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Summary of The Activities of the Purdue Electric Power Center December 1987-June 1988

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I. Objectives of the Purdue Electric Power Center

1.1 Objectives and description of the PEPC program

The Purdue Electric Power Center (PEPC) is a consortium of Purdue University and fifteen companies with an interest in power engineering. Together with Purdue University, these companies have established and maintained a center of excellence in power engineering at Purdue. The program was begun in 1970. Most of the charter founders of PEPC remain members; however, there have been some companies which have withdrawn and there have been some new members. Table 1.1 shows the present membership.

The faculty at Purdue has found that the maintenance of both a large undergraduate and graduate program in power engineering involves a *continuing* effort. Students appear to be readily attracted to certain high-visibility areas such as computer engineering. However, it is necessary to effectively *present* the challenges of power engineering to each student in order to acquaint them with the scope of field. We have found that this *orientation* should occur early in the student's academic career—preferably at the sophomore and junior level.

The main goals of the Purdue Electric Power Center are to acquaint the student with contemporary challenges and needs of the power engineering industry and to maintain a center of excellence in power engineering education at Purdue. The former goal, i.e. to orient the students to modern power engineering, is a very important component of PEPC. This is discussed in some detail in Section 1.3 of this summary. Additional activities of the program are intended to provide an environment conducive to the professors and students to work in power engineering. Some of these activities are:

- Support of undergraduate and masters level students who work on power engineering projects.

Table 1.1

Members of the Purdue Electric Power Center

Bechtel Power	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 and Michigan Electric	Fort Wayne, IN
Indianapolis Power and Light	Indianapolis, IN
Northeast Utilities	Hartford, CT
Northern Indiana Public Service	Hammond, IN
Pacific Gas and Electric	San Francisco, CA
Public Service Indiana	Plainfield, IN
Sargent & Lundy Engineers	Chicago, IL
Sohio	Cleveland, OH
Southern Indiana Gas & Electric	Evansville, IN

- Awarding scholarships and "senior of the year" recognitions to qualified undergraduate students.
- Bringing industrial representatives to the campus to meet and speak with students.
- To support travel by the professors and students to the sponsors and regional meetings.
- To support travel by students as field trips.
- Purchase of power engineering textbooks for the engineering library.
- To provide "seed funds" to obtain research contracts from major funding agencies.
- To fund word processing, duplicating, and mailings related to the PEPC program and in closely related activities.
- To provide an interface between the companies and the students for recruiting and other activities.
- To bring industrial input into the power curriculum.

Our present budget is about $98,000. This level has been approximately constant for the last three years. Some supporters have had to reduce their level of support due to financial pressures of the power industry. Other supporters have significantly raised their level of support. Section 1.3 describes our future budgetary plans.

The Purdue Electric Power Center is the base of the power engineering program at Purdue. Expenditures by PEPC are committed to undergraduates and masters level support. At the present, most of the students who are directly participating in the programs are in Electrical Engineering. The Schools of Mechanical Engineering and Nuclear Engineering also participate in PEPC both in administration and distribution of support.

1.2 Administration of the program

The administration of the Purdue Electric Power Center is centered in the School of Electrical Engineering and Dr. Richard J. Schwartz, Head of the School is responsible for the program. The actual operation of the program is the responsibility of the PEPC Committee which is listed in Table 1.2.

Table 1.2

The Purdue Electric Power Center Committee

Dr. Franklyn Clikeman	Nuclear Engineering
Dr. Keith Hawks	Mechanical Engineering
Dr. Gerald Heydt	**Electrical Engineering**
Dr. Paul Krause	Electrical Engineering
Dr. Lawrence Ogborn	Electrical Engineering
Dr. Chee-Mun Ong	Electrical Engineering
Dr. Oleg Wasynczuk	Electrical Engineering
Dr. Walter Weeks	Electrical Engineering

For the past five years, the Head of the School of Electrical Engineering has charged the committee with election of its own chairman. This is done in April and the term of office is one year. The current chairman is Dr. Gerald Thomas Heydt.

1.3 Our future plans: the PEPC-MESTER

The power engineering educational program is divided into the undergraduate (BSEE, BSME, BSNE) and graduate (MSEE, MSME, MSNE, PhD.) programs. Graduate students come from many countries to study at Purdue. The PEPC program has supported only United States nationals and permanent residents. Foreign students are supported by teaching or research assistantships, or funds from their home country. In the past five years, there has been an erosion of the number of students in the graduate power program. This has been reversed last year through publicity of our program both locally and nationally. At this time, we feel that our progress in increasing the size of the masters level program has been adequate and all our PEPC supported assistantships will be filled. The undergraduate enrollment in power, however, should be increased. For this reason, the present focus and goals of PEPC are largely targeted at the undergraduate power engineering enrollment. Approximately 50 undergraduate EE students each year elect to take the junior level power engineering course. About 30 of these students also elect additional course work in power. *We plan to double these figures in the next five years.* The most important program to bring about this goal is the PEPC-MESTER, a semester in which our students will take a high concentration of power courses.

The basics of the PEPC-MESTER are that a group of power engineering students will be brought together through course registration, seminars, and a scholarship program so that the challenges and demands of power engineering can be effectively presented. Students participating in the program will register for at least three power area courses plus a power laboratory. The courses will be selected from:

EE321	Principals of Electromechanical Energy conversion (3 credits)
EE425	Electric Machines (3 credits)
EE495P	Principals of Electric Power Systems (a new 3 credit course)

EE496 Selected Topics in Electrical Engineering - a three hour power engineering project with a PEPC professor

ME527 Solar Energy Systems (3 credits)

NUCL597M Alternate Energy Conversion (3 credits)

Also, the student will select at least one laboratory from the following:

EE421 Electromechanical Energy Conversion Laboratory (1 credit)

EE431 Electric Power Systems Laboratory (2 credits)

The courses EE421 and EE431 will have one common meeting hour which shall be the PEPC Seminar, a seminar for power area students at which job opportunities, research in the power area, and industrial projects will be presented.

Up to eighteen students enrolled in the PEPC-MESTER will receive $900 scholarships intended to go toward the student's tuition and fees. Eligible students shall be U.S. nationals or permanent residents who will have between approximately 30 and 60 hours remaining for graduation at the end of the Fall 1988 semester. Also, the student must be in good standing in the BSEE or BSCEE program. Part of the PEPC-MESTER is to introduce students to the sponsoring power engineering companies. Summer employment and intern positions with these companies will be actively sought. *The principal objective of the PEPC-MESTER is to acquaint students with the demands of the power engineering industry.* The first PEPC-MESTER will be the spring, 1989 semester. The PEPC-MESTER will be a continuing effort which will be repeated each spring.

Our future budgetary plans are to maintain graduate assistantships at the present level - about eleven assistantships to qualified EE, ME, and NE United States nationals in the masters program. The operating costs of the PEPC program have been reduced over the last five years to a low level. We intend to keep operating costs at this level. The only significant increase in budgetary items is due to the funding of the PEPC-

MESTER. This represents an increase of approximately 15% of the annual budget.

1.4 Additional PEPC programs

Several additional programs are in place to encourage undergraduates and masters-level students to pursue a career in power engineering. The schools of Electrical, Mechanical, and Nuclear Engineering cooperate in these efforts. The main programs are:

1. **UNDERGRADUATE PROJECTS** – The undergraduate projects are power engineering topics on which the students work and report. The students are paid on an hourly basis for the time they spend on a project. A small financial incentive is intended to encourage undecided students to try a power project.
2. **POWER WORKSHOPS** – The power workshops are held off-campus with member companies of PEPC. Here the students meet and interact with practicing engineers and are exposed to topics not always covered in the classroom. These are held in a pleasant setting, usually when classes are not in session.
3. **FIELD TRIPS AND CONFERENCES** – Field trips and conferences are attended by power students in our various courses. The field trips allow the students to see power industry facilities and equipment, while the conferences introduce the students to technical programs on a national level.
4. **SUMMER EMPLOYMENT** – Summer employment is arranged whenever possible for our undergraduate students with the PEPC companies. This gives the students valuable experience in industry while helping the PEPC companies become familiar with the students.
5. **GRADUATE ASSISTANTSHIPS** – The goals of the PEPC program in the undergraduate area are complimented by efforts in the masters program. A full range of masters level courses are offered to both graduate and undergraduate

students. These include high voltage engineering, electromechanical energy conversion, computer applications in power engineering, power systems studies, transmission engineering, power electronics, and topics in nuclear and mechanical engineering. The PEPC program offers graduate research assistantships to a limited number of masters level students in three schools, EE, ME, and NE. Their work usually results in a masters thesis which is made available to PEPC sponsors.

6. **LABORATORY FACILITIES** – Laboratory facilities have, in part, been supported by PEPC. More significant than the actual contribution of funds by the program, however, is the use of PEPC funding as "seed" money for outside support. Outside funding by many agencies has exceeded PEPC funding of laboratory facilities, but the very existence of this power center with utility sponsorship has enhanced the potential for funding from other sources.

The several undergraduate and graduate programs briefly described above are designed to increase student activity in power. There is no question that the first ten years of the PEPC program produced a marked positive effect on the graduate program and faculty. Financial difficulties in the utility industry and the total economy have introduced new variables and challenges but it is important that the second ten years continue the progress, at both the graduate and undergraduate level.

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 635 (Optimization and Economic Operation of Electric Power 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. He is also part of the Purdue Technical Assistance Program (TAP) which offers Indiana business, industries, and government institutions assistance in implementing new, advanced technologies. 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 power systems, power electronics, and adjustable speed drivers.

Dr. Ong is a member 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 a research project on the detection and location of partial discharges in power cables and other apparatus.

Dr. Weeks is currently Professor of Electrical Engineering.

2.2 Other power engineering faculty

Electrical Engineering

John Chiasson (Automatic Control)

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)

Electrical Engineering Professor Emeriti

Steven Freeman (Transmission and Distribution)

Carlton Sprague (High Voltage Engineering)

Mechanical Engineering

Dr. W. Phillips, Head

D. P. DeWitt (Heat Transfer)

R. W. Fox (Fluid Mechanics)

F. P. Incropera (Heat Transfer and Thermodynamics)

N. M. Laurendeau (Combustion)

W. Leidenfrost (Thermodynamics)

M. R. L'Ecuyer (Gas Turbines)

A. T. McDonald (Electric Vehicles, Transportation)

F. B. Morse (Power Engineering)

J. T. Pearson (Heat Transfer)

D. R. Tree (Energy Systems)

K. Wark (Air Pollution Thermodynamics)

C. F. Warner (Air Pollution, Heat Transfer)

Mechanical Engineering Professors Emeriti

R. Olsen

H. L. Solberg

E. J. Wellman

C. Messersmith

Nuclear Engineering

T. Downar

P. Lykoudis

O. H. Gailar

P. S. Lykoudis

K. O. Ott

A. A. Solomon

Nuclear Engineering Professors Emeriti

P. N. Powers

A. Sesonske

III. The 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 August, 1988.

ROBERT BRUCE is from Glens Falls, New York. Bob received the BSEE from Northeastern University. He has held industrial positions with the New England Electric Systems, and the United States Navy. He is interested in power system devices and instrumentation. He recently began a research project on fault location in underground power cables with Dr. W. L. Weeks.

KARL BOLLENBACH just joined the PEPC group in January, 1988. His advisor is Dr. Wasynczuk and he is working in the area of machine control.

JOHN CIEZKI will join the PEPC group in June, 1988 upon completion of his BSEE degree at Purdue.

ALAN ENGELMANN is from Chicago and he received the BSEE from Valparaiso University in 1985. He is completing work on a study of metal oxide lightning arrestor losses with Dr. W. L. Weeks.

JEFFREY MAYER is from St. Louis, Missouri. He joined the PEPC group in September, 1987 and he is completing a project on the analysis of a brushless motor with Dr. Wasynczuk.

BILL MCCOY is from Texas. He holds a Bachelors degree in Interdisciplinary Engineering from Purdue. He will complete the MSEE degree in 1988. His masters project is in electric utility operations and his emphasis is on the Mechanical

Engineering aspects. His advisor is Dr. K. Hawks.

SHAWN O'CONNOR is from Hammond, Indiana. He received the BSEE degree in 1987 from Valparaiso University. His interest are in power electronics and his advisor is Dr. L. Ogborn. Shawn will complete the MSEE in August, 1988.

KRAIG OLEJNICZAK is from Abrams, Wisconsin. Kraig is working on a masters thesis project in effects on three phase unbalance in six and twelve pulse rectifiers. His advisor is Dr. G. T. Heydt. Kraig will complete the MSEE in August, 1988.

SCOTT SUDHOFF has just 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.

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 December, 1988.

3.2 Other power engineering graduate students

AHMED BENSENOCHI is from Algeria. He is completing the PhD program under the direction of Dr. Ong. Area of interest: harmonics and reactive power requirement for HVDC converters with weak AC support.

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.

CHENG-TSUNG LIU is from Taiwan. He is a teaching assistant and he has taught EE 421 and EE 431, the power laboratories. He will complete the PhD degree in 1988 and he has plans to teach in Taiwan. Dr. Ong is his advisor. Area of interest: dynamic simulation of HVDC systems with sizeable AC network representation. He is also interested in estimation and adaptive control.

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.

THOMAS ROETTGER is from Evansville, Indiana. He is completing the PhD program under the direction of Dr. Ong. 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. He is in the final stages of the PhD 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 serves as his advisor.

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, seventy undergraduates wished to be listed as *power majors.* This is up from 43 in 1987. 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 6.9% of our 1230 undergraduate EE students are in power engineering. This is up by 0.9% over 1987. The geographical distribution of the states of residence of the students is concentrated on the Midwest.

An appendix to this report contains an updated directory of undergraduates.

IV. Education and Research Projects

4.1 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.

4.2 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.

4.3 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 are offerering an experimental course, EE 495, in the area of electromechanical motion control.

A new experimental course, EE495P, will be offered for the first time in the spring of 1989. This will coincide with the PEPC-MESTER (see Section 1.3). The course covers elements of power systems for undergraduate students. An array of topics on applied techniques will be included (economic optimal dispatch, power factor correction, HVDC, etc.). Dr. Heydt will organize this course.

Three new graduate courses of one credit each will be 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.

4.4 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 wide-band 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.

4.5 Research projects

Optimal Staircase Pulse-Width Modulation Technique

Norbert R. Klaes and C. M. Ong

The function of the pulse-width modulator is to reproduce a reference waveform - in most cases a sine wave - as a composition of pulses of variable width and position but fixed magnitude. This project deals with the theoretical development and implementation of a staircase modulation technique, which eliminates low order harmonics and at the same time produces a high fundamental voltage component using moderately low switching frequency. A digital version of the staircase modulator has been implemented and its performance tested on an analog simulation of an induction motor. By comparing the performance of the staircase modulator to that of a sinusoidal modulator, it can be concluded that the proposed staircase modulator has many characteristics which are superior to those of the sinusoidal modulator.

Reactive and DC Power Dispatch to Minimize Transmission Losses in an Integrated AC-DC System

S. S. Chen and C. M. Ong

As the cost of dc converter decreases, HVDC power transmission will play a wider role in the transmission and operation of modern power systems. Its ability to control the power flow could be used for network flow control and to achieve greater economy in the operation of the power system.

This project examines the additional economic benefits obtainable from coordinating the reactive power dispatch with the scheduling of the dc power transfers in an ac-dc power system. The minimization of the network losses is formulated as an LP problem. Numerical results obtained on a sample 30 bus, 5-terminal, ac-dc power system indicate that substantial reduction in network losses can be attained when the rescheduling of the dc power transfers is coordinated with the reactive power dispatch.

Modeling and Simulating the Dynamic Behavior of Switched Reluctance Motor Drives

Mehdi Moallem and C. M. Ong

With the availability of inexpensive switching devices, the switched reluctance motor drive, which is both robust and efficient, is becoming economically competitive with other types of drives. However, the doubly-salient and the highly saturated magnetic structure of the motor are formidable hurdles to any attempt so far to simulate the drive. Linear approximations are inadequate because of the highly saturated condition, and classical transformation techniques can offer no advantage in dealing with the doubly-salient motor. We propose to establish a method for simulating the transient behavior of a complete switched reluctance motor drive using an integrated field-network approach: the saturated field condition and doubly saliency structure to be handled by a finite element technique and the changing converter circuit topology by a tensor technique. The proposed method of simulation will require research in two main areas: the integration of tensor approach with the field-network approach and the search for more efficient computational schemes to solve the resulting set of stiff equations. We also propose to experimentally verify the method of simulation established before using it as a simulation tool to investigate excitation control schemes and magnetic designs which are suitable for high speed applications.

A Universal Digital Simulation Technique for Electric Drive Systems

Warin Suwanwisoot and C. M. Ong

There is a wide variety of industrial applications where adjustable speed drives are needed. The power rating ranges from fractional horsepower to over a million horsepowers. To our knowledge, there is no known software package specifically designed for simulating electric drive systems. Existing software packages which have limited capability for simulating machines or power electronic circuits are not adequate for simulating many of today drive systems. In this project we will investigate the modeling of drive systems using an integrated network-oriented and equation-oriented approach, which will have the essential capability of handling time-varying non-linear circuits with variable-dependent constraints. In addition we will examine various implicit differential equation solving schemes for their suitability in dealing with equations describing a system consisting of time-varying and discrete components. The objective is to develop a universal simulation package for electric drive systems.

The Problems with Operating Line-Commutated Inverter on a Weak AC Bus

Ahmed Bensenouci and C. M. Ong

This project deals with the problems of designing and operating line-commutated inverters which are to operate on weak ac buses. Many of the dc power transmission schemes currently considered by utilities around the world involves connecting the inverter to a relatively weak ac bus, often with a short circuit ratio under 3. While most of the problems with operating a line-commutated inverter onto a weak ac bus have been identified, and the cause and process seemingly understood, little has been done to probe it further. In this preliminary phase of the project we will try to determine the effective short circuit ratio of a 12 pulse Graetz bridge inverter that is connected to an ac bus with static harmonic filters, the ac network being represented by its Thevenin's equivalent. This will later be extended to the case of an ac network with two inverters that are close but not on the same ac bus. The objectives of this study are to determine what truly is the effective short ratio in these two situations, and to understand how the harmonic filters or perhaps a static var compensator might affect the effective short-circuit ratio.

Simulation and Control of HVDC Systems

Cheng-Tsung Liu and C. M. Ong

The first part of this project is a continuation of earlier works on hvdc system simulation and the connection matrix method. By using Beregon's method for the simulation of the ac and dc transmission networks (as in EMTP) and the connection matrix approach for the converters, we now have an efficient program for detailed simulation of general hvdc systems with a sizeable representation of the surrounding ac network. Other features added include nonlinear device characteristics, such as those of ZnO arrestors and transformers.

The second part of this project is on adaptive control of the converter. Techniques for on-line estimation of the ac network strength from terminal measurements and for adaptively tuning the converter control are being developed and tested.

Enhancement of the Harmonic Power Flow study Program

G. T. Heydt, W. Grady, D. Carlson***

*Dr. Grady is with the University of Texas, Austin.

**Mr. Carlson is with Minnesota Power.

In 1983, we commenced work on a harmonic power flow study for EPRI for the purpose of analyzing harmonic penetration of signals which result from nonlinear loads. The software developed is primarily for analysis of systems with large rectifiers, inverters, and fluorescent lighting loads. Other nonlinear loads can also be modelled. Work is continuing on a fourth version of the software. Our most recent efforts are:

- Sparsity coding of the Jacobian and admittance matrices
- Optimal ordering

- Induction motor modelling
- Improved load models at harmonic frequencies
- "Quick-look" options
- Inclusion of phase shifters
- Improved transmission line models
- TIF-KIT calculations
- Total positive, negative, and zero sequence signals are calculated
- Improved output format

Isolated Operation of Induction Motor Loads

O. Wasynczuk, F. D Rodriguez and P. C. Krause

Supported by a David Ross Grant

In transient stability programs, induction machines are represented using a reduced order model in which the rate of change of stator flux linkages are neglected in the stator voltage equations when expressed in a synchronously rotating frame of reference. It has been demonstrated that the resulting model predicts, with reasonable accuracy, the induction machine response following various system disturbances. However, it has recently been observed that significant inaccuracies may occur if this model is used to predict the open circuit stator voltages during isolated operation. The resulting error may be significant enough that in some cases it could lead to erroneous conclusions, as for example in studies involving the transfer of power station, induction motor loads from one bus to another where the transfer of an isolated machine is initiated when its voltage decays to a prescribed level.

A more accurate method of predicting the dynamic behavior of induction machines during isolated operating conditions has recently been developed. In this method, a refined model is derived by neglecting the rate of change of stator flux linkages in a reference frame whose speed varies as a function of the stator frequency. It has been shown that in cases where there are no significant rotor transients involved, the refined model provides a more accurate indication of the induction machine response during isolated operation. Moreover, the improvement in accuracy does not require an increase in the dynamic order nor a significant increase in complexity beyond that of the standard model.

Detection and Location of Partial Discharges in Power Equipment

W. L. Weeks, J. P. Steiner, and E. S. Furgason

Supported by Square D Corporation and Essex Power Conductor Group

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 waveform have been received and amplified in wide band channels, the signals are digitized and all subsequent operations are digital. The detection and location is 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.

Procedures and Instrumentation for Non-Disruptive Testing of Critical Power System Components

W. L. Weeks, J. P. Steiner, C. Erickson

Sponsored by US Army Corp of Engineers, CERL

A new concept for reliability enhancement of critical power systems is under study. The initial study involves cables, transformers, surge arrestors, and uninterruptible power supplies.

The concept involves the use of wide band digital cross correlators in two modes of operation. First, the power system is monitored at one or more locations for new electromagnetic noise being generated. This noise is then located for the purpose of component inspection and diagnostics. Second, often with the same ports and equipment, wide band noise at low levels is injected into the system with the object of detecting changes in the cross correlation functions at appropriate positions. Such changes come about as the electrical characteristics of components change, often indicative of impending failure or degraded performance.

The work involves various accelerated aging and failure tests.

Imbalanced Operation of Converters

K. Olejniczak, G. T. Heydt

Sponsored by the Purdue Electric Power Center

This project concerns the harmonic impact of imbalanced rectifiers and inverters. The case of small imbalance is highlighted. For this case, the phase values and symmetrical components of the harmonics have been calculated.

Superconducting Circuit Breaker

M. Mui, G. T. Heydt

The advent of the high temperature superconductor has brought new interest in applications of this phenomenon. In this project, the new ceramic superconductors ($YBa_2Cu_3O_7$) have been studied for use as a switch. The essence of the idea is to quench superconductivity to bring about circuit interruption. The project is in early stages using samples from the Department of Metalurgical Engineering.

Identification of Harmonic Sources and Study of Harmonic Signal Flows

Maged Najjar, G. T. Heydt

Sponsored by the National Science Foundation.

Two distinct studies are described here. The first deals with the use of state estimation to identity sources of harmonic signals in an electric power system. The weighted least squares method will be used. At this time, we are concentrating on characterizing and reducing the estimation error.

The second area deals with characterization of harmonic signal flows in power systems. The flow of distortion voltamperes has been studied in detail. Interesting and potentially very useful "rules of thumb" have been obtained for the estimation of harmonic signal levels.

Applications of AI Languages to Optimal Dispatch

Robert Tyson, G. T. Heydt

Supported by the Purdue Electric Power Center

This project concerns the application of artificial intelligence computer languages such as Prolog and Lisp to economic optimal dispatch. A dynamic programming based approach is being used to dispatch a hydro system. The dynamic programming algorithm is written in terms of rules which are subsequently coded in an AI language.

APPENDIX

Directory of Faculty and Students in Power Engineering

PURDUE ELECTRIC POWER CENTER DIRECTORY
3/29/88

Professors	Department	Login	Telephone	Office
Frank Clikeman	NuclE	clikeman	49-45746	NUCL 140A
Keith Hawks	ME	hawks	49-45716	ME 105
Jerry Heydt	EE	heydt	49-43520	EE 320
Paul Krause	EE	krause	49-43481	EE 254
Larry Ogborn	EE	ogborn	49-43472	EE 246
Chee-Mun Ong	EE	ong	49-43484	EE 268
Oleg Wasynczuk	EE	wasynczu	49-43475	EE 266
Walter Weeks	EE	weeks	49-43563	EE 348G
Secretaries				
Wanda Booth (Ogborn, Ong, Krause, Wasynczuk)	EE	wanda	49-43474	EE 249
Dee Dee Dexter (Weeks)	EE	dexter	49-43558	EE 339
Carol Edmundson (Heydt)	EE	carol	49-43510	EE 325A
Diane Forbes (Clikeman)	NuclE	nsec	49-45741	NUCL 140
Angela (Angie) Myers (Hawks)	ME	myersa	49-45783	ME 100
Teaching Assistants				
Cheng-Tsung Liu (Ong)	EE	lifen		
Mehdi Moallem (Ong)	EE	meysam		
PEPC Students				
Fadi Abdal (Wasynczuk)	EE	abdal	49-49069	KNOY 289
Karl Bollenbach (Wasynczuk)	EE	bollenba	49-43371	EE 002
Robert N. Bruce (Weeks)	EE	bruce	49-43447	EE 226
John Ciezki	EE	ciezki		
Jeffrey Mayer (Wasynczuk)	EE	mayer	49-43466	EE 238
Bill McCoy (Hawks)	EE	mccoyb	49-43468	EE 241A
Shawn O'Connor (Ogborn)	EE	smo	49-43468	EE 241A
Kraig Olejniczak (Heydt)	EE	olejnicz	49-43468	EE 241A
Scott Sudhoff	EE	sudhoff		
Robert Tyson (Heydt)	EE	rtyson	49-43378	EE 50
Other Graduate Students				
Ahmed Besenouci (Ong)	EE	ahmedb	49-43395	Hybrid Lab
Alan Engelmann (Weeks)	EE	engelman	49-43468	EE 241A
Mohamed Ghazy (Ogborn)	EE	ghazy		
Hamdy Hashem (Downar)	NuclE	hashem	743-6789	
Manshih Mui	EE	manshih	743-0259	EE Box 177
Maged Najjar (Heydt)	EE	maged	743-3141	EE Box 174
J. P. Steiner (Weeks)	EE	jp,z80	49-43468 or 49-43349	EE 241 or HV Lab
Warin Suwanwisoot (Ong)	EE	suwanwis	743-4195	

Purdue Electric Power Center Undergraduate Student Directory
3/29/88

Name (Dept. if not EE)	Login	Telephone	Graduation	State of res.	Campus address (West Laf.)	Interests (in addition to power)
Mahmoud Abdalla	mahmouda	497-1979	12/88	IN	28-6 Tower Dr.	
Kurt Adams	kadams	743-0980	5/88	MI	340 W. Stadium	CR
Ali J. Arik	alia	49-55431	5/88	FL	Box 13 Shreve Hall	C
Sawsan Ashour	ashour	743-0284	5/88		415 Young Grad Hse	
Barry Joe Bentley	bentley			IN	2550 Yeager Rd. #2-11	
Jeffrey Boehm		49-53788	5/91	IN	Box 25 Owen Hall	
Laura Christiansen		743-6766	5/88	IN	331 Northwestern #4	GM
John Ciezki	ciezki		5/88			
Johnny E. Clifford	jecliff	743-2418	5/88	IN	402 Northwestern #10	
Ralph Coan	coan	743-6713	8/89	IN	249 S. Salisbury #1	
Jim Collins	cola	743-5677	5/88	IN	450 S. Grant #13	
Jennifer Coffey	coffeel	743-9654	5/89	IN	405 Young Grad House	C
Gary Crawshaw	crawshaw	743-5251	5/88	IN	20 Littleton #3	CU
Abid Din	saira	743-6345	8/88		400 N. River Rd. #1710	CMU
Chris Downs	f0m	743-3287	5/88	IN	320 Brown #706	
Edward Escasa	escasa	743-2213	5/88	IL	611 Meridian St.	
Linda Fagan	faganl	743-5560	5/88	IN	136 Andrew Pl #4	Q
Tom Flohr	flohr	495-2088	12/89	IN	Box 289, Cary Quad	
Linda Foote	foote	743-1764	12/90	IN	45 N. Salisbury #4	
James Franchville	franchvi	743-1572	5/88	IN	110 E. Wood	
Joseph Franchville	joseph	743-1572	5/88	IN	110 E. Wood	
Gavin Furtado	gaven	743-3627	8/88	IN	515 W. Stadium #6	
Manuel Gabato	pahang		5/88		215 Littleton #9	
Rob Gerecke	robg	743-1481	5/88	IN	545 Hayes	
Mony Ghose		743-8217	5/88	IN	433 Harrison #1	C
Balwinder Girn	girn	493-1730	5/88	IN	11-10 Ross Ade Dr	C
Danny Gojmerac	gojmerac	495-2872	5/89		SE401 Cary Quad	
David Greene	deg	497-1036	12/88	IN	30-20 Hilltop	U
Steve Gunnerson	stipo	743-3767	12/88	IN	300 Russell	
Ronald Hatton	hatton	495-4232	5/91	IN	NE427 Tarkington	Q
Carl Hayden	haydenc	49-54331	5/90	IN	SE210 Tarkington	
Mau Dinh Hua	mau	743-9646	5/88	IN	301 W. Stadium #12	C
Edward Jen	ehjen	743-4544	5/88	IN	241 Sheetz #6	
Mona Juba	juba	495-7177	5/88	IN	239 NW Meredith	X
Sudha Kakarala	kararala	743-2697	12/88		419 Harrison St. #8	X
Jason Ketterer	jkettere	743-3967	12/88	IN	621 Waldron #7	CU
Anthony Klippel	tonyk	743-1481	5/88	IN	545 Hayes	
John Kuschewski	kuschews	743-6538	5/88	IN	1010 N. Salisbury #7	C
Brent Lahey	bal	743-9685	12/89	IN	525 University	
Keith Lannan	klannan	743-8201	5/88	IN	1010 N. Salisbury #11	CR

Thomas Larkner	larkner	743-0980	5/88	IL	340 W. Stadium	CN
Karen Letts	kare		5/89	IN	241 Sheetz #11	C
William McClintock	wmm	743-0446	5/89	IN	419 Vine	US
Marcia J. McCoy	mccoy		5/88	AL	504 Hawkins G.H.	
Jim Mellish		463-4490	5/88	IN	2550 Yeager #6-1	CT
David J. Meyer	meyerda	743-8784	5/89	IN	111-2 N. Salisbury	X
Chris Moberg			5/90		Box 217 Owen Hall	
Mark Momot	momot	743-3794	5/88	IN	217 Sheetz	C
Robert Morton	rmorton	497-3313 or 463-9521	5/88	IN	900 David Ross Rd	
Neal Nakafuji	ssr		5/88	HI	503 Young Grad Hse	C
Barbara Parkes	parkes	743-1407	8/88	OH	318 Waldron #4	C
Lisa Pfrommer	pfrom	743-1864	5/89	NY	501 Russell	C
Joe Pienta	pienta	743-1051	5/88	IN	690 Waldron	A
Christopher Prince	ctprince	743-8173	5/89	IN	318 Waldron #5	
Shannon Riegle	shannon	495-3389	5/88	IN	Shreve Hall	E
Jim R. Rose	jrose	463-3509	5/88	IN	32-2 Hilltop	C
Susan Rutter	rutters	743-0332	5/89	IN	238 Pierce #2	
Michael Sanderbeck	sanderbe	743-8655	5/88	PA	456 Hawkins G.H.	C
Robert Schwyn	booger	743-9721	5/88	IN	300 N. Salisbury	
Chuck Sembroski	sembrosk	495-2308	12/88	IN	Box 844 Cary Quad	
Jeffrey Sensmeier	jsens	463-0941	5/88	IN	32-17 Hilltop Dr	C
Hamsa Shad	hps	441-3293	5/88	MO	212 W. Fowler #E	C
Scott Shephard	shephard	463-9521	5/88	OH	900 David Ross Rd	
Ron Smolen	smolen	743-8133			217 Sheetz #15	
Brian Stallman	stallman	463-5586	5/88	IN	2450 Sycamore #30A	C
David Stolz	dds	495-2016	5/88		Box 894 Cary Quad	
Philip Strimbu	strimbu		12/89	IN		
Roger Stroup	stroup	743-4338	12/88	IN	240 S. Salisbury #7	C
Robert Tashijan	tashijar	743-8784	5/89	IN	111 N. Salisbury #2	
William Torp	torp	497-3560	5/88	IN	2501 Soldiers Home Rd #10D	
Robert Trajkovski	shibumi	495-5541	12/88	IN	831 Shreve Hall	C
Scott Venners	sv	743-5015	5/88	IN	512 W. Stadium	
Kent Wert	wertk	495-1792	5/88	IN	20-5 Ross-Ade Dr	C
Jon Woolsey	halz	743-6512	12/88	IN	527 N. Grant #8	C

Interest Area

A Computers
C Controls
E Electrical Contracting
G Management
M Manufacturing
N Nuclear power
Q Electromechanical systems
R Robotics
S Solid State Devices
T EET
U Communications
X Marketing, technical sales