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Annual Summary Activities of the Purdue Electric Power Center May 1988 - April 1989

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Purdue University

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Annual Summary

Activities of the Purdue Electric Power Center

May 1988 - April 1989

G. T. Heydt

TR-EE 89-13
April, 1989

School of Electrical Engineering
Purdue University
West Lafayette, Indiana 47907

Annual Summary

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Chapter I
The Purdue Electric Power Center

1.1 PEPC

The Purdue Electric Power Center (PEPC) is a consortium of fifteen power engineering companies and Purdue University whose goal is to maintain a center of excellence in power engineering at Purdue. The sponsoring companies are listed in Table 1.1 (a full directory appears in an Appendix). The PEPC program was founded in 1971, and since its inception there have been changes in its industrial membership, but the majority of the original sponsors are still program sponsors. The approximate 1988 budget was $120,000.

The PEPC program forms a base of support for the power program at Purdue. It brings together students, faculty, and the sponsors in ways which promote power engineering. Major efforts of the program include encouragement of undergraduates to work in power, support of masters level students in the power area, providing resources for laboratory development, and providing resources for faculty professional development.

The Purdue Electric Power Center has had its successes and its disappointments. However, the principal point which we can claim is that we are maintaining an active power engineering program at Purdue. Our principal disappointment is that we are not achieving the growth which we would like.

Our efforts in power engineering encompass a wide range of area including:

- High voltage engineering
- Distribution engineering
- Instrumentation
- Power electronics
- Power systems
- Reliability
- Transients
- Alternate energy sources
- Simulation techniques
- Energy conversion
- High voltage DC systems
- Mechanical engineering aspects of power engineering
- Nuclear power

Table 1.1
PEPC Sponsoring Companies

American Electric Power	Columbus, OH
Applied Energy Services	Arlington, VA
Bechtel National	San Francisco, CA
Central Illinois Public Service	Springfield, IL
Cleveland Electric Illuminating	Cleveland, OH
Commonwealth Edison	Chicago, IL
General Electric	Fort Wayne, IN
Illinois Power	Decatur, IL
Indiana Michigan Power	Fort Wayne, IN
Indianapolis Power and Light	Indianapolis, IN
Northern Indiana Public Service	Hammond, IN
Pacific Gas and Electric	San Francisco, CA
Public Service Indiana	Plainfield, IN
Sargent and Lundy Engineers	Chicago, IL
Southern Indiana Gas and Electric	Evansville, IN

The PEPC program is administered by the School of Electrical Engineering, but the Schools of Mechanical and Nuclear Engineering are also active in PEPC. The day-to-day operation of the program is administrated by the committee shown in Table 1.2. Professor G. T. Heydt served as the committee chairman in 1988.

1.2 Principal PEPC activities

Graduate student support

A major effort in the area of graduate student support continues to be made by PEPC. Only Masters level students, United States nationals (or permanent residents) are supported. Eight such students were supported by PEPC in the fall semester of 1988 and nine students were supported in the spring of 1988 and nine students were supported in the spring of 1989.

Undergraduate student support

Undergraduates are employed in the high voltage laboratory and as project assistants. This year, PEPC supported six such students.

Senior of the year

The PEPC committee selects one student from each of the participating departments, EE, ME, NE, as the senior of the year in power engineering. The main criteria of this selection are academic excellence and committment to power. This year the EE award was made to twin brothers in Construction Engineering because of academic excellence in work in Electrical Engineering. The recipients for 1988 were:

Joseph Franchville,	CE,	Fort Branch, IN
James Franchville,	CE,	Fort Branch, IN
Donna Geraghty,	ME,	Chicago, IL
John Stevens,	NE,	W. Lafayette, IN

PEPC - Mester

In the spring 1989 semester, we began a new program for undergraduates: the PEPC - Mester. This program is intended to encourage undergraduates to work in power engineering. The main features of the PEPC - Mester are a tuition rebate program, work on a power project, a summer intership in the power industry, and presentation of a seminar on their project work. Participants were selected on the basis of academic record and interest in power. The program is intended primarily for students in their junior year. Each participant is required to register for at least 10 hours of power courses. This year's participants are:

Table 1.2
The PEPC Committee

F. Clikeman	Nuclear Engineering
K. Hawks	Mechanical Engineering
G. T. Heydt	Electrical Engineering
P. Krause	Electrical Engineering
L. Ogborn	Electrical Engineering
C. M. Ong	Electrical Engineering
O. Wasynczuk	Electrical Engineering
W. Weeks	Electrical Engineering

Erik Hanson,	Cossayuna, NY
Glen Nakafuji,	Honolulu, HI
Charles Thompson,	Amherst, OH
George Wegh,	Terryville, CT

The participants are working on a project on speed control of a 5 Hp, three phase induction motor. Mr. Michael Porter, an undergraduate, is also working on the project.

Field trips

The Purdue Electric Power Center supports field trips by undergraduates. This year visits were made to the Cayuga Generating Station (Public Service Indiana), Cayuga, IN; a power seminar at the University of Illinois, Champaign, IL; and a power seminar at Iowa State University, Ames, IA.

PEPC Annual Meeting - 1988

The PEPC Annual Meeting was held in May, 1988. This meeting is intended to report PEPC activities to the sponsoring companies. A morning session is dedicated to solicitation of input from the sponsoring companies. The students report the results of their projects at afternoon sessions. This year, 42 participants attended the PEPC Annual meeting.

Power Quality Seminar

A PEPC Seminar on Power Quality is planned for March 2, 1989. Table 1.3 shows the schedule for the seminar.

1.3 Other activities

North American Power Symposium

The 1988 North American Power Symposium, NAPS, was held at Purdue, September 26-27, 1988. This is a meeting intended to bring power engineering educators and students together to discuss their work. This year, the attendance was 80, and we had good support from local utility companies. There was a useful representation from the power industry across the United States and Canada. Table 1.4 shows the program schedule. The 1989 NAPS will be at the University of Missouri-Rolla. Copies of the Proceedings of the 1988 NAPS are available from Dr. Heydt at $35/copy.

Table 1.3
Power Quality Seminar

G. T. Heydt, Coordinator
3/2/89

Objectives

To raise awareness of issues relating to electric power quality. Also, to describe the technical details of generation, propagation, and amelioration of non-sinusoidal phenomena in electric power networks.

Attendees

The seminar will be open to all interested persons. There is no registration fee for attendees from PEPC companies

Instructors

G. Heydt, Purdue University; R. Kramer, Northern Indiana Public Service Co.; L. Ogborn, Purdue University; K. Olejniczak, Purdue University; C-M. Ong, Purdue University

Schedule

8:30 a.m.	Registration
9:00	Introduction, Definitions of terms. Examples, G. T. Heydt
9:30	IEEE Standard 519, G. T. Heydt
10:00	Electrical power converters, C. M. Ong
10:45	Break
11:00	Constant voltage transforms and uninterruptable power supplies, G. T. Heydt
12:00	Lunch
1:30 p.m.	Experience with instrumenting and monitoring of transients and harmonics at NIPSCO, Dr. Robert Kramer, Director of Electric Operations, NIPSCO
2:30	Capabilities of Semiconductor switching devices, minimizing problems at the device site, and FCC regulations, L. L. Ogborn L. L. Ogborn
3:15	Break
3:30	Laplace, Fourier, and Fast Fourier Transform solutions, K. Olejniczak
4:30	Propagation of pulses, G. T. Heydt
5:15	Adjourn

Table 1.4
North American Power Symposium
September 26-27, 1988

NAPS-I **Load Flow Studies and Protection**

Graphic and Symbolic Analysis of Power Systems
C Cañizares, F. Alvarado
University of Wisconsin, Madison

Z-Loop Distribution Load Flow Calculations Considering Enclosure Loops
C. Lin, Y. Huang, C. Huang
Chen Kung University,
Institute of Aeronautics & Astronautics, Taiwan

High Speed Digital Directional Relay Using Amplitude Comparator Technique
K. Prakash, O. Malik, G. Hope
University of Calgary

A Microprocessor Protective Relaying System for a Plant Class Substation
M. Vichitchot, A. Ghandakly
University of Toledo

Unbalanced Network Load Flow Analysis
H. Kua, D. Koval, D. Kelly
University of Alberta

NAPS-II **Reactive Power and Voltage Control**

The History of Reactive Power
A. Kloss
BBC Brown Boveri Ltd. (Switzerland)

Reactive-Power Dispatch by an Active-Set/Quadratic Programming Method
V. Quintana, M. Santos-Nieto
University of Waterloo

Design of Reactive Power Modulation Control Over a Wide Range of Load Characteristics for AC/DC Systems
K. Ellithy, M. Choudhry
West Virginia University

A New Method for Optimal Voltage Control
J. Momoh,
Howard University

NAPS III-A **Security and Reliability**

An Efficient Approach to Load Modeling for Multi-Area Reliability Calculations
A. Lago-Gonzalez, C. Singh
Texas A & M University

State Estimation Based External Network Model
C. Lu, K. Liu
Harris Corporation

Analysis of Faulted Power Systems Using the Householder's Formula
A. Pahwa
Kansas State University
A. Chavez
Escuela Superior Politecnica del Litoral (Ecuador)
J. Shultis
Kansas State University

Application of Dynamic Security Region Approach to Electric Power System
F. Malek
Trenton State College
D. Nevius
North American Electric Reliability Council
K. Loparo
Case Western Reserve University

NAPS III-B **Power Systems Transients and Control**

Design of a Model Reference Adaptive Controller for Coordinating the Exciter and Governor Loops of Power Generators
P. Idowu, A. Ghandakly
University of Toledo

A Parametric State Feedback Control for the Exciter and Governor Loops of a Synchronous Generating Unit
H. Tantawy
Al-Azhar University
A. Ghandakly
University of Toledo

Some Recent Issues and Applications of Modal Analysis in Power System Dynamics
A. Hamdan, H. Hamdan
Virginia Polytechnic Institute and State University

Evaluation of Transient Stability Economic Benefits of SVC
T. Jung, F. Alvarado
University of Wisconsin

NAPS IV-A **Power Systems Transients and Security**

Dynamic Security Assessment Including Relay Performance
F. Dobraca, M. Pai, P. Sauer
University of Illinois at Urbana-Champaign

Time Dependent Network Reliability Evaluation
H. Kua, D. Koval
University of Alberta

Network and Generation Rescheduling for Security Load Flow of Power Systems
N. Muller, V. Quintana
University of Waterloo

NAPS IV-B **High Voltage Engineering**

Accurate Theoretical Expressions for Computing Unipolar DC Corona Losses
M. Aboelsaad
University of Manitoba
M. Marcos
Kansas State University

Choice of Air Insulation Clearances Based on Random Energization Transients in EHV Systems
M. Morcos
Kansas State University
H. Anis
Cairo University

Voltage Flicker Problems Associated with a Single Phase Induction Furnace Operation: Wisconsin Power and Light Experience
M. Muslu, R. Schultz
University of Wisconsin-Platteville
A. Brown, W. Stroees,
Wisconsin Power and Light Company

NAPS V-A **Harmonics and Simulation**

Harmonic Analysis of Repulsion Motor Controlled Via a Stator Triac
Z. Salameh, C. Cho
University of Lowell

Phase Plane Analysis of DC-DC Converters
R. Bass, P. Krein
University of Illinois at Urbana-Champaign

Investigations on Rotor Harmonics of Induction Motors
R. Natarajan,
Pennsylvania State University

Harmonic Impact of an Unbalanced Six-Pulse Converter
K. Olejniczak, G. T. Heydt
Purdue University

NAPS V-B **Machines I**

Self-Excitation in Single, Line Commutated Inverters in Utility-Connected Residential Photovoltaic Applications. Part I - Analysis
S. Ranade, N. Prasad, S. Omick
New Mexico State University

Self-Excitation in Single Line Commutated Inverters in Utility-Connected Residential Photovoltaic Applications. Part II - Comparison with Field Tests
S. Ranade, N. Prasad, S. Omick
New Mexico State University

Reduction of the DC Motor Drive Armature Copper Losses Via Optimal Control, Part I - Problem Formulation and Solution
M. Ostojic, V. Lukic,
University of North Carolina at Charlotte

Reduction of the DC Motor Drives Armature Copper Losses Via Optimal Control, Part II - Algorithm
M. Ostojic, V. Lukic, N. Liu
University of North Carolina at Charlotte

NAPS VI-A **Machines II**

A Digital Controller Hardware Design for a Laboratory Power Generating Unit Using an IBM PC
A. Ghandakly,
University of Toledo

A New Approach to the Digital Simulation of 2-Phase Induction Machines
T. Sustersic, A. Keyhani,
Ohio State University

Time Domain Simulation of Synchronous Machine Imbalanced Faults Using PC-Matlab
H. Saadat,
Michigan Technological University

NAPS VI-B **Analysis of Power System Dynamic Operation**

Power System Stability Behavior for Multiple Generation Shifts
J. Moore
Iowa State University

Performance of Electromagnetic Transients Program (EMTP)
R. Natarajan, D. Gentzler
Pennsylvania State University

Reducing the Output Voltage Ringing in Three-Phase Power Conditioning Systems Via Design Modifications
S. Miri
University of North Carolina

A. Keyhani
Ohio State University

NAPS VII **Power System Operations**

Assessment of Battery Energy Storage for Industrial Loads
B. McKinney, M. Anderson, E. Richards
R. Kluczny
University of Missouri-Rolla

Integrated Computing Environment for Electric Power Networks
M. Daneshdoost, R. Chaath
Southern Illinois University

Artificial Intelligence and Its Application to Expert Systems in Power System Operation
S. Arunachalam, E. Tweed, E. Richards
University of Missouri - Rolla

NAPS VIII **Power System Transients and Stability**

Optimum Digital Feedback Gains Determined by Endpoint Performance Indices
B. Granborg
University of Hawaii

Time-Scale Analysis of Excitation Control
A. Varghese, P. Sauer, M. Pai,
University of Illinois at Urbana-Champaign

Second Order Correction to the Energy Margin Sensitivity In the TEF Method
E. Zhou, A. Fouad
Iowa State University

Approximation of Dissipation Terms In the Transient Energy Function
H. Shih, V. Vittal
Iowa State University

International Conference on Harmonics in Power Systems

The Third International Conference on Harmonics in Power Systems, ICHPS, was held in Nashville, Indiana on September 28 - October 1, 1988. The meeting was sponsored by Purdue. The meeting brought together over 160 power engineers from around the world to discuss harmonics in power systems. Table 1.5 shows the meeting schedule. Proceedings of the meeting are available from Dr. Heydt at a cost of $50/copy.

Societal-Professional Awarness Conference

On January 25, 1989, the IEEE student branch hosted Societal-Professional Awareness Conference (S-PAC) at Purdue. Professor Zoltowski, organized the meeting. Mr. Larry Dwon, reired power engineer, opened the meeting.

Visiting Fullbright Fellow

Mr. Dejan Ostojic of the University of Belgrade, Belgrade, Yugoslavia is spending a year at Purdue as a visiting Fullbright Fellow. Mr. Ostojic is working in the area of power system stability. He will be at Purdue through September, 1989.

PIWI Meeting

The University of Illinois hosted the third Purdue-Illinois-Wisconsin-Iowa State (PIWI) meeting at Champaign in November, 1988. The meeting brings together power professors and students at the four universities to help foster power engineering and encourage students to work in this area. Among the PIWI projects which are underway are the preparation of a paper on power engineering education for the 1989 American Power Conference and production and exchange of videotaped lectures on power engineering topics.

NSF-REU Grant

The National Science Foundation made a "Research Experience for Undergraduates" (REU) grant to Dr. Heydt in 1988. This was a $9,000 grant to support two undergraduate students in a research-laboratory setting. Messrs. Robert Trajkowski of Hammond and Dan Gojmerac, also of Hammond, IN, worked on measurement of harmonic signals in unbalanced three phase distribution systems. A report is available.

1.4 News items

Dr. Ahmed H. El-Abiad

Dr. Ahmed H. El-Abiad, Professor Emeritus at Purdue, died after a heart attack in Cairo, Egypt. Dr. El-Abiad was 62 years old. Dr. El-Abiad had taught in power engineering at Purdue for over 20 years.

Table 1.5
Third International Conference on
Harmonics in Power Systems
Sept. 27 - Oct. 1, 1988

Keynote Presentation

A. Emanuel, J. Orr, D. Cyganski, "Review of harmonics fundamentals and proposal for a standard terminology," Worcester Polytechnic Institute, USA.

ICHPS I Analysis Techniques

I-1 A. P. S. Meliopoulos, G. J. Cokkinides, "Effects of transmission line model accuracy on the computation of harmonic resonance parameters," Georgia Institute of Technology, USA.

I-2 D. Xia, Z. Shen, Z. Shu, "Unified fundamental frequency and characteristic harmonic load flow solution in AC/DC power systems," Xian Jiaotong University, PRC.

I-3 H. Tsuchihashi, K. Sato, N. Shinohara, T. Naito, K. Komatsugi, "Analysis of commutation overshoot phenomena in distribution systems," Tokyo Electric Power Co., JAPAN.

I-4 Y. Yao, A. M. Sharaf, "Uncharacteristic harmonics caused by AC system imbalances and the effects of smoothing reactor," University of New Brunswick, CANADA.

I-5 P. K. Dash, A. M. Sharaf, "A Kalman filtering approach for estimation of power system harmonics," Regional Engineering College-Rourkela, INDIA.

ICHPS II Computational Techniques and Non-ideal Conditions

II-1 A. M. Dan, "Harmonic content of the phase to ground fault current and its decreasing," Technical University of Budapest, HUNGARY.

II-2 Y. Baghzouz, S. M. Ertem, "A direct method to compute voltage harmonic distortion caused by static power converters," University of Nevada - Las Vegas, USA.

II-3 W. E. Kazibwe, T. H. Ortmeyer, M. S. A. A. Hammam, "Probabilistic evaluation of uncharacteristic harmonics in static VAR compensators," Clarkson University, USA.

II-4 G. Carpinelli, A. Piccolo, M. Scarano, G. Vicedomini, "Harmonics evaluation in static VAR compensators with thyristor-controlled reactor under non-idealized conditions," University of Cassino, ITALY.

ICHPS III Applications and Case Studies

III-1 G. Lemieux, "Power system resonance - a documented case," Hipp Engineering, CANADA.

III-2 W. T. Jewell, R. I. Egbert, "A study of harmonics in Kansas utility systems," Wichita State University, USA.

III-3 P. L. Atwater, M. L. Jacobs, "A new single phase directional harmonic overcurrent relay," U. S. Bureau of Reclamation, USA.

III-4 H. Mori, S. Tsuzuki, T. Sakurai, Y. Kojima, N. Satoh, "Identification of harmonic current characteristics in power systems," Meiji University JAPAN.

III-5 D. Melvold, F. Hormozi, "AC filter specifications and performance on various HVDC projects of the Los Angeles Department of Water and Power," Los Angeles Department of Water and Power, USA.

III-6 G. Montanari, M. Loggini, "Harmonic distortion in electrical plants supplying non-linear loads," Universita di Bologna, ITALY.

ICHPS-IV Measurement Techniques

IV-1 L. C. de Alcantara Fonseca, P. F. Ribeiro, R. Ximenes, "Measurement and analysis of harmonics due to a static compensator operating in a long radial system (Brazil's Northeast)," Companhia Hidro Electrica do Sao Francisco, BRAZIL.

IV-2 X. Dai, T. Tang, "A novel three-phase power harmonic analyzer based on the quasi-synchronous sampling principle," Tsinghua University, PRC.

IV-3 M. L. Jacobs, G. Langer, "An ultra-low distortion, isolation potential transformer for power system harmonic measurements," U.S. Bureau of Reclamation, USA.

IV-4 R. S. Thallam, "Impedance — frequency characteristics of a 115 KV distribution system," Salt River Project, USA.

IV-5 G. E. Littler, "A digital harmonic analyzer for electrical power systems," Queensland Institute of Technology, AUSTRALIA.

IV-6 P. S. Filipski, R. Arseneau, "Definition and measurement of apparent power under distorted waveform conditions," National Research Council, CANADA.

ICHPS V(A) Loads and Distribution Circuits

VA-1 G. Franceschini, S. Pirani, M. Rinaldi, C. Tassoni, "Theoretical and experimental investigation on switched reluctance drive on-line harmonics," Instituto di Elettrotecnica Industriale, ITALY.

VA-2 W. Song J. Ai, "Harmonic analysis of current supplied to an electric railroad locomotive," Tianjin University, PRC.

VA-3 M. G. Wickramasekara, D. Lubkeman, "Application of sensitivity factors for the harmonic analysis of distribution system reconfiguration and capacitor problems," North Carolina State University, USA.

VA-4 B. Shperling, L. Menemenlis-Hopkins, "Generation and distribution of current harmonics on EHV systems," New York Power Authority, USA.

ICHPS V(B) Filtering Techniques

VB-1 D. W. Hart, G. T. Heydt, "Active filter design power system network analysis in the vicinity of HVDC converters," Valparaiso University, USA.

VB-2 D. Kim, T. Nakajima, E. Masada, "Harmonic analysis of a capacitor filtered rectifier in low voltage distribution network," University of Tokyo, JAPAN.

VB-3 T. Kuwabara, N. Itoh, "Practical application of series filter for power system," Toshiba, JAPAN.

VB-4 M. Loggini, G. C. Montanari, E. Tironi, D. Zaninelli, "Non-Linear resistance for filter design," University of Bologna, ITALY.

ICHPS VI HVDC, Converters, and Cycloconverters (I)

VI-1 Albert Kloss, "Interaction between the DC and AC side of large twelve-pulse converter systems," BBC, SWITZERLAND.

VI-2 Y. Xu, V. I. John, G. E. Dawson, "A new method for spectral calculation of switching converters." Dr. John, Queen's University, CANADA.

VI-3 M. Grotzbach, B. Draxler, L. Lorenz, "Influence of ripple and commutation on the line harmonics of controlled six-pulse bridge converters," University of Federal Defense, WEST GERMANY.

ICHPS VII HVDC, Converters and Cycloconverters (II)

VII-1 J. C. de Oliveira, J. Resende, R. Yacamini, "DC side harmonics and their effect on AC side harmonics associated to multiple converter systems under non-ideal conditions," Universidade Federal de Uberlandia, BRAZIL.

VII-2 A. Bensenouci, C. M. Ong, "AC current harmonics from HVDC converters," Purdue University, USA.

VII-3 G. M. Brown, L. Magnard, B. Szabados, "Improving the harmonic performance of a cycloconverter by a novel jitter control method," McMaster University, CANADA.

VII-4 H. M. Rashid, A. I. Maswood, "Analysis and performances of forced commutated 3-phase AC-DC converters under unbalanced supply conditions," Concordia University, CANADA.

VII-5 D. Xia, Z. Shen, Q. Liao, "Solution of non-characteristic harmonics caused by multiple factors in HVDC transmission system," Xian Jiaotong University, PRC.

ICHPS VIII Compensation and Reactive "Power".

VIII-1 S. Sun, "Considerations on the compensation of the reactive current and harmonics," Tsinghua University, PRC.

VIII-2 J. Arrillaga, E. Acha, N. Watson, N. Veale, "Ineffectiveness of transmission line var compensation at harmonic frequencies," University of Canterbury, NEW ZEALAND.

VIII-3 W. Xu, H. Dommel, "Computation of steady-state harmonics of state VAR compensators," University of British Columbia, CANADA.

VIII-4 Y. Baghzouz, "Power factor correction for combination of linear and non-linear loads under balanced and unbalanced conditions," University of Nevada - Las Vegas, USA.

ICHPS IX Modelling

IX-1 A. Keyhani, H. Tsai, "Transfer function determination and parameter estimation for power transformer models from frequency domain data," The Ohio State University, USA.

IX-2 A. E. Emanuel, "The effect of harmonic randomness upon temperature rise of electrical equipment," Worcester Polytechnic Institute, USA.

IX-3 C. E. Lin, J. B. Wei, C. L. Huang, C. L. Cheng, C. J. Huang, "Harmonics analysis of magnetizing inrush current in transformers under no-load condition," Cheng

Kung University, REPUBLIC OF CHINA.

IX-4 G. L. Viviani, L. Li, "A transformer model for investigating the effects of harmonics," Lamar University, USA.

IX-5 T. H. Ortmeyer, N. Kakimoto, T. Hiyama, M. S. A. A. Hammam, "Harmonic performance of individual and grouped loads," Clarkson University, USA.

IX-6 E. Acha, J. Arrillaga, "Modal analysis of harmonic propagation with particular reference to the effect of transmission line transpositions," University of Canterbury, NEW ZEALAND.

IAEA Project in Guatemala

Dr. G. T. Heydt completed a project on electric power quality sponsored by the International Atomic Energy Agency in December, 1988. The project started in March, 1988 and was principally located in Guatemala City. The IAEA is the technical arm of the United Nations, and it is represented in the United States by Argonne National Laboratory. The project concerned alternative power conditioning technologies, and applications of uninterruptable power supplies.

Professor Krause returns from sabbatical leave

Dr. Paul C. Krause returned from sabbatical leave in September, 1988. He had spent a year working in the area of electric power engineering research.

EE Centennial celebrated

The School of Electrical Engineering celebrated its Centennial (1888-1988) on October 15-18, 1988. Highlights of the celebration were the laying of the cornerstone of the new Materials and Electrical Engineering Building by Govenor Orr, a lecture "a la 1930's" by Professor Emeritus William H. Hayt, and a series of distinguished lectures.

1.5 Future plans

Our most pressing goal is to increase the size of the undergraduate program. There are several main elements in our efforts in this area including the continuation and expansion of the PEPC-Mester. This is a scholarship and educational program with the following key features

- Tuition rebate
- Students must have a substantial semester course load in the power area
- Students must work on a power project
- A summer intern program will be made available to participants
- Field trips and visits to some of the sponsoring companies will be made.

In addition to PEPC-Mester, we plan to hold power workshops in an off-campus setting for 20-30 students. These are intended to motivate undergraduate engineers to work in the power area. The next PEPC-Mester is planned for the Spring, 1990.

In the graduate program, we expect that the PEPC support of 10-15 master's level, U.S. nationals will continue. It is necessary to expand our other support sources to allow us to have 30 to 50 graduate students in power. A group of this size is needed to allow us to offer all the graduate courses in our educational program.

Chapter II
The Faculty in Power Engineering

2.1 The PEPC committee

FRANKLYN CLIKEMAN is Professor of Nuclear Engineering and represents the School of Nuclear Engineering on the PEPC Committee. He joined the Purdue Faculty in 1970. He has been chairman of the undergraduate curriculum committee in Nuclear Engineering and the head student advisor since 1974. Professor Clikeman is Acting Head of Nuclear Engineering.

Professor Clikeman's research interests include the experimental investigation of neutron and gamma-ray transport in fast reactor blankets, radiation transport in fusion reactor blankets and the application and detection of nuclear radiation. He is director and principal investigator of the Fast Breeder Blanket Facility which is supported by DOE, EPRI, and PEPC.

KEITH H. HAWKS joined the faculty of the School of Mechanical Engineering after completing his Ph.D. in 1969, and now is an Associate Professor. He teaches regularly the courses ME 430 and 431, Power Engineering I and II in ME plus other power related subjects.

Dr. Hawks brings valuable additional experience to the committee since he has been a consultant and project supervisor for Purdue's own Physical Plant since 1976, with emphasis on energy management. He is the author of several papers in this area. He is also Co-op Coordinator in Mechanical Engineering and Purdue's representative to the American Power Conference.

GERALD T. HEYDT is Professor of Electrical Engineering and Chairman of the PEPC Committee. His interests include stochastic methods in power system analysis, matrix methods, reliability, large system studies, rural electrification, and state estimation. Dr. Heydt has recently worked on several research projects in the area of harmonic power studies. In teaching Dr. Heydt taught EE 532 (Computational Methods in Power Systems Analysis) and EE 301 (Signals and Systems), during the last year.

Dr. Heydt is a Senior Member of IEEE, and a registered Professional Engineer in Indiana and New Jersey.

PAUL C. KRAUSE has been Professor of Electrical Engineering at Purdue since 1970. He is interested in simulation of power system components, transmission lines and energy conversion. In research, Dr. Krause has been active in many sponsored projects including, "Security Assessment of Power Systems Including Energy Storage" (DOE), "Fabrication, Interfacing, and Testing of a Special Purpose Power System Simulator" (DOE).

Dr. Krause is also active in graduate and undergraduate teaching. He is a member of Sigma Tau, Eta Kappa Nu, Pi Tau Sigma, Phi Theta Kappa, and a Fellow of IEEE.

LAWRENCE L. OGBORN is Associate Professor and Director of Laboratory Programs in the Electrical Engineering Department at Purdue University. While at Purdue, he has developed and taught several new undergraduate and graduate courses in the areas of physical electronics, electronic circuits, instrumentation, automatic control, and power electronics. He has taught similar courses in industry and has done experimental research in magnetics, general electronic circuits, measurements, instrumentation, and power electronics. He worked with the interdisciplinary team studying the opportunities and risks associated with the development of electronic and hybrid vehicles, and did research in the areas of electric vehicle battery chargers, electric vehicle instrumentation, and data analysis. In 1987, Dr. Ogborn was named coordinator of the undergraduate program in the School of Electrical Engineering.

Prof. Ogborn's research interests include simulation and analysis of dc/dc converters, optimal design techniques, and power electronic devices. He is a registered Professional Engineer in Indiana.

CHEE-MUN ONG joined the faculty in Electric Power Engineering in August 1978. He received the Bachelor of Engineering (First Class Honors) degree from the University of Malaya, Malaysia in 1967 and the M.S. and Ph.D. degrees from Purdue University in 1968 and 1974 respectively.

He was a faculty member at the University of Malaya from 1968 to 1973 and 1976 to 1978. At Purdue University he was Visiting Assistant Professor in 1975, Assistant Professor in 1978, Associate Professor in 1981, and is now Professor. His fields of interest are converters and machines with special emphasis on control and simulation.

Dr. Ong is a fellow of the Institution of Electrical Engineers (United Kingdom), a Senior Member of the IEEE, and a registered professional engineer in Indiana.

OLEG WASYNCZUK joined the faculty in Electric Power Engineering in August 1979. He received his BSEE degree from Bradley University in 1976 and his MSEE and Ph.D. degrees from Purdue in 1977 and 1979, respectively. He was a Visiting Assistant Professor from 1979-1980 at Purdue University and he is now an Associate Professor. He has recently taught EE 321 (Introduction to Electrical Energy Engineering) and EE 636 (Dynamics and Control of Integrated Power Systems).

Dr. Wasynczuk's research interests are in the area of power system dynamics and control. He has conducted extensive research concerned with the analysis and damping of subsynchronous resonance and concerning the dynamic behavior of dispersed, grid connected photovoltaic power systems. Dr. Wasynczuk is a member of the Institute of Electrical and Electronics Engineers (IEEE), Eta Kappa Nu, Tau Beta Pi and Phi Kappa Phi.

WALTER L. WEEKS came to Purdue in 1963. His principal interests (in electric power engineering) center on the transmission and distribution of electromagnetic energy, associated instrumentation, and the determination and detection of unwanted and "stray" electromagnetic fields. Professor Weeks is internationally known for his textbooks on electromagnetic field theory and antenna engineering. He was responsible for the initial concept and material development for the Purdue Individualized Instruction Center. He is author of the text "Transmission and Distribution of Electric Energy." He also has responsibility for the High Voltage Laboratory and research projects on the detection and location of partial discharges in power cables and other apparatus.

Dr. Weeks is currently Professor of Electrical Engineering.

2.2 Visiting and professional staff

DEJAN OSTOJIC came to Purdue as a Fulbright Scholar in Septermber, 1988. Mr Ostojic is from the University of Belgrade, Belgrade, Yugoslavia. He has interests in power system stability, pattern recognition, neural net theory, and the control of large scale systems.

J. P. STEINER completed his Ph.D. at Purdue in 1988 working in the area of detection of faults in power cables. Dr. Steiner subsequently joined the professional staff working in the High Voltage Laboratory.

2.3 Other power engineering faculty

Electrical Engineering

Raymond A. DeCarlo (Systems Studies)
Fritz J. Friedlaender (Magnetics)
Antti J. Koivo (Systems Studies)
Richard J. Schwartz (Photovoltaics, Head of the School of Electrical Engineering)
Stanislaw Zak (Automatic Control)

Mechanical Engineering

D. P. DeWitt (Heat Transfer)
R. W. Fox (Fluid Mechanics)
F. P. Incropera (Heat Transfer and Thermodynamics)
N. M. Laurendeau (Combustion)
W. Leidenfrost (Heat Transfer)
M. R. L'Ecuyer (Gas Turbines)
A. T. McDonald (Electric Vehicles, Transportation)
J. T. Pearson (Heat Transfer)
D. R. Tree (Energy Systems)

K. Wark (Air Pollution Thermodynamics)

Mechanical Engineering Professors Emeriti

C. Messersmith
F. B. Morse
R. Olsen
H. L. Solberg
E. J. Wellman
C. F. Warner

Nuclear Engineering

C. K. Choi
M. Ishii
T. Downar
P. Lykoudis
O. H. Gailar
K. O. Ott
A. A. Solomon

Nuclear Engineering Professors Emeriti

E. Hungerford
S. McLain
A. Sesonske

Chapter III
Students in Power Engineering

3.1 Graduate students supported by PEPC

FADI ABDAL is from Damascus, Syria. He is working on a project on the current control of a three phase brushless motor with Dr. Wasynczuk. Fadi will receive the MSEE in May, 1989.

KARL BOLLENBACH joined the PEPC group in January, 1988. His advisor is Dr. Wasynczuk and he has completed a project in the area of brushless DC synchro drive systems. His thesis has been circulated to the PEPC companies.

JOHN CIEZKI joined the PEPC group in June, 1988 upon completion of his BSEE degree at Purdue. He is completing a project on electric machine under the supervision of Dr. P. C. Krause.

ALAN ENGELMANN is from Chicago and he received the BSEE from Valparaiso University in 1985. He is completed work on a study of metal oxide lightning arrestor losses with Dr. W. L. Weeks in 1988. Subsequently, he worked for one semester in the High Voltage Laboratory at Purdue. Mr. Engelmann is currently an engineer at the Commonwealth Edison Co.

DONNA GERAGHTY is from Chicago. She was named Mechanical Engineering senior of the year in 1988. She holds the BSME from Purdue and she is presently completing a PEPC project under the direction of Dr. K. Hawks.

PAUL KUBAN is from Lockport, Illinois. He has industrial experience with Texaco. His BSEE is from Southern Illinois University. Paul is presently completing an MSEE PEPC project on electric power conditioners. Dr. Heydt serves as his advisor. He will complete the MSEE in August, 1989.

JEFFREY MAYER is from St. Louis, Missouri. He joined the PEPC group in September, 1987. In 1988, he completed a project on the analysis of a brushless motor with Dr. Wasynczuk. This has been issed as a technical report which was circulated to the PEPC companies. Currently, Mr. Mayer is a teaching assistant in the Department of Electrical Engineering at Purdue.

BILL MCCOY is from Texas. He holds a Bachelors degree in Interdisciplinary Engineering from Purdue. His masters project is in electric utility operations and his emphasis is on the Mechanical Engineering aspects. His advisor is Dr. K. Hawks. He is presently on leave from Purdue working at Alcoa.

SHAWN O'CONNOR is from Hammond, Indiana. He received the BSEE degree in 1987 from Valparaiso University. His interests are in power electronics. Shawn completed the MSEE in August, 1988, and he is presently with the Commonwealth Edison Co., Chicago.

KRAIG OLEJNICZAK is from Abrams, Wisconsin. Kraig recently completed a masters thesis project in effects on three phase unbalance in six and twelve pulse rectifiers. His advisor is Dr. G. T. Heydt. Kraig is presently an assistant in the Technical Assistance Program and he is working toward has Ph.D. degree.

MICHAEL ORR is a student in the Masters degree program in the Department of Nuclear Engineering. He is completing a PEPC project under the direction of Professors Clikeman and Gailar.

LORILYNN RUX is from Portland, Oregon. She is working on an MSEE PEPC project with Dr. W. L. Weeks in the area of high voltage engineering.

ROBERT SPARKS is from Redding, California. He holds the BSEE from the University of California-Davis. He is working toward his MSEE degree with Dr. Heydt in the area of analysis of transients in electric power systems.

SCOTT SUDHOFF joined the PEPC group in May, 1988. Scott is from Madison, Indiana and his BSEE degree is from Purdue. He is interested in applications of automatic control of power systems. He will complete the MSEE in May, 1989.

ROBERT TYSON is from Portland, Oregon. He has had industrial experience with the Northern Indiana Public Service Company. He is interested in object oriented computer languages and the applications of artificial intelligence to power systems. His advisor is Dr. Heydt. Bob will complete the MSEE in May, 1989.

3.2 Other power engineering graduate students

RODGER BARKLUND is a MSEE student who is also working with Nucor Steel Co., Crawfordsville. Rodger is working on a project on the modelling of an electric furnace. Dr. Heydt serves as his advisor.

HUSAM BEIDES recently joined the Ph.D. program. He is from the West Bank (Palestine), and he holds the MSEE from King Fahd University of Petroleum and Minerals (Saudi Arabia). Husam is working on a project on state estimation in power systems. Dr. Heydt serves as his advisor.

AHMED BENSENOUSI is from Algeria. He has just completed the PhD program under the direction of Dr. Ong. Area of interest: harmonics and reactive power requirement for HVDC converters with weak AC support. Dr. Bensenousi's thesis has been made available to the PEPC companies. He is presently is teaching in Algeria.

FIAZ CHAUDHRY is from Pakistan. He holds the MSEE degree from the Illinois Institute of Technology, Chicago. Mr. Chaudhry is working in the area of transient stability under Dr. Heydt.

SCOTT FREDERICK is from Los Angeles. he holds a BSEE degree from the University of California-Davis. He is presently completing the MS degree in Industrial Engineering under the direction of Dr. S. Nof. Scott is also working in the area of power system reliability with Dr. Heydt.

MOHAMED GHAZI is from Egypt. He is in the early stages of the PhD program under the direction of Dr. Ogborn. Area of interest: power electronics.

HAMDY HASHEM is from Egypt. Mr. Hashem is working in the Department of Nuclear Engineering under Dr. Downar.

HENRY HEGNER is on leave from a government position to complete the MSEE degree at Purdue. He is working with Dr. P. C. Krause.

KENNETH KAISER is working in the area of electric field interactions with atomized sprays. His advisor is Dr. W. L. Weeks.

CHENG-TSUNG LIU is from Taiwan. In 1988, he completed the Ph.D. program in the area of estimation and self tuning control of hvdc systems. He is currently an Associate Professor of Electrical Engineering at the National Sun Yat Sen University, Kaoshiung, Taiwan.

MEHDI MOALLEM is from Iran. He is completing the Ph.D. degree under the direction of Dr. Ong. Mehdi is a teaching assistant in the power area. Area of interest: finite element techniques in switched reluctance machines.

MANSHIH MUI is from Hong Kong. Mrs. Mui came to Purdue in January, 1988. She is working on an MSEE project in superconductivity with Dr. Heydt. The project concerns the use of a superconducting element as the basis of a power circuit breaker.

MAGED NAJJAR is from Lebanon. His BSEE is from the University of Toledo, and his MSEE is from Purdue. He is in the PhD program supported by the National Science Foundation under the direction of Dr. Heydt. Area of interest: state estimation.

ALEX PEAT is from Cheyenne, Wyoming. Alex is on leave from the United States Air Force completing the MSEE degree at Purdue. His advisor is Dr. Heydt.

SHANNON RIEGLE is working in two areas for his MSEE degree: circuit theory and electric power engineering. He is from Vincennes, IN and his advisor is Professor Lin.

THOMAS ROETTGER is from Evansville, Indiana. He is completing the PhD program under the direction of Dr. Ong. Tom also holds a position with the Sunstrand Corporation, Rockford, IL. Tom's BSEE and MSEE are from Purdue. Area of interest: advanced control of HVDC converters with weak AC support.

J. P. STEINER is from Milwaukee, Wisconsin. In 1988, Dr. Steiner completed the Ph.D. program working in the area of incipient fault detection in cables. He has been supported by several industrial grants and the Electric Power Research Institute. Dr. Weeks served as his advisor. Upon completion of his degree, Dr. Steiner joined the staff of the Electrical Engineering Department.

WARIN SUWANWISOOT is from Thailand. He is in the Ph.D. program under Dr. Ong's direction. Area of interest: dynamic simulation of general adjustable speed drives.

3.3 Undergraduate students

It is difficult to firmly identify all of our undergraduate students who are in power engineering. In the Electrical Engineering department, there is a range of students who take from zero to five undergraduate courses in power. When polled, 59 undergraduates wished to be listed as *power majors*. It is estimated that an additional 10 to 20 students are in allied fields such as power electronics, and certain areas of automatic control. These figures suggest that about 6.1% of our 1230 undergraduate EE students are in power engineering. The geographical distribution of the states of residence of the students is concentrated on the Midwest.

An Appendix to this report contains an updated full directory of undergraduates. However, we would like to make special mention of the following undergraduate students:

ERIK HANSON is a PEPC-Mester student from Cossayuna, N.Y. Erik will complete the BSEE in May, 1990. His interests are power engineering and automatic control.

RONALD HATTON is an undergraduate student and laboratory assistant in the High Voltage Laboratory. He expects to complete the BSEE in May, 1991.

DAN GOJMERAC is a senior from Hammond, IN. He worked on an NSF "Research Experience for Undergraduates" in the area of instrumentation of harmonic signals near converters. He will receive the BSEE in May, 1989.

ANDREW KERSCHRAUM is a student in the Mechanical Engineering Technology (MET) program. He is working in the High Voltage Laboratory.

BRIAN LEDGER is working in the High Voltage Laboratory with Dr. Steiner. He expects to complete the BSEE in December, 1989.

GLEN NAKAFUJI is from Honolulu. He is a PEPC-Mester student working in the area of electric machines. He will complete the BSEE degree in May, 1990.

MICHAEL PORTER is from Hammond, IN. Mike is presently working on a project on the speed control of induction machines. He will complete the BSEE degree in May, 1989.

CHARLES THOMPSON is a PEPC-Mester student from Amherst, OH. He is beginning his junior year in the BSCEE program (Computer and Electrical Engineering).

ROBERT TRAJKOWSKI completed the BSEE in December, 1988. He was a participant in the NSF "Research Experience for Undergraduates" in the summer of 1988.

GEORGE WEGH is a PEPC-Mester student from Terryville, CT. He will complete the BSEE degree in May, 1990.

Chapter IV
Research Projects

Superconducting Circuit Breaker

M. Mui and Gerald T. Heydt

This project is to investigate the feasibility of the use of superconductors in power circuit breaker applications. The property used is the change in resistance of a superconductor in going from the superconducting to normal state. The superconducting circuit breaker has the possibility of interrupting current faster from a conventional breaker, and there is less reliance on the zero crossings of alternating current thereby suggesting application to direct current interruption. The quenching of the superconductivity may be accomplished by heating the superconducting element past the transition temperature. This may be done by introducing warmer liquified gasses, microwave heating of carbon targets on the superconductor, or laser light. Also, direct resistive heating may be used by passing current in a plane perpendicular to the direction of superconductivity (see Figure 4.1). Since the new high temperature superconducting materials have insufficiently low resistivity just above T_C, it may be necessary to use the mechanism described to decrease the circuit current sufficiently to permit interruption by a conventional air or vacuum breaker.

Laboratory work is being done using the YBa_2Cu_3 superconductor at liquid Nitrogen temperatures.

Harmonic Impact of Unbalanced Converters

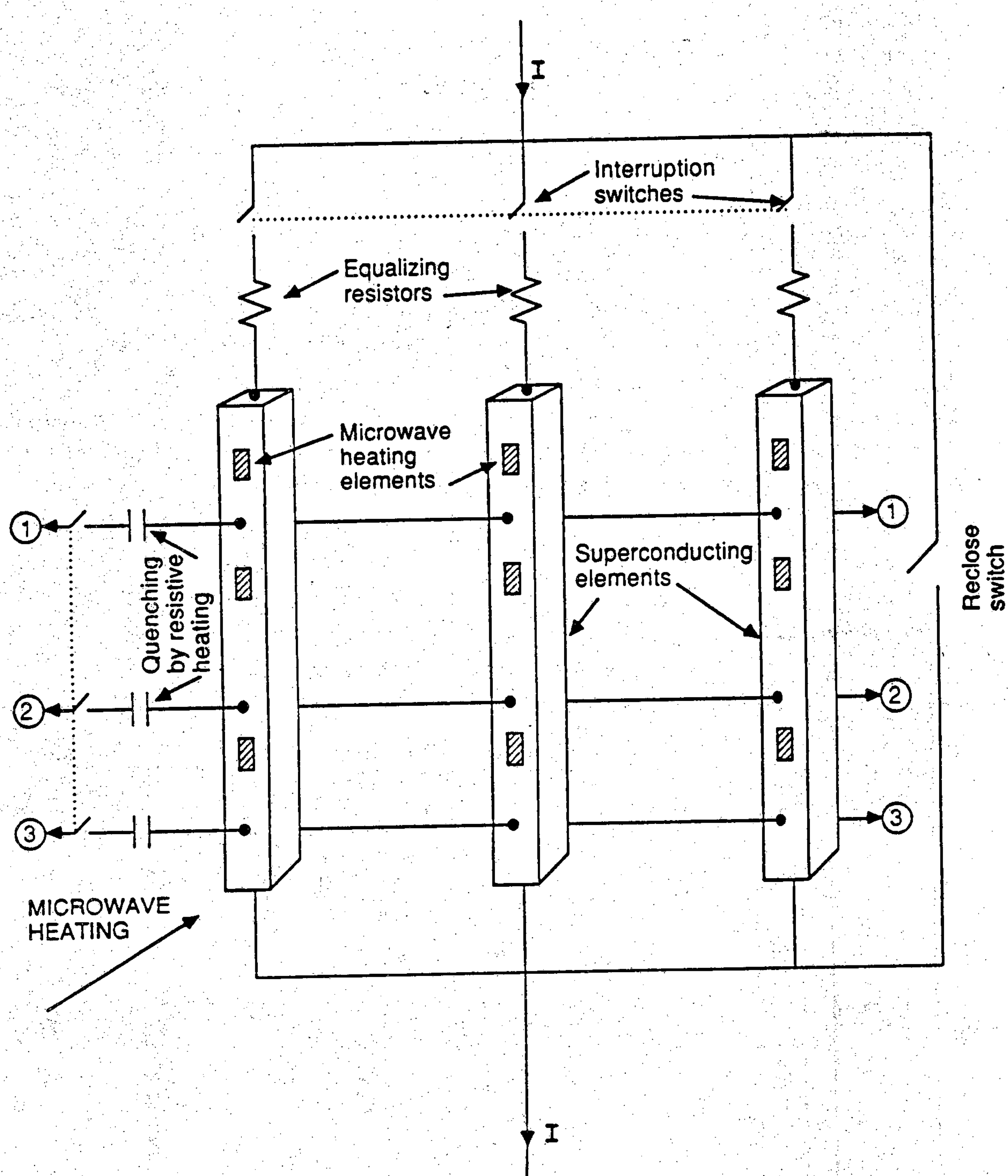
K. Olejniczak and Gerald T. Heydt

Sponsored by the Purdue Electric Power Center

Familiar six and twelve pulse converters (rectifiers and inverters) inject characteristic harmonics into the AC network at frequencies $pn \pm 1$ times the fundamental (power) frequency where p is the pulse order and n=0,1,2,3,... However, in field tests, one observes non-characteristic frequencies not predicted by this formula. In this project, we are investigating some of the reasons for this

When the AC bus voltage is imbalanced, non-characteristic harmonics may occur. Also, the sequence of the characteristic harmonics is altered. It is possible to quantify these deviations from ideal behavior in the case of small discrepancies from balanced operation. This has been done and reported in [1].

Also under study is the effect of mismatched diodes in the Graetz bridge. This study is incomplete.



GENERAL CONFIGURATION FOR A
SUPERCONDUCTING CIRCUIT BREAKER

Figure 4.1.

Reference

[1] K. Olejniczak, G. T. Heydt, "Basic Mechanisms of Generation and Flow of Harmonics Signals in Balanced and Unbalanced Three Phase Power Systems," IEEE Trans. on Power Systems, accepted for publication.

Harmonic Signal Flows and Identification in Electric Power Systems

M. Najjar and Gerald T. Heydt

Supported by the National Science Foundation

Nonlinear loads and sources in power systems result in nonsinusoidal currents. These currents usually possess a Fourier series each of whose terms is a harmonic signal. Harmonics "flow" in the network as prescribed by the Kirchhoff laws which are coupled to each other by power specifications of the form $S=VI^*$. This power flow problem is of high dimension. It is possible to identify or estimate harmonic flows and voltages using state estimation techniques.

For the last five years, there has been serious discussion in the United States in upgrading IEEE Guide 519. If customers served must maintain load currents within specified harmonic limits

$$|I^{(h)}| \leq L_h$$

where L_h is the limit on harmonic h, some methods for identifying violations should be studied. Alternative possibilities include:

i. Direct measurement. Telephone interference, computer interference, inordinate incidences of shunt capacitor failures, and other evidence of high harmonic signal levels may be used to identify circuits (typically, distribution circuits) which serve devices which violate harmonic limits Direct measurement may be used to localize harmonic sources. This technique is limited to radial circuits, cases of evident harmonic interference, and field conditions which permit measurements.

ii. Simulation. When the configuration of connected converter loads/sources are known, simulation may be used to calculate injection currents at harmonic frequencies. Generally, this technique is not sensitive to network configuration. Unfortunately, the model parameters of loads which are harmonic sources are difficult to obtain.

iii. State estimation. Heydt has recently proposed the use of several network measurements (e.g., harmonic currents) in connection with a state estimator to find harmonic injection currents. Let the line current flows, $\bar{I}$, be related to the bus injections, I, by

$$I = L^t \bar{I}$$

AI Applications in Electric Power Dispatch

R. Tyson, Gerald T. Heydt, and Mark A. Yoder

Supported by the Purdue Electric Power Center

Artificial intelligence approaches to engineering problems has "spun off" a range of computer languages which are designed to accommodate the problem formulation. In this project, AI languages will be assessed for application in the electric power dispatch problem. Some progress has been made in the use of Prolog in this application.

The electric power dispatch problem is an optimization problem in which total fuel cost is to be minimized subject to the following constraints

1. The load must be satisfied
2. Generators must be operated within their ratings.

These constraints may be coupled because generators may be coupled (e.g., common header, hydro generators on the same river).

3. Transmission constraints
4. Environmental constraints.

Some of these constraints are readily represented as "rules". The collection of rules are used in the AI formulation of the problem.

At this time, the main focus of the project is on hydroelectric dispatch. This is particularly difficult in algorithmic techniques because the constraints are difficult to quantify and characterize in algorithmic terms. Dynamic programming has been implemented in Prolog to solve simple dispatch problems.

Modeling and Analysis of a Single-Phase Brushless DC Drive System

J. Mayer and Oleg Wasynczuk

Supported by the Purdue Electric Power Center

Brushless dc machines are rapidly displacing conventional dc machines in applications such as computer peripherals and low power, variable speed drive systems. In this research, a single-phase brushless dc motor, used in computer disc drive applications, is analyzed. A detailed computer simulation has been developed and verified by comparison with measured results. Steady-state relationships have been derived relating the average electromagnetic torque to the rotor speed for varying input voltages. These relationships are used to investigate methods of improving the torque producing capabilities of the motor using voltage phase-angle and pulse width modulation control. In addition, methods of predicting and improving the starting torque are investigated.

Current Controlled Brushless DC Drive Systems
F. Abdal and Oleg Wasynczuk
Supported by Purdue Electric Power Center

Brushless dc motor drive systems typically consist of a voltage source dc-to-ac inverter connected to a 2- or 3-phase permanent magnet ac motor. Controlling the inverter ac voltages as a function of the rotor position results in electromechanical characteristics which resemble those of a conventional dc machine.

In this research, methods of controlling the source inverter output currents are investigated using pulse width modulation and current band control strategies. Controlling the inverter output currents instead of voltages results in improved dynamic response, reduced motor losses and reduced risk of rotor demagnetization.

Modeling and Analysis of Advanced Spacecraft Power Systems
Oleg Wasynczuk and Paul C. Krause
Supported by NASA Lewis Research Center under grant NAG 3-848.

A major objective of the research is to develop a detailed computer simulation of the proposed Space Station power system employing parallel Solar Dynamic (SD) and Photovoltaic (PV) sources. A candidate power system configuration selected for purposes of investigation consists of SD and PV sources coupled to a 20 kHz distribution system through resonant dc-to-ac inverters (drivers). Also included in the system are numerous ac-to-dc resonant receivers.

Of concern is how these components (sources, drivers and receivers) interact when they are interconnected as a coupled system. Also of concern are methods of controlling the sources, drivers and loads which improve the reliability and dynamic characteristics of the power system, making it insensitive to variations in loads, system faults and/or device failures. In addition, the ability to identify system faults and/or device failures, take corrective action, and restore steady-state operation without major disruption of service is a desirable, if not necessary, feature of space power systems.

Investigations have been conducted into methods of controlling the sharing of power between the parallel SD and PV power sources while maintaining precise regulation of the ac system voltage. Also, investigations into the start-up characteristics of the source drivers, and the system transients due to a sudden loss of source or load and to system faults have been conducted. The information gained from these studies sets the stage for future work in autonomous power system operation and control.

Finite Element Analysis of an Advanced, Capacitive-Discharge Ignition Coil
Oleg Wasynczuk and G. Vasmatzis
Supported by Delco Remy Division-General Motors

It presently appears that advanced capacitive-discharge ignition systems possess significant advantages over conventional inductive-discharge systems. However, in order to fully exploit the anticipated advantages, it is essential to understand fully the ignition dynamics and how the ignition process is affected by design parameters such as transformer leakage and magnetizing inductances, core materials and parasitic effects. Present research is directed at predicting the ignition coil dynamics using a finite-element based model of the ignition coil.

Detection and Location of Partial Discharges in Power Equipment
Walter L. Weeks, J. P. Steiner, and Eric S. Furgason

Substantial improvements have been made in the instrumentation for the detection and location of partial discharge sites in power cables and in transformers. This includes improvements in the electronics, in the probes and sensors, and in the data handling and processing.

In both applications, once the waveforms have been received and amplified in wide band channels, the signals are digitized and all subsequent operations are digital. The detection and location are accomplished with one or another form of cross correlation.

The probes take various forms depending on the application. For transformers, a new magnetic probe for the electromagnetic sensing and special ultrasonic transducers for acoustic sensing are proving to be most useful.

Novel arrangements for the required high voltage generation are also being developed.

Advanced Cable Fault Locator

Walter L. Weeks, J. P. Steiner, and R. Bruce

Supported by EPRI

The techniques developed for partial discharge location are being adapted for fault location on underground power cables. The prefault and faulting transients are received at one or more locations and processed digitally to deduce the fault location. A model underground distribution system is being constructed to study and demonstrate the processes.

Power Losses in MOV Surge Arrestors

Walter L. Weeks and A. J. Engelmann

Supported in part by the Purdue Electric Power Center

Measurements were made to determine the power losses in Metal Oxide Varistors of the type often employed in power distribution systems, in particular in the cylindrical modules having a height of .75 inch and an overall diameter of 2 inches. These units typically have a "turn-on" or "breakover voltage" in the 3.2 to 3.7 kilovolt range. Power losses were measured at 60 Hz and at harmonics of 60 Hz to 1020 Hz. Measurements were also made with the applied voltage being a combination of 60 Hz and different higher harmonics.

Dynamic Simulation of Switched Reluctance Motor Drive

M. Moallem and C. M. Ong

Keywords: Switched reluctance machine, finite element

The availability of inexpensive and reliable power switching devices and electronic logic circuits (microprocessors) has stimulated the recent interest in the switched reluctance drive. Advantages, such as simple and robust rotor construction, unidirectional operation which requires fewer switching devices, and high efficiency, make SRM drive technically and economically attractive. However, the doubly-salient iron structure and highly saturated iron core are formidable hurdles to any attempt so far to simulate the drive in detail. Linear or piecewise linear approximation of the magnetic structure are inadequate because of highly saturated condition, and classical d-q transformation for elimination of time-varying coefficient is just not applicable to the doubly-salient motor.

Predicting the developed torque of a switched reluctance machine from its finite element field solution is complicated by the high field gradient in the narrow airgap. In this work, we found that much of the inaccuracy in the computed torque from the

Maxwell stress-tensor and the local virtual work method can be traced the errors in the calculation of the radial and tangential components of the flux density in the airgap. With a vector potential formulation, the continuity condition on the normal components of the flux density at the border of the finite elements is fulfilled, but that on the tangential component is not. In examining the discretization errors, we showed that a proper choice of element shapes and rotor stepping will yield reasonably accurate torque/angle characteristic. The proposed approach works well with the global virtual work method, the Maxwell stress-tensor method, and the local virtual work method; for a 5 kW test machine, the computed results from all these three methods and the measured results agree very well.

Presently, we are performing experimental verification of a method for dynamic simulation of a SRM drive using integrated field-network approach. This simulation approach, which will be useful for detailed design and control studies, handles the complex geometry and magnetic nonlinearity of the machine by finite element method, and the changing converter circuit topology by tensor method.

Modeling, Estimation, and Self-Tuning Control of AC/DC Systems

C-T. Liu and C.M. Ong

Keywords: Modeling, estimation, self-tuning, ac/dc systems

Currently, most of the design and planning studies of HVDC systems are performed on analog and scaled-down simulators in industrial laboratories. In this research, we have developed a modular digital simulation of a DC terminal that can be interfaced with Bergeron's technique of network simulation used in the Electromagnetic Transient Program (EMTP). The new combination is much easier to setup than the TACS - Bergeron combination presently used in EMTP. The modular simulation has been successfully integrated with simulations of other terminal equipment, such as the static var compensator, zinc oxide arrestors, and nonlinear converter transformer.

The determination of suitable parameters for the controls of the dc system is accomplished with a discrete linear model of the entire AC/DC link. Test results, compared to those obtained with a detailed simulation, confirmed the suitability of such a linear model for purposes of stability and controller optimization studies.

It is known that conditions out in the AC/DC networks have a dominant effect on the transient behavior of the converter. However, the condition of the AC network, in particular, changes with loading and generation. In exploring the possibility of handling such uncertainties by estimation and self-tuning techniques, we tried using a combination of singular value decomposition and recursive least square techniques to estimate the parameters of the AC/DC model as viewed from the current controller of the terminal. The techniques used do not require the use of an extraneous disturbance.

Information on the estimated model of the AC/DC system is then used to periodically tune the gain of the current controller. Results obtained with and without self-tuning showed a notable improvement in the dynamic response of the AC/DC system.

Harmonic Characteristics and Voltage Support for Inverters with Weak AC Support

A. Bensenouci and C.M. Ong

Keywords: Harmonics, ac/dc systems

This is a two-part investigation. The first part deals with the harmonic characteristics of an inverter with weak AC support under balanced and unabalanced network conditions using the two most common firing schemes: individual pulse control and equidistant firing control. The second part deals with the operational behavior of an inverter with weak AC support when supplementary VAR support in the form of a static var compensator (SVC) is used. Aside from evaluating the improvements in dynamic and transient behaviors achievable with different control strategies, the study also looked for possible adverse interaction between the controls of the inverter and the SVC.

Simulation of Electric Drives

W. Suwanwisoot and C. M. Ong

Keywords: Simulation, electric drives

In this research, we have developed numerical and modeling techniques for simulating electric drive systems on the digital computer, and are applying these techniques in a general-purpose simulation package. Most of the existing simulation programs are for specific drives, and many cannot handle mixed discrete-continuous systems. As a result, engineers usually have to write their own simulation programs whenever they encounter anything new.

Our approach to providing the program with a good degree of flexibility is to design the simulation program to accept inputs in both network-oriented and equation-oriented forms. The individual components can be characterized by equations of the form $\mathbf{f}(\mathbf{y},\dot{\mathbf{y}},t) = \mathbf{0}$; except for distributed parameter systems, this will remove any model limitation. The interconnection of the components can be conveniently described by a network-oriented language, such as that used in SPICE. Our program will allow the users to specify the interconnection of not only electrical components but also non-electrical components. The information on the interconnection of non-electrical components can be provided in the form of block diagrams.

The simulation program also has a special way to handle nonlinear devices, that of using Petri nets to simulate finite state machines. This provision contributes to some improvement in both speed and robustness of the simulator.

A Variable Structure Approach for AC Voltage Control at HVDC Converter Terminals

T. D. Roettger and C. M. Ong

Keywords: Variable structure control, hvdc system

This study explores the use of variable structure control (VSC) in controlling the AC voltage of an HVDC terminal. Of particular interest are HVDC terminals connected to weak AC systems. If the connecting AC system has an appreciable internal impedance (i.e. has a low short circuit capacity), it is considered weak. There are several problems encountered with HVDC terminals connected to weak AC systems: harmonic instability, possibility of repetitive commutation failures, and DC control system sensitivities to network parameter variations. This research will be limited to investigating the latter. Converter station operating conditions and system contingencies determine the shunt impedance and the connecting AC network Thevenin impedance. These network parameters can be varied significantly due to the DC power schedule or from line openings following faults. These network parameter uncertainties will impact the converter controls. Typical linear control techniques tend to be sensitive to parameter variations consequently, yielding a compromise between stability, performance and robustness. The focus of this research is to examine the advantages of VSC theory applied to this problem.

Chapter V
Educational Program

5.1 Graduate courses

EE 525 Analysis of Electromechanical Systems I Sem. 1. Class 3, cr. 3. Prerequisite: EE 425 or graduate standing.

Modern analysis of synchronous and induction machines in electromechanical systems. The concept of multiple reference frames used to analyze unbalanced conditions. Computer simulations. Analysis of operating point stability and variable frequency drive systems. Professor Krause and staff.

EE 527 Direct Energy Conversion (ME 530) Sem. 2. Class 3, cr. 3. Prerequisite: a first course in thermodynamics plus topics in elementary fluid mechanics and elementary electromagnetics (as available in minicourse form).

Energy sources; basic science of energy conversion, thermoelectric, thermionic, and magnetohydrodynamic systems; photovoltaic effects; fuel cells.

EE 530 High Voltage Engineering Sem. 2. Class 2, lab. 3, cr. 3. Prerequisite: EE 311.

Lecture and laboratory experience in the generation and measurement of high voltages, in analysis and measurement of arc parameters, and in study of thermonuclear plasma characteristics. Professor Weeks and staff.

EE 532 Computational Methods for Power System Analysis Sem. 2. Class 3, cr. 3. Prerequisite: EE 432.

System modeling, and matrix analysis of three-phase power networks. Applications of numerical methods and computers to the solution of a variety of problems related to the planning, design, and operation of electric power systems. Professor Heydt and staff.

EE 535 Transmission and Distribution of Electric Energy Sem. 2. Class 3, cr. 3. Prerequisite: EE 311.

A study of factors which are important in the design and operation of the hardware necessary to deliver large amounts of electrical energy, reliably, over substantial areas. Particular emphasis is placed on the factors which limit power handling capability. A review of line parameters and loss mechanisms, high voltage and current limitations in the form of corona, audible noise, radio noise, field effects, and heat transfer are considered. Also included is an introduction to system protection. Professor Weeks.

EE 554 Electronic Instrumentation and Control Circuits Class 3, cr. 3. Prerequisite: EE 255 and 301.

Analysis and design of special amplifiers, pulse circuits, operational circuits. DC amplifiers, and transducers used in instrumentation, control, and computation. Professor Ogborn.

EE 610 Energy Conversion Sem. 1 and 2. Class 3, cr. 3. Prerequisite: EE 321.

Basic principles of static and electromechanical energy conversion. Control of static power converters. Reference frame theory applied to the analysis of rotating devices. Analysis and dynamic characteristics of induction and synchronous machines. State variable analysis of electromechanical devices and coverter supplied electromechanical drive systems.

EE 625 Analysis of Electromechanical Systems II Class 3, cr. 3. Prerequisite: EE 525

Extension of EE 525. Electric propulsion systems including presentation of cycloconverter and rectifier-inverter drive systems. Dynamic and steady-state analysis of machine performance with series controlled rectifiers in the stator or rotor phases. MMF space harmonic analysis. Professor Krause and staff.

EE 631 Direct Current Transmission Systems Sem. 2. Class 3, cr. 3. Prerequisite: EE 432.

Fundamental analysis of line-commutated, three-phase bridge converters, as applied to HVDC transmission systems. Methods of control, system protection, abnormal behavior, harmonics. Professor Ong and staff.

EE 633 Computational Methods for Power System Components Sem. 1. Class 2, lab. 3, cr. 3. Prerequisite: EE 425 or 432 or graduate standing.

Analysis and simulation of basic power system components. Appropriate application of analog, digital, and hybrid computers to the study of electric machines, transformers, rectifiers, inverters, and traveling waves on transmission systems. Professor Ong and staff.

EE 635 Optimization and Economic Operation of Integrated Power Systems Sem. 1. Class 3, cr. 3. Prerequisite: EE 633

Theory of optimization under equality and inequality constraints, computational methods, and applications to generation scheduling in integrated power systems. Professor Heydt and staff.

EE 636 Dynamics and Control of Integrated Power Systems Sem. 2. Class 3, cr. 3. Prerequisite: EE 532.

Description of a variety of transient and control problems associated with interconnected power systems and techniques for their analysis and solution. Practical methods for dynamic analysis of large systems are stressed. Professor Wasynczuk and staff.

5.2 Undergraduate courses

EE 321 Principles of Electromechanical Energy Conversion Sem. 1 and 2. Class 3, cr. 3. Prerequisite: EE 202; MA 262; PHYS 261.

The general theory of electromechanical energy conversion is set forth wherein electric circuit variables are related to electromagnetic and electrostatic forces. The fundamental concepts of rotating electric machines are presented including the basic equations and operational behavior of alternating- and direct-current machines. Attention is also given to special-purpose motors for control and robotics applications. Professor Krause and staff.

EE 421 Electromechanical Energy Conversion Laboratory Sem. 2. Lab. 3, cr. 1. Prerequisite or corequisite: EE 425.

Laboratory experiments involving transformers, direct-current, induction, and synchronous machines. Professor Krause and staff.

EE 425 Electric Machines Sem. 2. Class 3, cr. 3. Prerequisite: EE 321.

A study of the energy conversion principles and operating behavior of AC and DC electric machines. Develops circuit models to study their steady-state characteristics and simple mathematical models to study their transient responses. Considers engineering aspects of practical machines. Examines industrial methods of starting and controlling these machines, including the use of power electronics in dc machine control. Emphasis on formulations that lend themselves readily to digital computational techniques. Professor Ong and staff.

EE 431 Electric Power Systems Laboratory Sem. 1 and 2. Class 1. Lab. 3, cr. 2. Prerequisite or corequisite: EE 432.

Electric power systems topics including: instrumentation, three-phase circuits, transformers, phase shifters, voltage regulation, power flow control, protective devices, and systems aspects of solar energy conversion. A plant visit and consultation with practicing power engineers is required. Professor Heydt and staff.

EE 432 Elements of Power System Engineering Sem. 1 and 2. Class 3, cr. 3. Prerequisite: EE 321 or consent of instructor.

Fundamental concepts and operation consideration of power systems, basic component model representations, steady state performance, operating strategies, and control of power systems. Professor Wasynczuk and staff.

5.3 Experimental courses and projects in power engineering education

The course number EE 496 is used for project work at the undergraduate level. At present there are five undergraduate projects in progress. The course numbers EE 695, and EE 696 are used for graduate project work. There are three such projects presently in progress in the power area. Also, Professors Krause and Wasynczuk offered an experimental course, EE 495, in the area of electromechanical motion control.

Three new graduate courses of one credit each were offered in the fall, 1988. Each course is a five week "mini-course". The course topics are high voltage DC systems, control of synchronous machines, and control of power systems. Professors Krause, Ong, and Wasynczuk will offer these courses.

5.4 Laboratory facilities

High Voltage Laboratory

The high voltage laboratory is located in the Duncan Annex of the Electrical Engineering building. Sinusoidal steady state sources include a 350 KV, 1 A single phase transformer energized at 4800 V by a motor-generator set; computer controlled data acquisition facilities based on the Data 6000 and IBM PC AT; a wideband linear power amplifier rated at 9 KW (custom made by Behlman); a 100 KV Hipotronics dielectric test set; a 250 KV impulse generator; and two ± 70 KV DC sources.

Electric Machines Laboratory

The electric machines laboratory contains 20 machine sets including induction synchronous, and dc machines. Most of these sets are in the 3-5 Hp range. There are five 7.5 Hp synchronous machines. All are rated at 200 V, three phase. Instrumentation includes an HP-85 instrumentation system which is HP-IB compatible. There are a wide range of more 'vintage' instruments and distribution transformers. Dr. Ong has developed several fractional horsepower machine sets used for machine drive experiments.

Appendix

Directory of PEPC Liaisons

and

Directory of the Faculty, Staff, and Students

PEPC DIRECTORY OF LIAISONS
2/3/89

COMPANY	TECHNICAL LIAISON	PERSONNEL LIAISON
American Electric Power AEP Service Corporation 1 Riverside Plaza Columbus, OH 43216	**John Struyk** Senior Vice President - Engineering and Design (614) 223-2900	**Susan Neymeyer** Manager, Employment (614) 223-1860 **Sue Strutner** Administrator, Co-op/Intern Programs (614) 223-1856
Applied Energy Services 1925 N. Lynn St. Arlington, VA 22209 703-522-1315 FAX 703-528-4510	**Mark S. Fitzpatrick** Vice President 703-522-1315	**Mark S. Fitzpatrick**
Bechtel National, Inc. 50 Beale Street San Francisco, CA 94119	**Timothy S. Killen** Manager of Engineering and Construction Technologies Bechtel National, Inc. P.O. Box 3965 San Francisco, CA 94419-3965 (415) 768-8600 **R. Castleberry** Bechtel Power Corp. 15740 Shady Grove Rd. Gaithersburg, MD 20877 301-258-3205	**Jane Howard** Bechtel Power Corp. 15740 Shady Grove Rd. Gaithersbury, MD 20877
Central Illinois Public Service Company 607 East Adams Street Springfield, IL 62701	**G. B. Fritz** Manager, Electric System (217) 525-5408	**H. L. Gaffney** Employee Development Supervisor (217) 525-5397
Cleveland Electric Illuminating Company P.O. Box 5000 Cleveland, OH 44101-5000	**Donald G. Halliday** Manager, Distribution, Dispatching and Design (216) 479-3727	**Bruce D. Campbell** Employment Supervisor (216) 479-4955
Commonwealth Edison Company P.O. Box 767 Chicago, IL 60690-0767	**James Johnson** Senior Vice President (312) 294-2930	**Michael J. Kurzeja** Office of the Senior Vice-President 38 FN East (312) 294-4021 **W. R. Wroblewski** Professional Placement (312) 294-4489

General Electric 1635 Broadway P.O. Box 2230 Ft. Wayne, IN 46801-2230	**John Hooker** (219) 428-3241	**John Hooker**
Illinois Power Company 500 South 27th Street Decatur, IL 62525	**G. E. Huck** Manager of Planning (217) 424-6702	**Robert Kruep** (217) 424-6824 **G. Robert Teel** Professional Recruiting Specialist (217)424-6817
Indiana Michigan Power Company P. O. Box 60 One Summit Square Fort Wayne, IN 46801	**Albert H. Potter** Manager Transmission & Distributioin (219) 425-2109	**Jerry Reidy** Personnel Director (219) 425-2108
Indianapolis Power and Light Company 25 Monument Circle Indianapolis, IN 46206 (317) 261-8261	**Robert W. Rawlings** Vice President for Engineering & Construction	**Linda J. Hardwick** Director Employment and Training Department **James O. Crowley** Supervisor Employment Division
Northern Indiana Public Service Company 5265 Hohman Avenue Hammond, IN 46325	**Dr. Robert A. Kramer** Director of Electric Engineering and Applied Research (219) 853-5508 **Ronald L. Jacobs** (219) 853-5549 **Donald W. Hitzeman** General Field Engineer (219) 853-5404	**Gene Freese** Manager of Organizational Department (219) 853-5191
Pacific Gas & Electric Company 77 Beale St. San Francisco, CA 94106 (415) 974-3411	**John G. Wood** Electrical Engineering Department (415) 972-6787	**John G. Wood** or, for Summer Intern **Christene Bryan** Rm. F1000 (415) 972-5194
Public Service Indiana 1000 East Main Street Plainfield, IN 46168	**T. W. McCafferty** Manager Research (317) 838-1482	**Jerry Land** Manager, College Recruitment and Employee Services (317) 838-1472

Sargent and Lundy Engineers 55 East Monroe St. Chicago, IL 60603 (312) 269-2000	**W. A. Chittendon** Senior Partner (312) 269-2000 **Don Clark** Head Electrical Project Engineering Division **Greg Hinshaw** Electrical Engineering 25th Floor (312) 269-2170	**David Holcomb** 16th Floor (312) 269-2586
Southern Indiana Gas and Electric Company 20 N.W. Fourth Street Evansville, IN 47741	**G. W. Husky** Director of Electrical Engineering (812) 464-4673	**Rod Penfield** Dir. of Industrial Relations (812) 464-4651 **Henry Woodall** Supervisor of Employment (812) 464-4652

PURDUE ELECTRIC POWER CENTER DIRECTORY
2/20/89

Professors	Department	Login	Telephone	Office
Frank Clikeman	NuclE	clikeman	49-45746	NUCL 140A
Keith Hawks	ME	hawks	49-45716	ME 108
Jerry Heydt	EE	heydt	49-43520	EE 320
Paul Krause	EE	krause	49-43481	EE 144
Larry Ogborn	EE	ogborn	49-43472, 43390	EE 148
Chee-Mun Ong	EE	ong	49-43484	MSEE 358
Oleg Wasynczuk	EE	wasynczu	49-43475	EE 146
Walter Weeks	EE	weeks	49-43563	EE 348G
Professional Staff				
J. P. Steiner	EE	jp,z80	49-40632 49-43349	EE 348E HV lab
Fulbright Scholar				
Dejan Ostojic	EE	ostojic	743-6721, 49-40729	EE 331A
Secretaries				
James Archibald (Weeks)	EE	archie	49-43649	EE 339
Lisa Reeves (Ogborn, Krause, Wasynczuk)	EE	reevesl	49-43474	EE 145
Diane Crose (Clikeman)	NuclE	nsec	49-45741	NUCL 140
Carol Edmundson (Heydt)	EE	carol	49-43510	EE 325A
Jo Johnson (Ong)	EE	jo	49-43435	MSEE 364
Angela (Angie) Myers (Hawks)	ME	myersa	49-45783	ME 100
Teaching Assistants (Advisor)				
Jeffrey Mayer (OW)	EE	mayer	49-49064	EE 242W
John Suriano (CMO)	EE	suriano	49-40624	EE 130
PEPC Students (Advisor)				
John Ciezki (PCK)	EE	ciezki	49-40623	EE 154
Donna Geraghty (KH)	ME	geraghty	49-49067	MSEE 048S-B
David Kish (PCK)	EE	kish	49-49067	MSEE 048S-B
Paul Kuban (GTH)	EE	pakuban	49-49621	MSEE 022B-R
Lorilynn Rux (WLW)	EE	lrux	49-49067	MSEE 048S-B
Robert Sparks (GTH)	EE	robsprks	49-40629	MSEE 048A
Scott Sudhoff (PCK)	EE	sudhoff	49-40623	EE 154
Michael Orr (O. Gailar & FC)	NuclE	orr	477-6523	
Other Graduate Students				
Fadi Abdal (OW)	EE	abdal	49-40624	EE 155
Rodger Barklund (GTH)	EE	rodgerb	362-8953	Nucor Steel
Husam Beides (GTH)	EE	beides	49-43468	EE 241A
Fiaz Chaudhry (GTH)	EE	fiaz	49-49067	MSEE 048S-B
Scott Frederick (S. Nof)	IE	fscott	743-0527	
Mohamed Ghazy (LLO)	EE	ghazy		
Hamdy Hashem (T. Downar)	NuclE	hashem	743-6789	
Henry Hegner (PCK)	EE	hegner	497-0076	
Ken Kaiser (WLW)	EE	kaiser	49-40631	EE 348D
Bill McCoy (KH & GTH)	EE			Alcoa
Mehdi Moallem (CMO)	EE	meysam	49-46641	EE 57C
Manshih Mui (GTH)	EE	manshih	on leave	
Maged Najjar (GTH)	EE	maged	742-4219 or 49-43468.	EE 241A
Kraig Olejniczak (GTH)	EE	olejnicz	49-43468	EE 241A
Alex Peat (GTH)	EE	peat	49-43468 or 447-9307	EE 241A
Shannon Riegle (P.M. Lin)	EE	shannon		
Thomas Roettger (CMO)	EE	roettger	463-6863	
Warin Suwanwisoot (CMO)	EE	suwanwis	743-4195	

Purdue Electric Power Center Undergraduate Student Directory
2/22/89

Name (Dept. if not EE)	Login	Telephone	Graduation	State of res.	Campus address (West Laf.)	Interests (in addition to power)
Mark Aldridge	aldridge		5/90	IN	224 W. Fowler #F	
Dan Boes	me	49-54073	5/89	IL	B740 Shreve	
Jeffrey Boehm	boomer	49-53788	5/91	IN	Box 25 Owen Hall	
Ralph Coan	coan	743-6713	8/89	IN	249 S. Salisbury #1	
Jennifer Coffey	coffeel		5/89	IN		C
Michael A. Cook	baskervi	743-0135	5/90	IN	152 E. Stadium #2	
James Crane	cranej	447-5205	5/90	IN	2725 Bonny Ln., Laf.	
Randy Crutchfield	randyc	49-55751	5/89	IN	SE110 Wiley	
Bryce Currie	magnum			IN	353 1/2 State St.	
Phil Embry	embry	743-6682		IN	200 Russell	
James Eitsert	zeus	447-1549		IN	708 N. 18th St. Laf.	
James Finneran	finneran	743-5453		IN	419 Vine #B16	
Tom Flohr	flohr	49-52088	12/89	IN	Box 289, Cary Quad	
Chris Gallmeyer	gallmeye	497-2977			2550 Yeager #21-10	
Michael Gansman	gansman		5/90	IN	416 N. Chauncey	
Mark A. Gloudemans	gloudema	49-51864	5/89	IN	19-2 Ross Ade Dr.	H
Dan Gojmerac	gojmerac		5/89	IN	305 N. Salisbury Apt. 6	F
Richard Hatter	hatter	49-54370	5/90	IN	NE 326 Tarkington	
Erik Hanson	harmoth	743-1807	5/90	NY	225 S. Grant	
Ronald Hatton	hatton	49-54242	5/91	IN	NE 447 Tarkington	
Charles Huckleberry	hucklebe	743-9788				
Peter Karaba	rookie		5/90		NE 146 Wiley	
Michael M. Kass	kass	49-52291	5/91		NW308 Cary Quad	
Ken Kawasaki	kawasaki	743-9617		IN	318 W. Lutz	
Andrew Kerschbaum (MET)					c/o J.P. Steiner, HV Lab, EE	H
Brent Lahey	bal	743-9685	12/89	IN	525 University	
Brian Ledger	ledger	49-54413	12/89	IN	Box 606 Tarkington	
Karen Letts	kare		5/89	IN	241 Sheetz #11	C
Marc Lipski	lipski	743-9679 or 743-8205	5/89	PA	417 Waldron	
Aaron Long	aaronl		5/91		634 N. Fifth, Laf.	Y
Michael Martus	martus	743-4619			329 Russell	

William McClintock	wmm	743-0446	5/89	IN	419 Vine	US
David B. McCutcheon	cutch		5/89			
Bradley Meyer	meyerba		12/89	IN	109-16 Married Students Ct.	
David J. Meyer	meyerda	743-6864	5/89	MS	220 N. Salisbury	X
Ron Meyer	rmeyer	49-40753 or 743-9518	5/89	IN	1010 N. Salisbury #13	
Chris Moberg	moberg		5/90		Box 217 Owen Hall	
Glen Nakfuji	nakafuji	49-57392	5/90	HI	Owen SE401	
Lisa Pfrommer	pfrom	743-1864	5/89	NY	501 Russell	C
Michael Porter	porterm	743-9008	5/89	IN		C
Christopher Prince	ctprince	743-8173	5/89	IN	318 Waldron #5	
Paul Reynolds	paulr	743-2732	5/89	IN	503 N. Grant #6	
Susan Rutter	rutters	743-0332	5/89	IN	238 Pierce #2	
James Schipp	schipp		5/91	IN	344 Northwestern	
Mark David Smith	mdsmith	49-54466	5/91		NE327 Tarkington Hall	
Todd Smith	todds	743-0120	5/89	IN	175 Littleton #2	
Ron Smolen	smolen	743-8133	5/90	IN	217 Sheetz #15	
Philip Strimbu	strimbu		12/89	IN		
Robert Tashijan	tashijar	743-8784	5/89	IN	111 N. Salisbury #2	P
Darrell K. Taylor	taylor	49-53965			241 NE Owen Hall	
Michael Taylor	taylorm		5/89	IN	214 Marstellar #3	
Charles Thompson	charlest	49-51862	5/91	OH		
Erik W. Walker	walkerw	743-2720			440 S. Grant #12	
Todd Warrix	warrix		5/91	IN	755 Tarkington Hall	
George Wegh	geo		12/89	CT	300 Russell	
Steve Wooldridge	wooldrid		5/90			
Jack Wynne	wynnej		5/91		800 Northwestern	
Asif Zaidi	zaidi		5/89	India	427 S. River Rd. #8	

Interest Area

A	Computers
C	Controls
E	Electrical contracting
F	NSF Undergraduate Research Program
G	Management
H	High voltage
M	Manufacturing
N	Nuclear power
P	TAP intern
Q	Electromechanical systems
R	Robotics
S	Solid state devices
U	Communications
X	Marketing, technical sales
Y	Power electronics