied to the energy recovered from the load.

The converter was dynamically modeled using Simulink to isolate the loss mechanisms. Switching device models were developed and used to gain an understanding of the effects of the device capacitance. In the high voltage low current (20 mA) conditions of the converter, the device capacitance can be a source for significant loss as it must be charged and discharged 100,000 times a second. Both experimental and computational results confirm this. The conventional practice of placing two or more devices in parallel to reduce device resistance has, in this case, the counterintuitive effect of decreasing the recovery efficiency by increasing total device capacitance. An IGBT was found to have the greatest recovery efficiency of as high as 87%.

Trong Nguyen

Date of Birth:	September 10, 1966
Place of Birth:	Vietnam
B.S.:	December 1997, University of Illinois
M.S.:	May 1999, University of Illinois
Ph.D.:	In progress
Professional Interests:	Power system stability, control and computation.

Dynamic ATC Computations Using Sensitivity Functions

Trong Nguyen with advisors M. A. Pai I. H. Hiskens

Supported by the National Science Foundation

ABSTRACT

In this research we wish to investigate the use of trajectory sensitivities as a tool to compute dynamic available transfer capabilities (ATC) in a power system. Currently, transient energy function (TEF) method is being proposed but its major drawback is the need to compute the controlling unstable equilibrium point (u.e.p.) to obtain the critical energy. However, the TEF is a very useful concept and can be used as a metric in computing an estimate of t_{cr} without computing the u.e.p. Initial results are very encouraging. The sensitivity approach is independent of modeling complexity. Sensitivity of power transfer over tie lines with respect to generation for a set of contingencies gives useful information regarding rescheduling of generation if found necessary. This concept has been successfully tested on a 10-machine, 39-bus system. The idea can be extended to compute dynamic ATC.

Cory Papenfuss

Date of Birth:	November 28, 1975
Place of Birth:	Dubuque, IA
B.S.:	University of Alaska, Fairbanks
M.S.:	In progress
Professional Interests:	Power electronics, embedded control

Measurement and Control of Series Hybrid Electric Vehicle (HEV) Batteries and APU Charging System

Cory Papenfuss with advisor P. T. Krein

Supported by Grainger CEME

ABSTRACT

The charging and monitoring of an HEV's transient energy source presents a number of power flow measurement and control issues. Because the transient power requirements of the traction system vary widely from large negative power during regenerative braking to almost full battery power capacity, large currents from the battery cause the DC bus voltage to vary significantly during normal operation. Normal control of the engine-generator's rectifier regulates either output voltage or current; either of these regulations cause large variations in generator power as the battery bus voltage fluctuates. To address this, an analog controller to regulate the voltage-current product was used to control the generator power and effectively isolate the transient traction power requirements from the engine-generator power delivery. The speed-torque curve for the car's diesel engine needed to be considered. Because an internal combustion engine has an increasing torque curve as speed increases, a true constant power load is inherently unstable. In addition to the power regulation, a "load-droop" characteristic was added to the rectifier control to stabilize the system.

Cesar Pascual

Date of Birth:	June 15, 1968
Place of Birth:	Teruel, Spain
B.S.:	December 1992, Polytechnical University of Catalonia
M.S.:	January 1997, University of Illinois
Ph.D.:	In progress
Professional Interests:	Power electronics, control systems, digital signal processing, very large scale integrated circuit design.

All-Digital Audio Amplifier

Cesar Pascual with advisor P. T. Krein

Supported by Motorola

ABSTRACT

Audio amplifiers have traditionally been analog, built upon Class-A, -B or -AB stages. All of these linear amplifiers exhibit relatively low efficiencies, mainly because their power transistors are always in mid-conduction. More recently, some switching amplifiers have overcome the efficiency problem by using pulse width modulation (PWM) and Class-D stages. This allows the power transistors to work either in the on or off state, and increases the efficiency drastically. However, most of these solutions have difficulties with radiated interference and with offering a high audio quality. If the audio source is digital, as it is the trend nowadays, it would seem more logical to generate the PWM signal directly from the digital input, without using D-to-A or A-to-D conversion. Careful digital signal processing can improve the audio quality, reduce the interference, and keep the efficiency at its maximum. This project investigates several approaches to the concept of an all-digital audio amplifier.

Karl Reinhard

Date of Birth:	August 18, 1960
Place of Birth:	Camp Hanford, Washington
B.S.:	May 1982, United States Military Academy
M.S.:	May 1992, University of Texas at Austin
Ph.D.	In progress
Professional Interests:	Advanced linear method for contingency analysis.

Lieutenant Colonel Karl Reinhard, U.S. Army, with advisor P. W. Sauer

Supported by the U.S. Army

ABSTRACT

This project is investigating advanced linear methods for predicting results of contingency analysis in available transfer capability computation. Goals include the identification of critical elements which lead to cascading failures. Current work is focusing on line outage angle factors and the associated line closure generator current distribution factors.

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

Transmission Congestion Management in Multiple Transaction Networks

Shu Tao with advisor G. Gross

Supported by the Grainger Fellowship

ABSTRACT

At the time when the transmission system can not transfer more power from a source point to a load point without violating one or more physical and/or operating constraints of the system, transmission congestion occurs. While transmission congestion does not impose a major issue under the vertical integrated utility (VIU) environment, it becomes a much more critical issue for the system security in the open access regime, in which sellers and buyers of electricity independently arrange bilateral power transactions with each other according to their own interests, and the transmission network is used in the *common carrier* mode by the Independent Grid Operator (IGO) to accommodate these various transactions. The increasingly enlarged number of such market-driven transactions is bound to result in more serious congestion and more frequently. Therefore, in the transaction-based environment, congestion is a very important issue that has direct impacts on the system reliability and must be addressed appropriately.

We first reviewed the existent congestion management schemes. The pros and cons of these schemes are analyzed and discussed. On the basis of the multi-transaction framework previously constructed, we proposed a new two-stage congestion management scheme for a multiple transaction network. This scheme consists of the congestion allocation stage and the congestion relief stage. The congestion allocation stage determines each transactions contribution to the overload congestion. The congestion relief stage formulates the IGO's least-price congestion relief problem as an OPF, in which the IGO acquires congestion relief services to remove each transactions congestion burden accordingly. A marginal-cost-pricing scheme is also developed to determine the charges to each transaction for its actual usage of the system. This proposed scheme was implemented in various IEEE test-cases to illustrate its desirable characteristics.

Eric Thomas

Date of Birth:	November 28, 1974
Place of Birth:	Ann Arbor, Michigan
B.S.:	December 1997, Michigan State University
M.S.:	August 1999, University of Illinois
Professional Interests:	Motor design, simulation and control.

Engine Simulation Control of an Induction Motor

Eric Thomas with advisor P. W. Sauer

Supported by the Power Affiliates Program

ABSTRACT

This project is investigating the theoretical and practical aspects of controlling an induction motor to make it behave like an internal combustion engine. The application is a mechanical engineering hydraulic test stand which is being constructed to study alternative hydraulic designs and controls. Since the test stand is in doors, an actual internal combustion engine was not feasible. A sophisticated commercial variable-speed drive is being used as the primary mechanism for the induction motor control. This drive is capable of almost instantaneous speed control in response to load torque on the motor. The drive also includes digital outputs of motor voltage, current and torque. The variable speed drive will receive commands from an engine simulation which will be programmed to duplicate various engine details. The engine simulation will receive inputs from the variable speed drive.

Svetlana Troitskaia

Date of Birth:	March 15, 1971
Place of Birth:	Chik, Novosibirsk County, Russia
B.S.:	February 1995, Novosibirsk State Technical University, Russia
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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.

Jamie Weber

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Place of Birth:	Platteville, WI
B.S.:	May 1995, University of Wisconsin-Platteville
M.S.:	January 1997, University of Illinois
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A Simulation-Based Approach to the Optimization of Electricity Markets Including Consumer and Full Transmission System Modeling

Jamie Weber with advisor T. J. Overbye

Supported by the Grainger Foundation

ABSTRACT

The restructuring within the electric power industry throughout the world has created a need for innovative new approaches to power system analysis. Most importantly, new economic analysis tools are needed by the industry. One tool that will be of interest is an electricity market simulator.

The optimal power flow (OPF) algorithm that was developed during my master's degree has been enhanced to include the modeling of consumer price elasticity. (In other words, consumers who change their consumption based on the price signals they receive). Using this enhanced OPF, we are able to determine the optimal behavior of the market from a global perspective. Over the past year, we have developed techniques to more closely simulate an individual's behavior explicitly within this OPF framework. Nash equilibrium as well as market oscillations have been observed. Participants in the market could use this tool for economic benefit, while regulators could use this to study how participants may behave under a given set of market rules.

Sean West

Date of Birth:	December 17, 1974
Place of Birth:	Denver, CO
B.S.:	December 1997, University of Illinois
M.S.:	February 2000, University of Illinois
Professional Interests:	Hybrid automotive design and power electronic circuits.

Performance Evaluation of Switched Capacitor Battery Equalizer

Sean West with advisor P. T. Krein

Supported by the Power Affiliates Program

ABSTRACT

Battery applications, including large energy storage systems involving lead-acid chemistry, are experiencing rapid growth. New generations of electric and hybrid vehicles and uninterrupted power supplies (UPS) place extreme requirements on batteries. In these applications, the batteries must be placed in series to produce enough power. When batteries are placed in series, one might expect that the complete battery pack will operate as the sum of the *n* batteries from which it was constructed. This is not the case. Voltage imbalance in a series string can lead to degradation of an individual battery cell, leading in turn to premature failure of the entire pack. An *equalization* process to balance the batteries is needed to help avoid this failure mode. In this project, several sets of batteries were subjected to accelerated life testing to compare the effects of equalization methods. It was found that batteries should be held to a match within about 50 mV to avoid long-term imbalance. Fast cycling is especially hard on batteries. In a fast cycle test, less than 10% of the expected life was actually achieved without equalization or when the equalization process was too gradual to keep up with the cycle. In high-temperature tests, equalization methods helped maintain the expected life. An active equalization method invented at UIUC in a prior project shows considerable promise as a possible low-cost precision equalization approach suitable for many types of batteries.

Yiqing Zhu

Date of Birth:	September 30, 1974
Place of Birth:	Yichang, P.R. China
B.S.:	July 1995, Huazhong University of Science & Technology (P.R. China)
M.S.:	October 1999, University of Illinois
Ph.D.:	In progress
Professional Interests:	Power system simulation, operation.

Costing of Ancillary Services

Yiqing Zhu with advisor T. J. Overbye

Supported by the Grainger Foundation and PSERC

ABSTRACT

The focus of this project is to investigate methods for establishing justifiable costs for ancillary services. The initial work has focused on implementing an efficient optimal power flow algorithm. Once this work has been completed, the algorithm will then be used to aid in the costing of reactive power and voltage control. The goal of the project is to seek answers to questions such as what it costs to maintain voltage, what it costs an energy provider to utilize an exciter, what operating costs can be allocated to voltage control, and the feasibility of these services being provided by a third party.

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.

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 one IBM AIX workstation and eight advanced personal 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 Windows NT. Some of the commercial software packages currently in use include:

Mathematica (an advanced symbolic mathematics package)
SYMNON (system analysis and design software)
IPFLOW (Interactive Power Flow)
SSSP (Small Signal Stability Analysis)
MatLab and Simulink
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 wattmeters, 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. The equipment allows experimental work to be more complete without sacrifice of hands-on experience for students.

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 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's computer facilities communicate with the Grainger Power Engineering Software Laboratory through the building network.

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