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FOURTEENTH ANNUAL REPORT
OF THE
POWER AFFILIATES PROGRAM

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FOREWORD

This report is a summary of the activities of the Power Affiliates Program in the Department of Electrical and Computer Engineering at the University of Illinois for the calendar year 1992. The information is intended to be a progress report to the affiliate companies. The following companies have provided support for the Power Program at Illinois in the past year:

Amoco Oil Company
Bechtel Power Corporation
Central Illinois Light Company
Central Illinois Public Service Company
Commonwealth Edison Company
Illinois Power Company
Iowa-Illinois Gas and Electric Company
Northern Indiana Public Service Company
Pacific Gas and Electric Company
PSI Energy
S&C Electric Company
Sargent & Lundy
Sorensen Company
Union Electric Company
W. W. Grainger, Inc.
Wisconsin Power and Light Company

We would like to express our thanks to these companies for their continued support.

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 provide financial assistance to students studying electric power engineering and to increase university-industrial interaction at all levels of education and research in electric power engineering. The program is described further in Reference [1].

Throughout the past fourteen 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 research support.

This annual report is organized as follows. A financial statement for the calendar year 1992 is given in Section 2. This statement reflects our commitment to utilizing the majority of funds for student support. 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 gives 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 itemizes the activities of both the student and faculty members during the 1992 calendar year. Section 6 provides a brief summary of research projects which 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 1992 was prepared from a detailed University statement as of December 31, 1992, Reference [2].

Income carried over from the calendar year 1991	$42,605
Total income during calendar year 1992	$51,607
Total available income during calendar year 1992	$94,212

Expenditure Category	Expenditure Amount
Personnel (Assistantships, wages)	$35,519
Materials/Supplies (Laboratory, library, office supplies)	$ 7,062
Transportation (Class trips, travel)	$ 6,019
Services (Publications, clerical, mailing, duplication, computer software, equipment maintenance)	$29,456
Equipment (Inventory equipment)	$ 3,480
Total	$81,536

Summary

Amount available during calendar year 1992	$94,212
Amount expended during calendar year 1992	-$81,536
Balance as of December 31, 1992	$12,676

3. THE POWER PROGRAM WITHIN THE DEPARTMENT

As of 1979, all entering electrical engineering students are required to complete 128 hours of course work for a B.S.E.E. degree. A detailed description of the undergraduate program as well as a 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 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 areas as follows:

Bioengineering and Acoustics
Circuits and Signal Processing
Communication and Control
Computer Engineering
Electromagnetics
Physical Electronics
Power and Energy Systems
Remote Sensing and Propagation

While the Department does not have official options in each of these areas, the eight areas serve as a representative grouping of major faculty activities and interest. In terms of size, the Power and Energy Systems area represents about 1/20 of the total active faculty and about 1/10 of the total student enrollment. A faculty committee is assigned to each area and given the responsibility for administering courses in that area within the Department.

The Power and Energy Systems Area Committee and associated faculty for the 1992 - 1993 academic year together with their general interests are:

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 and Stability of Power Systems)

P. W. Sauer (Modeling and Simulation of Machines and Power Systems)

R. J. Turnbull (Energy and Conversion Technology)

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 1992-1993 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
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

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 ECE473 were not taught during the 1992-1993 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 1992-1993 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. 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 required text was: Electric Circuits by J. W. Nilsson. The total enrollment for academic year 1992-1993 was 782.

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). The required text was Electromechanical Dynamics, Part I by H. H. Woodson and J. R. Melcher, and supplementary notes by M. A. Pai. The total enrollment for the academic year 1992-1993 was 130.

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 1992-1993 was 22.

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. This course was not taught during the 1992-1993 year.

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 required text was Principles of Power Electronics by Kassakion, Schlecht and Varghese. The enrollment for academic year 1992-1993 was 49.

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 1992-1993 was 26.

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 and relaying. The course is designed to give the basic fundamentals of power system analysis and provide preparation for the follow-on course. The required text in the academic year 1992-1993 was Power System Analysis by A. R. Bergen. The enrollment was 29.

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 for the academic year 1992-1993 was Computer Analysis of Power Systems by Arriliaga and Arnold. The enrollment was 18.

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 1992-1993 was 28.

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 academic year 1992-1993. 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 load flow, security constrained economic dispatch, multistage rescheduling and equivalents. This course was not taught during the 1992-1993 academic year.

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 the video tape. The enrollment for the 1992-1993 academic year was 4.

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 1992-1993 was 21.

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

1980-1985 Annual Average Power Area Graduates

B.S.E.E.	-	30
M.S.E.E.	-	5
Ph.D.	-	2

1985-1992 Annual Average Power Area Graduates

B.S.E.E.	-	35
M.S.E.E.	-	6
Ph.D.	-	2

1992-1993 Power Area Graduates

B.S.E.E.	-	37
M.S.E.E.	-	7
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 calendar year 1992. The major events are listed below:

- Pete Sauer served as the Program Director for Power Systems at the National Science Foundation.

- IEEE Power Engineering Society Winter Meeting
  - Tom Overbye presented a paper on voltage collapse and attended committee meetings.
  - M. A. Pai, Pete Sauer and Stan Helm attended committee meetings.

- Sargent and Lundy Faculty Engineering Conference
  - Pete Sauer and Stan Helm attended.

- ECE333 Student Class Trip to S&C Electric

- Engineering Open House
  - ECE333 students presented machinery demonstrations.

- American Power Conference
  - Stan Helm coordinated the UI participation in the sponsored student, sponsored faculty program.
  - 10 students and faculty sponsored by Central Illinois Public Service Co., Commonwealth Edison Co., Illinois Power Co., Sargent & Lundy, Union Electric, Wisconsin Power and Light.
  - Tom Overbye and Phil Krein attended.

- IEEE Power Electronics Specialists Conference
  - Phil Krein chaired the Education Committee, and presented a paper on optimal control alternatives.
  - Phil Krein attended IEEE Power Electronics Society Ad Com meeting.

- IEEE Power Engineering Society Summer Meeting
  - Pete Sauer chaired the working group on dynamic security assessment.
  - Tom Overbye and Stan Helm attended committee meetings.

- IEEE Industry Applications Society Annual Meeting
  - Phil Krein chaired a session on Electrohydrodynamics and Pulsed Systems.
  - Bob Turnbull and Phil Krein attended committee meetings.

- M. A. Pai organized a workshop on "Recent Advances in Energy Management and Control" at the J. N. Advanced Study Centre at the Indian Institute of Science, Bangalore, India, in August 1992 and gave state of the art lectures on "Voltage Security" and "Dynamic Security Assessment."

- M. A. Pai has been asked to serve on the DSA Advisory Council of the EPRI. He attended a meeting of the committee in October 1992 at San Francisco, CA. He also attended the workshop on DSA at that time organized by EPRI.

- M. A. Pai and Pete Sauer attended two EPRI project review meetings and made presentations.

- M. A. Pai was elected an Associate of the Center of Advanced Study at the University of Illinois for the Spring 1993.

- M. A. Pai gave seminars at Howard University and the University of Notre Dame.

- North American Power Symposium
  - Pete Sauer and Bernie Lesieutre attended.
  - Bernie Lesieutre presented a paper on load modeling.

- Hosted Guest Lecturers from Industry

- ECE376 Student Class Trip to Illinois Power Facilities

- ECE378 Student Class Trip to Commonwealth Edison Control Center and Joliet Generating Station

- IEEE International Symposium on Circuits and Systems
  - Tom Overbye presented a paper on power system stability analysis.

- IEEE Conference on Decision and Control
  - Tom Overbye and M. A. Pai presented papers on power system voltage stability analysis.

- College of Engineering Advisory Board Meeting
  - Phil Krein participated as a faculty representative.

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.

Electrohydrodynamics of a Conductive Liquid Meniscus

J. C. Chato, P. T. Krein, G. Wright

Tektronix, Inc.

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

This program involves the control of liquid drops with electric fields. Objectives are to determine liquid properties important to the interactions, and to identify conditions under which a meniscus can be disrupted with a field. Possible applications include liquid spraying and electrically activated ink jets.

Observer-based Control of AC Induction Machines

P. T. Krein, F. Disilvestro

Sivensa Scholarship

High-performance control schemes for induction motors require knowledge of the dynamic states – currents, fluxes, and speed. Measurement of flux is especially difficult and costly. The implementation of observers and state estimators for use with various ac motor control methods is being explored. Sensitivity of performance to both nonlinear magnetic effects and motor parameter uncertainty is being examined. The results have implications in field-oriented control, feedback linearizing control, and related nonlinear methods.

Implementation of an Advanced Nonlinear Induction Motor Controller

P. T. Krein, S. A. Ellerthorpe

National Science Foundation Fellowship

Many hypothetical nonlinear methods for motor control have not been tested experimentally. This project involves construction of a hybrid digital-analog-power electronic system for testing advanced motor control concepts. The system will support algorithms for feedback linearization, several distinct field-oriented methods, and modern nonlinear techniques such as integratorbackstep methods. Observers, estimators, and intelligent sensors will permit conventional induction motors to be investigated. Limits on dynamic performance will be identified.

High-Performance Power Supplies

P. T. Krein, P. Midya, U. Ekambaram

Sorensen Co.

Operational techniques required in high-performance switching power supplies are being explored. Control methods based on geometric and optimal concepts are under study for applications in supplies with fast dynamic response. The methods represent a large-signal approach to design and control. Synchronous rectifiers and related switching techniques are being studied for applications in low-voltage systems. The new techniques are expected to lead to performance improvements while simplifying the design process.

Hybrid Electric Vehicle Program

P. T. Krein, R. A. White, P. Guziec, R. Weinstock, et al.

University of Illinois; U. S. Department of Energy; Ford Motor Co.; Illinois Corn Growers Assn.; Illinois Power Co.; other industrial sponsors

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

A hybrid electric vehicle combines an electric traction system with a fueled auxiliary power unit. Such a vehicle can perform like a gasoline car, with substantial emission reductions, at reasonable cost. Design tradeoffs differ from those in purely electric vehicles. This project involves the complete design, construction, and testing of a practical hybrid electric vehicle. An advanced power electronic traction drive system is a key electrical element in the system. More than 100 undergraduate students and several additional faculty consultants are involved.

Simulation Methods for Switching Power Networks

P. T. Krein, Dan Beck

Sundstrand Corp.

Switching power conversion networks pose severe problems for conventional circuit simulators. The discontinuous action, the wide disparities in time scales, and the sensitivity to semiconductor device models offer challenges. This project compares several power electronic simulation methods. Test circuits for use as benchmarks will be identified. Performance predictions will be compared with actual operating results to identify the advantages and disadvantages of the various approaches.

Harmonic Effects in Power Line Filter Networks

P. T. Krein, M. Kim

U. S. Army Construction Engineering Research Laboratory

Harmonic currents and voltage distortion are growing problems in electric power networks. Harmonics create electromagnetic interference, additional losses, and can even damage certain types of equipment. Power line filters are often used to correct harmonics. If parasitic elements and resonant effects are neglected in filter design, harmonic problems can actually be made worse under certain conditions. Models of filter performance under harmonic conditions are being evaluated using high-frequency loss results. The objective is to recommend mitigating methods or derating practices for various government and military facilities.

Advanced Nonlinear Induction Motor Control

P. T. Krein, F. Disilvestro, J. Locker, M. Ransick, B. Truax

National Science Foundation Fellowship; Sivensa Scholarship; University of Illinois

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 is available for tests.

Optimal Control Approaches to Power Electronic Systems

P. T. Krein, P. Midya, J. Locker

National Science Foundation Fellowship

Power electronic circuits are inherently nonlinear and can be controlled only through operation of switches. In past practice, linearization and small-signal approximations are often applied to such circuits for control design purposes. Optimal control methods offer a way to decide how "best" to control such circuits. However, conventional optimal methods do not apply to nonlinearities of the type found in power electronics. This project develops approaches, based on standard optimization, which can be used for switching control. The results can be used to provide good large-signal performance as well as excellent small-signal operation. Geometric methods can be used to demonstrate that the alternatives give approximate optimal operation of a power electronic circuit.

Use of Energy Methods to Improve Power System Voltage Security

T. J. Overbye, R. A. Lateef

University of Illinois

As the electric power system becomes more stressed as a result of increased loads and larger interutility power transfers, efficient system operation is becoming increasingly threatened because of problems of voltage instability and collapse. This research project investigates the use of energy methods to provide a means of quantifying how close a power system is to the point of voltage instability. This information can be used to determine which controllers to change in order to enhance system security.

Integrated Framework for Power System Security Assessment Using Energy Methods

T. J. Overbye, D. R. Brown, D. K. Cullum

National Science Foundation, ECS 92-09570

Direct methods using Lyapunov energy functions have been used for assessing power system transient stability. More recently, these methods have also been successfully applied to the much longer time frame problem of maximum stable loadability of the power system. This research project has shown that, in general, complete decoupling of the two phenomena is not possible, particularly in stressed systems. The focus of the research is to use energy methods to develop an integrated framework for security assessment. The goal of this framework is to encompass the full range of power system dynamics, from the fast dynamics associated with transient instability through the much slower dynamics of the maximum loadability problem.

Implementation of EPRI-based Software in a Unix-based Environment

M. A. Pai, P. W. Sauer, A. Kulkarni, M. Laufenberg

National Science Foundation, ECS 87-19055 REU

In an earlier effort we converted the EPRI-ETMSP program, which is VMS based, to the ULTRIX (Unix-based) system in the department's Grainger Software Laboratory. We have now converted the small signal stability package (SSSP) to the ULTRIX system. We are making the programs suitable for easy operation for teaching and research purposes.

Structural Stability in Power Systems

M. A. Pai, P. W. Sauer, B. Lesieutre, R. Ranjan, S. Fernandes

Electric Power Research Institute, RP 8010-21

In this research we are looking at the effect of parameter variations on the stability of power systems. Structural stability refers to the property of the system when the qualitative behavior is not significantly altered when a parameter varies. When the behavior alters significantly, the structural stability boundary is reached. In the literature this is also referred to as the bifurcation point. Applications of this theory include voltage collapse and robust design of power system stabilizers. We have investigated the effect of nonlinear voltage-dependent loads on voltage collapse. Also the effect of uncertainties in load modeling on robust stability has been investigated using Kharitonov-Barmish testing functions.

Parallel Processing in Dynamic Simulation of Large-Scale Power Systems

M. A. Pai, A. Kulkarni

National Science Foundation, ECS 91-19428

Parallel processing algorithms for dynamic response calculations of large power systems with detailed models are being developed. The work is based on solving the differential-algebraic system of equations of the power system using the simultaneous-implicit method. We have obtained excellent results on a 50-machine system using a classical model by parallelizing the predictor corrector algorithm. It is being extended for detailed models. Instead of parallelizing the L-U method for solving the resulting system of linear equations at each time step using Newton's method, we use the conjugate gradient method. Suitable preconditioners are being investigated so that speedup is improved. Conjugate gradient methods are easily parallelizable.

Reduced-Order Dynamic Modeling of Multimachine Power Systems - Linear and Nonlinear

P. W. Sauer, M. A. Pai, A. Varghese

National Science Foundation, ECS 87-19055

This project deals with the systematic derivation of reduced-order dynamic models of interconnected synchronous machines and their controls. It uses the inherent time-scale properties of physical states to formulate fast and slow subsystems. It also exploits natural decoupling that exists between voltage and frequency control systems. Efficient methods to compute critical eigenvalues in large-scale power systems are also being formulated.

Dynamic Security Assessment in Power Systems

M. A. Pai, M. Laufenburg

National Science Foundation, ECS 91-19428

Both angle and voltage stabilities have been investigated via energy function methods. The latter uses only the potential part of the energy function and different unstable equilibrium point (uep), while the former uses the total energy function and the controlling uep. We are re-examining the question of computing the path-dependent integrals in angle stability. The effect on the stability boundary as the system is stressed is also being investigated. Understanding the basic phenomena and visualization is being emphasized. A new approach to compute the region of attraction for transient stability is also being initiated for first swing and multiswing instabilities.

Rapid Transfer of Induction Motors

P. W. Sauer, H. Maase

U.S. Army Construction Engineering Research Laboratory

This project is developing a simulation package for analyzing induction motor shaft torques during fast voltage supply transfer. The simulation will allow straight transfer after time delay or transfer after a rapid short-circuited period. The package is being prepared for a company for use on PCs.

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:

Brown, Douglas (M.S.)
Cullum, David (M.S.)
DiSilvestro, Francisco (M.S.)
Ekambaram, Uma (M.S.)
Ellerthorpe, Scott (M.S.)
Fernandes, Stephen (M.S.)
Klump, Ray (M.S.)
Kulkarni, Ajit (M.S.)
Lateef, Rezwan (M.S.)
Laufenberg, Mark (M.S.)
Lesieutre, Bernie (Ph.D.)
Locker, Jonathan (M.S.)
Midya, Pallab (M.S.)
Morris, David (M.S.)
Ranjan, Rajeev (M.S.)
Savignon, Dan (M.S.)
Truax, Byron (M.S.)
Weinstock, Rob (M.S.)
Wright, Graham (Ph.D.)

Douglas Brown

Date of Birth:	September 28, 1969
Place of Birth:	Iowa City, Iowa
B.S.:	May 1992, University of Illinois
M.S.:	In progress
Professional Interests:	Power systems, control systems.

Use of FACTS Devices for Power System Stability Enhancement

Douglas Brown with advisor T. J. Overbye

Supported by the Power Affiliates Program and the National Science Foundation

ABSTRACT

Increased loading on utility transmission systems has resulted in an increased potential for transient and voltage instabilities. Traditionally, power system control has been limited by electromechanical response times which are commonly on the order of seconds or minutes. However, recent advances in FACTS (Flexible AC Transmission System) devices have introduced the possibility of electronic controllers with response times on the order of milliseconds. The main objective of this research is the development of new control techniques using FACTS devices for fast intervention during system disturbances to increase the systems stability margin.

David Cullum

Date of Birth:	December 1, 1969
Place of Birth:	Peekskill, New York
B.S.:	January 1992, University of Illinois
M.S.:	In progress
Professional Interests:	Power system protection, voltage instability and collapse.

Use of Energy Methods to Approximate Maximum Power System Loadability

David Cullum with advisor T. J. Overbye

Supported by the Power Affiliates Program and the National Science Foundation

ABSTRACT

Energy methods have been shown to be useful measures for approximating the vulnerability of power systems to voltage instability and collapse. An energy-based measure has been developed for system models with constant real power and voltage-dependent reactive power load models. This energy measure can be related to the area enclosed by a Q-Ln(V) curve, or that of a P-α curve. This relationship shows promise because it provides an interpretation of the energy measure for an operational environment by giving information about the maximum loadability of the system. This energy-based voltage security measure relationship, however, is an approximation for the case with transfer conductances. The objective of this research is to develop a better approximation for the transfer conductance case which will not degrade the ease of computation nor destroy the relationships with the Q-V curve and P-α curves.

Francisco DiSilvestro

Date of Birth:	February 26, 1965
Place of Birth:	Caracas, Venezuela
B.S.:	May 1988, Universidad Metropolitana (Venezuela)
M.S.:	August 1992, University of Illinois
Currently employed at:	Arthur Anderson Consulting, Caracas, Venezuela

Fast Controllers for AC Drives

F. DiSilvestro with advisor P. T. Krein

Supported by Sivensa Scholarship,
sponsored by Sivensa Siderurgica Venezolana S.A., Caracas,
and the Power Affiliates Program

ABSTRACT

The control schemes for an induction motor require a reference-frame transformation, internal control operations, and then a reverse transformation to obtain the actual operating voltages. These steps can be combined into a single transformation between machine states and voltages. The resulting expressions require less computation, make sensitivity analysis more direct, and allow comparisons between different approaches. The technique is used to compare four induction motor control algorithms. One outcome is a simplified algorithm which operates with little performance sacrifice compared to those for the most advanced schemes. It is also shown that advanced nonlinear control methods offer significant performance improvements over vector techniques, even without flux sensing.

Uma Ekambaram

Date of Birth:	November 24, 1969
Place of Birth:	Madras, India
B.S.:	May 1991, College of Engineering Guindy, Madras, India
M.S.:	In progress
Professional Interests:	Control systems, power electronics, circuits.

Distributed Low Voltage Power Converters

U. Ekambaram with advisor P. T. Krein

Supported by the Power Affiliates Program and Sorensen Company

ABSTRACT

Distributed power converters are being used increasingly today. These have special requirements for control, priority, current sharing and failure protection. This project involves the building of a 48V to 2V dc power converter in two stages. The output specifications are extremely tight and various control methodologies using concepts of interleaving with coupled inductors and active compensation have been used to achieve them. This will be used in the distributed configuration to supply low-voltage loads.

Scott A. Ellerthorpe

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B.S.:	December 1988, Purdue University
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Currently employed at:	Naval Undersea Warfare Center, Newport, RI

A Generic Digital Testbed for Induction Motor Controllers

S. A. Ellerthorpe with advisor P. T. Krein

Supported by a National Science Foundation Fellowship

ABSTRACT

In recent years several new methods of control have been proposed for induction drive systems, such as feedback linearization and direct nonlinear control. These techniques have been shown to be stable, but have not yet been implemented. A generic testbed allows a user to program an advanced control algorithm in a high-level language (such as C) and observe the resulting system performance. This will facilitate comparisons between methods and assist researchers in developing new ones. Such issues as elimination of the encoder and increasing the inverter switching speed can also be explored. High computational throughput is achieved by the use of a floating-point digital signal processor, while a microcontroller handles all of the interfacing functions. This task sharing prevents the testbed from being the limiting factor in controller performance.

Stephen Fernandes

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B.S.: May 1989, Institute of Technology
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M.S.: July 1992, Oregon State University

Ph.D.: In progress

Professional Interests: Control systems, power systems.

Structural Stability and Bifurcation Analysis in Power Systems

Stephen Fernandes with advisor M. A. Pai

Supported by the National Science Foundation and the Electric Power Research Institute

ABSTRACT

Earlier work in this project examined the critical modes leading to voltage instability in power systems. This on-going project with EPRI will now examine the nature of oscillations after Hopf bifurcation by simulating the nonlinear model of the power system. The effects of generator limits and different types of loads is being examined. Also the effects of other parameters as well as structural changes on the bifurcation phenomenon will be investigated.

Ray Klump

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Place of Birth: Berwyn, Illinois

B.S.: May 1993, University of Illinois

M.S.: In progress

Professional Interests: Power systems, power electronics.

Simulation and Development or Facts Devices for Power System Stability Enhancement

Ray Klump with advisors T. J. Overbye and P. T. Krein

Supported by the Power Affiliates Program and Grainger Endowments

ABSTRACT

As power demands have increased and the economics of expanding transmission systems have become prohibitive, quick and effective means of maintaining system stability in the presence of transients and voltage disturbances have generated much interest. A promising outgrowth of this interest has been the development of Flexible AC Transmission Systems (FACTS) which use various power electronic devices to implement system controllers having rates of response on the order of milliseconds. Such quick response to transient and voltage instabilities, coupled with the ability to make accurate time measurements, can significantly improve the stability limits of power systems. This investigation explores the utilization and design of FACTS devices and develops methods for characterizing their control and response through computer simulation and analysis.

Ajit Kulkarni

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Place of Birth:	Chicago, Illinois
B.S.:	May 1988, Arizona State University
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Ph.D.:	In progress
Professional Interests:	Development of and applications of computer methods to large scale power system analysis, including application of supercomputers. Interested in a career in the electric utility industry.

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 Endowments

ABSTRACT

The focus of this research is to investigate the use of parallel processing in power system dynamic simulation. Efficient use of computer hardware of the supercomputer, such as Cray machines, and research into better numerical algorithms which are parallelizable are being investigated. Currently, the linear multistep predictor corrector method has been successfully used on the Cray-2 machine with four processors both in the autotasked mode and the macrotasked mode. A classical model for the machine is used. A system with up to 50 machines has been tested, and for the numerical integration portion, a speed up of 3.79 compared to a theoretical speed of 4 has been obtained. Current research involves extending the technique to systems containing both differential and algebraic equations. Parallelizing the simultaneous implicit method using the conjugate gradient with suitable preconditioners has been done on the Cray Y-MP4 for a 10-machine 39-bus system with detailed 2-axis representation for each machine. Further work includes use of better preconditioners and testing on large systems.

Rezwan Lateef

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B.S.:	May 1991, University of Illinois
M.S.:	October 1992, University of Illinois
Currently employed at:	American Electric Power Company

Direct Assessment of Power System Stability Using Structure Preserving Energy Functions with Detailed Generator Models

R. Lateef with advisor T. J. Overbye

Supported by the University of Illinois at Urbana-Champaign Research Board

ABSTRACT

Due to the increased loading of power system transmission networks, the problems associated with voltage instability have become more prominent. This research investigates the problem of system vulnerability to voltage collapse by using structure preserving energy functions (SPEF) to obtain a scalar measure of system stability. The SPEF used in this research is based on the standard two-axis model (having a field winding on the direct axis and a damper winding on the quadrature axis) and incorporates a standard IEEE Type I excitation system model. Moreover, this SPEF also accounts for the effect of flux decay, transient saliency, and automatic voltage regulators (AVR) in machines. The main objective of this research is to utilize the above SPEF to successfully determine a power system's voltage stability.

Mark Laufenberg

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M.S.:	In progress
Professional Interests:	Power systems, control systems

Dynamic Security Assessment in Power Systems

Mark Laufenberg with advisor M. A. Pai

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

ABSTRACT

Direct methods using Lyapunov/energy functions for angle stability have been used for many years. The application of direct methods to voltage stability is more recent. Angle and voltage stabilities are not completely separate phenomena. In this work besides developing an integrated approach, we will examine the evaluation of path-dependent integrals using the trapezoidal rule. It is felt that both the straight-line approximation and not using a post fault stable equilibrium point introduce an error in the calculation of critical clearing time. Detailed structure preserving models will be considered also. The visualization aspect is also being emphasized.

Bernie Lesieutre

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Currently employed at:	University of Illinois

Dynamic Modeling and Simulation of Multimachine Power Systems

B. Lesieutre with advisor P. W. Sauer

Supported by Power Affiliates Program and the Grainger Endowments

ABSTRACT

This research is investigating several aspects of multimachine dynamic analysis with emphasis on the network algebraic equations and dynamic load modeling. Initial work is focusing on properly capturing the frequency dependence of the network and loads during transients. One objective is to provide a physically meaningful load model which allows the algebraic network plus load equations to be solved for any disturbance. The work also includes a study of the relationship between the dynamic load model and stability phenomena related to maximum loadability.

Jonathan Locker

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Place of Birth: Peoria, Illinois

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M.S.: In progress

Professional Interests: Control systems for industrial applications.

Real Performance of Scalar and Vector Controls for Induction Motors

Jonathan Locker with advisor P. T. Krein

Supported by the National Science Foundation and the Grainger Endowments

ABSTRACT

Many induction motor controls currently use simple scalar methods, such as constant volts per hertz or constant magnetizing current, to achieve good steady-state performance. Field-oriented control has also been successfully tested in some applications. Recent advances have produced high performance control algorithms, such as the flux observer-based and reduced-order controls, that have yet to be implemented on an actual system. The objective of this project is to compare and contrast the actual operating performance of these control methods on a real machine.

Pallab Midya

Date of Birth:	January 31, 1967
Place of Birth:	Bhilai, India
B.S.:	Indian Institute of Technology, Kharagpur
M.S.:	May 1990, Syracuse University
Ph.D.:	In progress
Professional Interests:	Research in electronic power conversion, teaching.

Control of Switching Power Conversion

P. Midya with advisor P. T. Krein

Supported by the Power Affiliates Program and Sorensen Company

ABSTRACT

Switching power conversion involves transferring power from one voltage level to another through a network of reactive elements and switches. The only control over the system is the state of the switches. Some concepts of optimal control have been used to develop a controller that governs the timing of the switches. The aim is to obtain a controller that is optimal subject to some constraints and that results in simple control laws. Certain adaptive control techniques can be used to develop control schemes that eliminate the necessity of measuring all of the states and help track parameter variation.

David Morris

Date of Birth: December 13, 1970

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Professional Interests: Power systems, control systems.

Analysis of Bifurcation and Chaos in Power Systems

David Morris with advisor M. A. Pai

Supported by the National Science Foundation and the Grainger Endowments

ABSTRACT

Static bifurcation analysis in power systems occurs in power systems for stressed systems through physical concepts such as voltage collapse and maximum loadability. In dynamic models of power systems, we have the Hopf bifurcation phenomenon. In this research we plan to investigate this and study the impact of other dynamic devices, such as SVC and PSS on Hopf bifurcation. Power systems are known to exhibit quasi-periodic or chaotic behavior though the amplitude of the oscillations may not be high. We wish to study the stability of this behavior through mathematical tools such as Lyapunov exponents as well support it through simulation.

Rajeev Ranjan

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M.S.:	August 1992, University of Illinois
Professional Interests:	Control systems, power systems.

Structural Stability in Power Systems

R. Ranjan with advisor M. A. Pai

Supported by the Electric Power Research Institute and the Power Affiliates Program

ABSTRACT

Structural stability in power systems refers to the condition in which small parameter variations result in different qualitative behavior of the system at a certain critical value of the parameter. This is also the point of bifurcation. In this research we investigate the effect of parameter variations on both angle and voltage stabilities. A comprehensive linearized model of a multimachine system with 2-axis machine representation and both IEEE Type 1 and fast-high gain exciters has been developed for this purpose. Steady-state stability analysis through eigenvalue computation is carried out. State variables which are most sensitive to a particular eigenvalue are identified through the use of participation factors. The system is progressively loaded and we observe the Hopf bifurcation phenomena. Through simulation on 3-machine and 10-machine systems, we are also able to verify the recent notion of "singularly induced bifurcation." We have also applied Kharitonov's theorem to find bounds on the load exponents n_p and n_q for robust stability at a given operating point using the testing function of Barmish. Both single- and three-machine test systems are used to illustrate the theory.

Dan Savignon

Date of Birth:	October 28, 1964
Place of Birth:	Urbana, Illinois
B.S.:	August 1987, University of Illinois
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Currently employed at:	U.S. Army Construction Engineering Research Laboratory

Maximum Power Supply Capacity and Simulation Interchange Calculations with Voltage Constraints

D. Savignon with advisor P. W. Sauer

Supported by the Power Affiliates Program and the Grainger Endowments

ABSTRACT

When performing maximum power supply and simultaneous interchange calculations, linear programming techniques using generator and transmission line capacity limits have been the preferred solution method. This project investigated ways to enforce bus voltage constraints in addition to the usual generator and transmission line capacity constraints when performing these calculations. It discovered a new method of approximating the change in bus voltage due to change in real power load. The new method uses the interesting fact that near maximum loadability, the impact of real power injection changes is nearly always equal to one half that of changes in reactive power injections. Since reliable sensitivities are available for reactive power and voltage, this provides a useful sensitivity for real power and voltage near maximum loadability.

Byron Truax

Date of Birth: January 30, 1953

Place of Birth: Columbus, GA

B.S.: June 1989, Southern Illinois University

M.S.: In progress

Professional Interests: Power electronics, industrial applications and controls.

A Generic Digital Testbed for Induction Motor Controllers

Byron Truax with advisor P. T. Krein

Supported by the University of Illinois ECE Dept.

ABSTRACT

This project builds on previous work by Scott A. Ellerthorpe to provide a testbed for implementation and evaluation of induction motor control strategies. The testbed includes a microcontroller (programmable in a high-level language [C]), sensors for measurement of a shaft position, speed, stator voltage and current, a switching power inverter, and an RS-232 user interface. A programmable load simulator using a dc motor (connected to the shaft of the induction motor) will be added to the system. The objective is to develop, demonstrate, and compare methods for precise dynamic control of induction motors, subject to the constraint that sensors must be external to the motor case.

Rob Weinstock

Date of Birth:	February 2, 1965
Place of Birth:	Des Plaines, Illinois
B.S.:	August 1989, University of Illinois
M.S.:	In progress
Professional Interests:	AC/DC motor drives and applications.

Optimal Sizing and Selection of Hybrid Electric Vehicle Components

Rob Weinstock with advisor P. T. Krein

Supported by the Hybrid Electric Vehicle Program and the Grainger Endowments

ABSTRACT

(Mr. Weinstock serves as Electrical Student Team Leader for the College of Engineering's Hybrid Electric Vehicle Program.)

A hybrid electric vehicle (HEV) combines electric traction with fuel energy storage. Proper execution of a successful HEV design for transportation applications requires optimal sizing of key mechanical, electrical, and power electronic components. An active program for HEV development is now in progress. The basic objective of an HEV design is to match the performance of a standard automobile while drastically reducing emissions. Constraints imposed while optimizing critical component selection are: vehicle range, acceleration, maximum speed, total emissions, cost, recharging, and driveability. A design example, based on readily available technology, is examined. It is reasonable to expect HEVs with good performance and order-of-magnitude emission reductions.

Graham Wright

Date of Birth:	December 12, 1961
Place of Birth:	Madison, Wisconsin
B.S.:	May 1984, Washington University
M.S.:	May 1987, University of Illinois
Ph.D.:	In progress
Professional Interests:	Research interests are application of electrostatic processes, computational fluid dynamics, advanced propulsion concepts and space technology, quantum mechanics, and analog circuits. Career interests in research and development in industry, academia, or government.

Electrohydrodynamics of a Liquid Meniscus

G. Wright with advisor P. T. Krein

Supported by Tektronix, Inc., and the Grainger Endowments

ABSTRACT

Electric fields can exert attractive force on the surface of conducting liquids. This is the basis of the electrostatic atomization (or spraying) phenomenon, which has found such diverse applications as in crop dusting, paint spraying, ink jet printing, and ion propulsion of spacecraft. The existing literature mainly examines cases in which the liquid surfaces are unmoving or the electric fields are static, and appears not to have addressed the theory of dynamic field-surface interactions. The project will analyze theoretically and experimentally the dynamics of a conductive meniscus formed with a Newtonian liquid and exposed to an electric field, in axisymmetric geometry. An improved understanding of electrified meniscus dynamics could open possibilities for dynamic manipulation of liquid surfaces using a time-varying electric field, which could be of benefit in the various applications.

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 six DEC engineering workstations, with a central VAXstation/GPX network server. Four stations have full color graphics. In addition, there are two advanced personal computers. A laser printer serves the computers. All eight 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)
PECO (Philadelphia Electric power system software collection)
ETMSP (EPRI Extended Transient Midterm Stability Program)
ATP (Alternate electromagnetics Transients Program)
MatrixX (system analysis software)
SYMNON (system analysis and design software)
Several EPRI packages

The software library is being expanded continually.

The Grainger Electrical Machinery Laboratory is now in its third year of operation. It 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 Hybrid 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 the Power Area. The facility has a dedicated 225 kVA three-phase supply and a 50 Kw d-c rectifier bank.

The laboratory has generated a great deal 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, a PC-controlled relay test system, high-performance distributed power supplies, and advanced ac motor controllers. Research in electrostatics is also conducted in this facility. Future projects in ultraminiature electrostatic motors are planned.

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