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FIFTEENTH ANNUAL REPORT
OF THE
POWER AFFILIATES PROGRAM

University of Illinois at Urbana-Champaign
Department of Electrical and Computer Engineering
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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 1993. The information is intended to be a progress report to the affiliate companies listed below. The PAP is the long-running and successful industrial liaison effort in the power and energy systems area. There are sixteen active affiliates associated with the PAP. They are:

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

1993 was an active year for the PAP and the highlights are covered in this report. We acknowledge the valuable support of the Affiliates and are most thankful to these companies for their continued support.

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

1. INTRODUCTION AND SUMMARY

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

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

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

Throughout the past fifteen 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 1993 is given in Section 2. This statement reflects our commitment to utilizing the majority of the PAP funds for direct 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 lists the activities of both the student and faculty members during the 1993 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 1993 was prepared from a detailed University statement as of December 31, 1993, Reference [2].

Income carried over from the calendar year 1992	$12,676
Total income during calendar year 1993	$58,500
Total available income during calendar year 1992	$71,176

Expenditure Category	Expenditure Amount
Personnel (Assistantships, wages)	$19,838
Materials/Supplies (Laboratory, library, office supplies)	$ 6,167
Transportation (Class trips, travel)	$ 8,258
Services (Publications, clerical, mailing, duplication, computer software, equipment maintenance)	$24,673
Equipment (Inventory equipment)	$ 503
Total	$59,439

Summary

Amount available during calendar year 1993	$71,176
Amount expended during calendar year 1993	-$59,439
Balance as of December 31, 1993	$11,737

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 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
Computer Engineering
Electromagnetics
Physical Electronics
Power and Energy Systems
Remote Sensing and Propagation

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 1/16 of the total active faculty and about 1/10 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 1993 - 1994 academic year together with their general interests are:

G. Gross	(Power System Economics, Planning and Operations; Public Utility Regulatory Policy, Utility Restructuring)
M. S. Helm, Emeritus	(Power System Analysis)
P. T. Krein	(Power Electronics, Machines, Electrostatics)
T. J. Overbye	(Dynamics, Stability and Operations of Power Systems)
M. A. Pai	(Dynamics, Stability and Computational Methods in Power Systems)
P. W. Sauer	(Modeling and Simulation of Machines and Power Systems)
R. J. Turnbull	(Energy and Conversion Technology, Sensors)

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

Two of the primary responsibilities of the Power and Energy Systems Area Committee are to update and staff the courses assigned to the Power and Energy Systems Area. In 1993-1994 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
ECE371HEV	Hybrid Electric Vehicle
ECE376	Power System Analysis I
ECE378	Power System Analysis II
ECE452	Computer Methods in Electric Network Analysis (Joint responsibility)
ECE468	Modeling and Control of Electromechanical Systems
ECE473	Operation and Control of Power Systems
ECE476	Dynamics and Stability of Power Systems
ECE490	Power and Energy Systems Area Seminar
ECE497GG	Electric Utility Resources Planning

The three-hundred level courses are advanced undergraduate or beginning graduate courses, while the four-hundred level courses are graduate. Of these courses, ECE468, and ECE476 were not taught during the 1993-1994 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 1993-1994 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 1993-1994 was 650.

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 1993-1994 was 110.

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 1993-1994 was 28.

ECE336 Advanced Electromechanical Energy Conversion

This three-hour course contains advanced theory and analysis of rotating and linear machines and drives. It includes power electronic drives for dc and ac motors. The analysis uses d-q transformations and related techniques. Emphasis is placed on the time scale modeling of electromechanical devices and on their function in drives. Class notes were used. The enrollment for the academic year 1993-1994 was 11.

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 Kassakian, Schlecht and Verghese. The enrollment for academic year 1993-1994 was 71.

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.

ECE371HEV/ME393DRW Hybrid Electric Vehicle

This project-oriented course involves the complete design, construction, and testing of a working hybrid electric vehicle which combines an electric traction system with a fueled auxiliary power unit. The enrollment for the 1993-1994 academic year was approximately 40, including students enrolled in the cross-listed Mechanical Engineering Section.

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 1993-1994 was Electric Power Systems by Del Toro. This course was also offered to off-campus working engineers by videotape. The enrollment was 28 on campus and 11 off campus.

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 1993-1994 was Power Generation Operation and Control by A. J. Wood and B. F. Wollenberg. This course was also offered to off-campus working engineers by videotape. The enrollment was 18 on campus and 9 off campus.

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 1993-1994 was 27.

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 offered during the academic year 1993-1994. The course has been produced on video tape.

ECE473 Operation and Control of Power Systems

The course includes energy control center functions, power system operating states, supervisory control and data acquisition, state estimation, on-line load flow, security assessment, economic dispatch, automatic generation control, optimal power flow, security constrained economic dispatch, multistage rescheduling and equivalents. The enrollment for the 1993-1994 academic year was 5.

ECE476 Dynamics and Stability of Power Systems

The course includes the dynamic representation of interconnected power systems - electrical plus mechanical, linearized dynamic models of multimachine systems, methods of coherency identification, order reduction by singular perturbation, time scale decomposition and aggregation techniques, dynamic equivalents, direct methods of stability analysis and power system stabilizer design. The current course text is a set of notes prepared by P. W. Sauer and M. A. Pai. This course is available on video tape. The course was not offered during the academic year 1993-1994.

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 1993-1994 was 21.

ECE497GG Electric Utility Resources Planning

This course provides coverage of the basic techniques in electric utility resource planning including methodologies for reliability evaluation and assessment, production costing, marginal costing, supply-side and demand-side planning and integrated resource planning. Throughout the course, probabilistic approaches are emphasized. In place of a text, notes specifically prepared by George Gross were used. The enrollment for 1993-1994 was 6.

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

1993-1994 Power Area Graduates

B.S.E.E.	-	51
M.S.E.E.	-	6
Ph.D.	-	1

5. ACTIVITIES

The faculty and students in the Power and Energy Systems Area participated in a considerable number of special activities during calendar year 1993. The major events are listed below:

- IEEE Power Engineering Society Winter Meeting
  - Tom Overbye presented a paper on Voltage Collapse and attended committee meetings.
  - Pete Sauer chaired the working group on Dynamic Security Assessment.
  - George Gross chaired the Computer and Analytical Methods Subcommittee meeting.
  - Stan Helm participated in committee meetings.

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

- ECE333 and ECE378 student class trip to the Cayuga generating station and the PSI Energy Control Center

- 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 Bechtel Power, Central Illinois Public Service Co., Commonwealth Edison Co., Illinois Power Co., Sargent & Lundy, Union Electric, Wisconsin Power and Light.
  - Tom Overbye and Pete Sauer attended.

- IEEE Power Electronics Specialists Conference
  - Phil Krein chaired the Education Committee, and presented papers on nonlinear ac motor control, on hybrid electric vehicle systems, and on power electronics education.
  - 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.
  - George Gross chaired the Computer and Analytic Methods Subcommittee meeting.
  - Stan Helm attended committee meetings.
  - Tom Overbye presented a paper on power flow solvability, attended committee meetings and received the Walter Fee Outstanding Young Engineer Award.

- IEEE Industry Applications Society Annual Meeting
  - Phil Krein presented a paper on electrostatic droplet control.
  - Bob Turnbull and Phil Krein attended committee meetings.

- IMA (Institute of Mathematical Analysis) workshop on "Systems and Control Theory for Power Systems" on March 15-19, 1993. M. A. Pai and P. W. Sauer presented invited papers.

- The hybrid electric vehicle team took part in the National 1993 Hybrid Electric Vehicle Challenge in Dearborn, Michigan. The team took first place in Engineering Design, fifth place overall, and received two special awards.

- M. A. Pai attended the Dynamic Security Assessment (DSA) Advisory Committee of the EPRI on March 10-11, 1993.

- Pete Sauer attended the Structural Stability final EPRI project review meeting and made a presentation.

- North American Power Symposium
  - Pete Sauer presented a keynote address on power engineering education.
  - Mark Laufenberg presented a paper on direct stability analysis.
  - Dave Cullum presented a paper on power system voltage stability.

- ECE376 Student Class Trip to Illinois Power Company's North Champaign Substation

- College of Engineering Advisory Board Meeting
  - Phil Krein represented the College with a presentation.

- Pete Sauer, M. A. Pai, and Tom Overbye presented an EPRI sponsored workshop on Nonlinear Dynamics in Power Systems. This workshop, which was held in November at Union Electric, was attended by more than 35 engineers and managers.

- Hybrid electric vehicle team visits to
  - Illinois Power
  - Commonwealth Edison
  - MagneTek, New Berlin, Wisconsin
  - Johnson Controls, Milwaukee, Wisconsin
  - Sorensen Company
  - Governors' Ethanol Coalition Annual Meeting, Peoria

- Phil Krein gave several presentations to university, civic, and industry groups about the hybrid electric car.

- Power Systems Computation Conference, Avignon, France, August 1993

  - George Gross was a member of the Technical Committee; organized and chaired a panel session on "The Opening of the Transmission System: Implications on Power System Planning, Operations and Control," presented a paper; and chaired a session.

- IEEE Power Systems Engineering Committee Triennial Meeting

  - George Gross was an invited speaker; he presented a plenary address in the restructuring of the electricity system in England and Wales.

- Wheeling and Dealing: Electric Transmission in the 1990's Conference, Oak Brook, IL

  - George Gross gave a presentation on transmission costing issues.

- Hosted the following guest speakers:

  - Prof. Felix Wu, University of California at Berkeley, "Net Plan: An Integrated Network Planning Environment"
  - Mr. Larry Brodsky, Illinois Power Co., "Deregulation: Does it really change anything?"
  - Prof. Hugh Rudnick, Universidad Catolica de Chile, "Deregulation of the power sector in Chile"
  - Dr. Young-Hyun Moon, Yonsei University, Korea, "A new approach to derive energy functions in power system stability analysis"
  - Dr. Brana Perunicic, University of Sarajevo, "Measurements for monitoring power quality"
  - Ms. Jennifer Sterling, Commonwealth Edison Co., "Voltage collapse"
  - Dr. Prabhakar and B. Patil, Ford Scientific Research Laboratory, "Ford Research in Electric Vehicles"

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.

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.; Magnetek, Inc.; Commonwealth Edison Co.; Central Illinois Light 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, J. Locker, M. Ransick, B. Truax

National Science Foundation Fellowship; 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.

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 as well as induction motor loads on voltage collapse. Also the effect of uncertainties in load modeling on robust stability has been investigated using Kharitonov-Barmish testing functions. An important result regarding the limits on load indices for existence of load flow solutions was obtained. The project has been completed and EPRI is coming out with the final report.

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 General Minimal Residual (GMRES) method which belongs to the family of conjugate gradient methods. Preconditioners using ILU(s) technique are successful in providing fast simulation. The convex C3 machine with 8 processors is used to demonstrate the technique. The research code simulates the 50 machine 145 bus IEEE system with a detailed two-axis model and IEEE Type I exciter.

Dynamic Security Assessment in Power Systems

M. A. Pai, M. Laufenberg

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 a 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 has been investigated. Visualization techniques assist the understanding of the energy function method. Preventive control strategies using sensitivity of the energy margin have been developed. Currently we are looking at a unified security assessment approach to both angle and voltage stability.

Hopf Bifurcation in Power Systems

M. A. Pai, D. Morris

National Science Foundation, ECS 91-19428

In this research we have developed a Matlab-based research grade program for Small Signal Stability Analysis (SSSA). This package is based on analytical linearization and gives exactly the same eigenvalue results as the EPRI-SSSP program. It uses the power balance equations and is flexible to include devices as well as to compute transient responses. We are investigating low frequency oscillations (Hopf bifurcation) in power systems using this software on a two-area system.

Multirate Integration Methods in Power Systems

M. A. Pai, T. Courtney, Katherine Blossfield

National Science Foundation ECS 91-19428 REU

In this research we are investigating the simulation of a power system having different time frames of dynamic phenomena using multirate integration techniques. The end objective is faster simulation. Instead of a purely numerical analysis approach, we do a time-scale decomposition of the system into fast and slow subsystems. We have obtained good results initially on a single machine system where the stator transients are considered fast and the rest of the dynamics are slow. This is an on-going project involving undergraduates in the department.

Load Modeling Concepts

P. W. Sauer and S. Fernandez

National Science Foundation, ECS 93-18695

This project is examining the basic structure of power system load modeling to determine the generic forms which capture critical phenomena. Time-scale analysis is being used to understand reduced-order models of aggregate loads and to formulate various levels of detail. Of particular interest is the effect that load models have on the nonlinear dynamic behavior of power systems. Initial results have shown that there is a fundamental difference between the effects of several large machines versus that of many small machines.

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:

Cullum, David (M.S.)
Ekambaram, Uma (M.S.)
Fernandes, Stephen (M.S.)
Finlay, David (M.S.)
Klump, Ray (M.S.)
Kulkarni, Ajit (M.S.)
Laufenberg, Mark (Ph.D.)
Locker, Jonathan (M.S.)
Midya, Pallab (M.S.)
Morris, David (M.S.)
Roethemeyer, Tim (M.S.)
Shimony, Anat (M.S.)
Truax, Byron (M.S.)
Wang, Shaojun (Ph.D.)
Weinstock, Rob (M.S.)
Wright, Graham (Ph.D.)

David Cullum

Date of Birth: December 1, 1969

Place of Birth: Peekskill, New York

B.S.: January 1992, University of Illinois

M.S.: May 1994, University of Illinois

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 was 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-Ln(V) curve and P-α curves.

Uma Ekambaram

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M.S.:	February 1994, University of Illinois
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Distributed Low Voltage Power Converters

U. Ekambaram with advisor P. T. Krein

Supported by the Power Affiliates Program and Sorensen Company

ABSTRACT

Low-voltage power distribution in automobiles, computers, telecommunications, and other applications is an issue of growing importance. With voltage levels of 12 V, 5 V, 3.3 V, or even less, distribution at the nominal voltage becomes difficult, and the wiring is heavy. For these systems, power can be distributed at a higher bus level, such as 48 V or 300 V, then converted to low voltage locally at each load. This project examined the special characteristics and problems in distributed dc-dc systems. The various distributed system arrangements were studied and compared based on typical applications. Solutions to some of the major special problems were proposed and tested. Analysis and experiments were conducted for a prototype 48 V to 2 V conversion system. One example of a special problem is bus overload response. Power converters act as constant power loads, and will draw excessive current if the distribution bus sags during an overload. A priority shutdown system was designed and tested to mitigate this problem. If a sag occurs, loads set for "low priority" will shut down to alleviate the overload while maintaining system operation. The project has successfully developed new design ideas for distributed dc-dc conversion systems.

Stephen Fernandes

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Place of Birth:	Rourkela, India
B.S.:	May 1989, Institute of Technology Varanasi, India
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 P. W. Sauer

Supported by the National Science Foundation

ABSTRACT

This project is examining the fundamental structure of aggregate load models. While dynamic load models need to reflect the wide use of induction motors, the system model cannot simply use a single induction motor dynamic model. General dynamic load models are being investigated to see which ones properly reflect the characteristics of many induction motors.

David Finlay

Date of Birth:	January 21, 1971
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B.S.:	July 1993, University College, Dublin, Ireland
M.S.:	In progress
Professional Interest:	Economics of power systems.

Generator Bidding Strategies in the England and Wales Power Pool

David Finlay with advisor George Gross

Supported by the Grainger Endowments

ABSTRACT

The privatization of the England and Wales electricity supply industry has unleashed competitive forces in all segments of electricity markets. Competition in the generation area has brought with it a whole new set of problems that until now have not concerned power system engineers. Not least of these problems is the development of bidding strategies to take advantage of the sealed bid auction for the right to serve load. Indeed such is the complexity of the pool rules that formulation of the problem itself is a challenge. Auction theory, optimization techniques and game theoretic tools will be used to shed some light on this new problem.

Ray Klump

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Professional Interests:	Power systems

Study and Enhancement of Newton-Raphson Power Flow Convergence Properties

Ray Klump with advisor T. J. Overbye

Supported by the Power Affiliates Program and Grainger Endowments

ABSTRACT

The Newton-Raphson formulation of the power flow has been a standard power systems analysis tool for many years. For most of that time, interest has focused primarily on finding a single power flow solution starting from an initial guess, which is normally close to the expected solution. However, as systems have become more heavily loaded, transient stability and voltage stability have become growing areas of concern. Assessing these types of stability often requires finding power flow solutions at which the power system typically would not operate; these are the so-called low voltage solutions. Finding these low voltage solutions poses a significant challenge and requires a substantial amount of guesswork because the convergence properties of the Newton-Raphson load flow equations are not very well-understood. The purpose of this investigation is to explore these convergence properties so as to make the Newton-Raphson power flow more deft at finding alternative solutions.

Ajit Kulkarni

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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 speedup 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 conjugate gradient style methods with suitable preconditioners has been done on the Cray Y-MP for a 10-machine 39-bus system with detailed two-axis representation for each machine. Further work includes use of better preconditioners and testing on large systems.

Mark Laufenberg

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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.

Jonathan Locker

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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

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B.S.:	Indian Institute of Technology, Kharagpur
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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. A sensorless current mode control scheme has been developed that eliminates the necessity of measuring all of the states. Active filtering techniques have been developed to suppress ripple and improve dynamic response.

David Morris

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Analysis of Bifurcations in Power Systems

David Morris with advisor M. A. Pai

Supported by the National Science Foundation and the Grainger Endowments

ABSTRACT

Static bifurcation in power systems which occurs in power systems for stressed cases is associated with physical concepts such as voltage collapse and maximum loadability. When dynamic models of power systems are included in the analysis, we have the Hopf bifurcation phenomenon. In this research we plan to investigate this and study the impact of other dynamic devices, such as the PSS on Hopf bifurcation. Enhancements to a MatLab software for small signal analysis (SSA) will be used to compare the results with the EPRI-SSSP package. A realistic two-area system will be used in the studies.

Tim Roethemeyer

Date of Birth:	July 26, 1964
Place of Birth:	Nashville, Illinois
B.S.:	August 1993, University of Illinois
M.S.:	In progress
Professional Interests:	Electric vehicles, traction systems.

Traction Motor Control of Electric Vehicles

T. Roethemeyer with advisor P. T. Krein

Supported by the Hybrid Electric Vehicle Program

ABSTRACT

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

This research deals with the complex control that accompanies an induction motor-based traction system for an electric vehicle. With recent advances in power electronics, variable speed induction motor drives are readily available. Only a vector-control drive can be used for the torque control which is required for a transportation vehicle. Primarily, dc bus current control may be used with an ordinary speed control drive to produce a quasi torque controller without the need for accurate attributes of the motor (as are necessary for proper operation of vector control drives). As well, the motor can also be directly coupled to a manual transmission in which proper motor control during the shifting process provides quick, accurate clutchless shifting.

Anat C. Shimony

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M.S.: In progress

Professional Interests: Bioelectromagnetics, computational techniques in electromagnetic fields and waves, power and control systems.

Development of Three-Dimensional Software Simulations of the Magnetic Fields in a Residence and Surroundings

Anat C. Shimony with advisors R. L. Magin, P. T. Krein and R. J. Turnbull

Supported by the Power Affiliates Program and the Grainger Endowments

ABSTRACT

The goal of this project is to develop a software simulation for the three-dimensional visualization of 60 Hz magnetic fields in a typical residence and its surroundings. The simulation and display software will provide a dynamic tool for the realistic analysis of magnetic field distributions. For example, the simulation could be used to explore field intensities in the vicinity of house appliances.

Byron Truax

Date of Birth: January 30, 1953

Place of Birth: Columbus, GA

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Professional Interests: Power electronics, industrial applications and controls.

A Generic Digital Testbed for Induction Motor Controllers, with Programmable Load

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 shaft position, speed, and stator voltage and current, a switching power inverter, and an RS-232 user interface. A programmable load simulator using a dc machine has been added to the system. The objectives are to develop, demonstrate, and compare methods for precise dynamic control of induction motors, under a variety of realistic load conditions.

Shaojun Wang

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Place of Birth:	Hebei, P.R. China
B.S.:	July 1988, Tsinghua University
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Ph.D.:	In progress
Professional Interests:	Power system planning and operation.

Title

S. Wang with advisor G. Gross

Supported by the Power Affiliates Program and Grainger Foundation

ABSTRACT

A systematic technique for assessing multiarea reliability is being explored with the view of extending it to evaluate multiarea production costing. The modeling of the lines and their constraints is being given special attention. A major part of the work will focus on the application of parallel computation for speeding up the multiarea production cost evaluation. Major applications include interchange contract evaluation, geographically differentiated marginal costing and strategic planning.

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
Current Status:	Student in M.B.A. program at UIUC.

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

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. An HEV designed and built at the University of Illinois has made good use of the tradeoffs. This vehicle has the look, feel, and performance of a stock automobile while providing emission reductions of 80-90% in extended driving, and up to 99% in short-range commuting.

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.:	October 1993, University of Illinois
Currently employed at:	Dept. of Mechanical and Industrial Engineering, University of Illinois

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 an 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 three IBM RS6000s and three DEC engineering workstations. Four stations have full color graphics. In addition, there are four advanced personal computers. A laser printer serves the computers. All stations are connected to the campus network, which, in turn, provides access to major international networks via Internet.

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

Mathematica (an advanced symbolic mathematics package)
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)
IPFLOW (Interactive Power Flow)
SSSP (Small Signal Stability Analysis)
INSITE (Interactive Nonlinear Systems Investigative Toolkit for Everyone)
MatLab

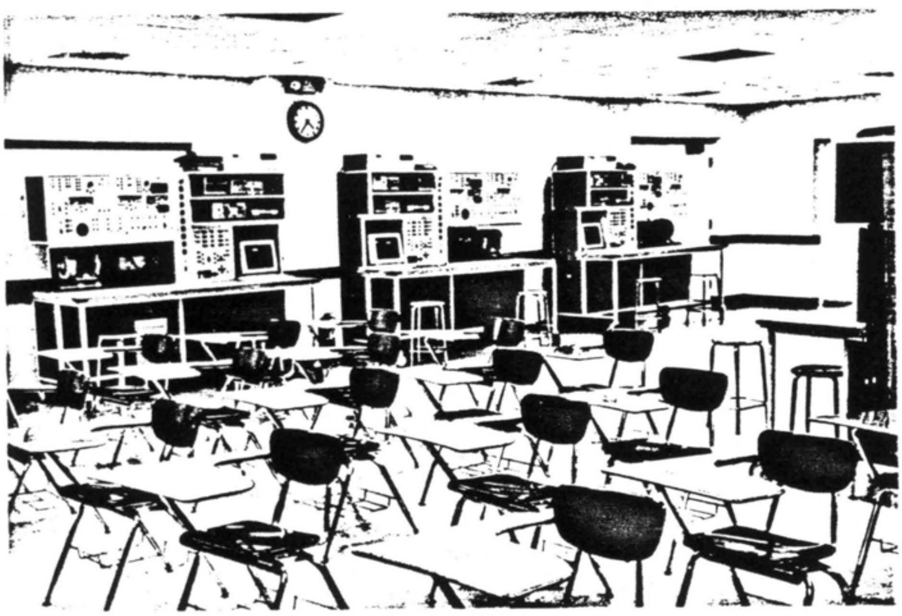
The software library is being expanded continually.

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

The laboratory has generated a 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, high-performance distributed power supplies, advanced ac motor controllers, and electric vehicle drives. Research in electrostatics is also conducted in this facility.



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