12-1-1987

Summary of the Activities of the Purdue Electric Power Center 1987

G. T. Heydt
Purdue University

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Summary of the Activities of the Purdue Electric Power Center 1987

G. T. Heydt

TR-EE 87-43
December 1987

School of Electrical Engineering
Purdue University
West Lafayette, Indiana 47907
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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 eighteen companies with 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 Most of the charter founders of PEPC remain members, however, there have been some companies which have withdrawn and there have been some new members.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 main goal of the Purdue Electric Power Center is to maintain a center of excellence in power engineering. This is targeted at the Schools of Electrical, Mechanical, and Nuclear Engineering at Purdue. The principal ways in which this objective is promoted are

- Support of undergraduate and masters level students who work on power engineering projects.
- 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 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.
Table 1.1

Members of the Purdue Electric Power Center

<table>
<thead>
<tr>
<th>Company</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amoco</td>
<td>Chicago, IL</td>
</tr>
<tr>
<td>Beahtel</td>
<td>San Francisco, CA</td>
</tr>
<tr>
<td>Central Illinois Public Service</td>
<td>Springfield, IL</td>
</tr>
<tr>
<td>Commonwealth Edison</td>
<td>Chicago, IL</td>
</tr>
<tr>
<td>General Electric</td>
<td>Fort Wayne, IN</td>
</tr>
<tr>
<td>Illinois Power</td>
<td>Decatur, IL</td>
</tr>
<tr>
<td>Indiana and Michigan Electric</td>
<td>Fort Wayne, IN</td>
</tr>
<tr>
<td>Indianapolis Power and Light</td>
<td>Indianapolis, IN</td>
</tr>
<tr>
<td>Northeast Utilities</td>
<td>Hartford, CT</td>
</tr>
<tr>
<td>Northern Indiana Public Service</td>
<td>Hammond, IN</td>
</tr>
<tr>
<td>Pacific Gas and Electric</td>
<td>San Francisco, CA</td>
</tr>
<tr>
<td>Public Service Indiana</td>
<td>Plainfield, IN</td>
</tr>
<tr>
<td>Sargent &amp; Lundy Engineers</td>
<td>Chicago, IL</td>
</tr>
<tr>
<td>Sohio</td>
<td>Cleveland, OH</td>
</tr>
<tr>
<td>Southern Indiana Gas &amp; Electric</td>
<td>Evansville, IN</td>
</tr>
<tr>
<td>Square D</td>
<td>Chicago, IL</td>
</tr>
<tr>
<td>Wisconsin Electric Power</td>
<td>Milwaukee, WI</td>
</tr>
</tbody>
</table>
• To provide an interface between the companies and the students for recruiting and other activities.
• To bring industrial input into the power curriculum.

In short, the PEPC program is the base of the power engineering program at Purdue. The present budget is $99,350/year. About 80% of this figure is committed to undergraduate and masters level support. At the present, most of the students who are directly participating in the programs are in Electrical Engineering. The majority of the remainder of the budget is to support the scholarship and "senior of the year" programs and in travel.

1.2 Administration of the program

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 2.

Table 2
The Purdue Electric Power Center Committee

<table>
<thead>
<tr>
<th>Dr. Franklyn Clikeman</th>
<th>Nuclear Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Keith Hawks</td>
<td>Mechanical Engineering</td>
</tr>
<tr>
<td>Dr. Gerald Heydt</td>
<td>Electrical Engineering</td>
</tr>
<tr>
<td>Dr. Paul Krause</td>
<td>Electrical Engineering</td>
</tr>
<tr>
<td>Dr. Lawrence Ogborn</td>
<td>Electrical Engineering</td>
</tr>
<tr>
<td>Dr. Chee-Mun Ong</td>
<td>Electrical Engineering</td>
</tr>
<tr>
<td>Dr. Oleg Wasynczuk</td>
<td>Electrical Engineering</td>
</tr>
<tr>
<td>Dr. Walter Weeks</td>
<td>Electrical Engineering</td>
</tr>
</tbody>
</table>
For the past four 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. From May 1986 to April 1987, Dr. Walter L. Weeks served as PEPC chairman. The current chairman is Dr. Gerald Thomas Heydt.

Prior to May, 1987, a coordinator was hired to help administer certain phases of the program. This position was occupied by Dr. Leonard Alan Kraft (1980-1984), Brian Johnson (1984-1985) and David Redding (1985-1987). At this time, this position is vacant and the duties of the coordinator are shared by the chairman and the committee.

1.3 Present PEPC focus and goals

A principal objective of PEPC is to encourage undergraduates and masters-level graduate students to pursue an education in power engineering. The three schools which participate in PEPC are Electrical, Mechanical and Nuclear Engineering. In an attempt to stimulate undergraduate and masters-level interest in power in these three schools, PEPC conducts several programs. These 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. UNDERGRADUATE SCHOLARSHIPS — The undergraduate scholarship program is intended to encourage undergraduate participation in power. Several scholarships are awarded annually to undergraduate students who demonstrate both an interest in power and academic excellence.

3. 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.

4. 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.

5. 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.

6. 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.

7. 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 far outstripped 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.
8. EXPANSION OF THE ELECTRIC POWER LABORATORY — Late in 1981, a generous gift was obtained from the Indianapolis Power and Light Co. as part of the Purdue Program "Plan for the Eighties." The theme of the Plan for the Eighties is one of vision in engineering education to the end of this century and beyond. The gift from the Indianapolis Power and Light Co. has been used to develop digital data acquisition and control capability.

Traditional electric power engineering laboratory experience has been centered on three areas: electric power systems, energy conversion, and high voltage engineering. In addition several other laboratory programs provide experience with AC circuits, control, power electronics, machine drives, and transformers. Recognizing that laboratory experience is an important ingredient in a top notch education in power, PEPC has aided in the sometimes difficult task of ensuring that at least one power laboratory course is offered each semester.

The broad objective of PEPC is to maintain an active center of excellence in power engineering. The reduced tax revenues in Indiana of the early eighties brought difficult financial conditions at state supported universities. Since the time of the inception of the PEPC program, the state expenditure per student has dropped drastically. Industrial support has helped to maintain adequate levels of facilities. In power engineering, we are fortunate to have support from the utility companies and others. It is extremely important that this support continue, in fact, at a higher level.

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.
1.4 Plans for the future

In the past 40 years in the United States, there has been a gradual decline in student interest in power engineering. While this trend has been broken by national and international events (e.g., the oil embargo), the overall trend in student interest is downward. The demand for power engineers is probably stable or growing at a low annual rate. The disparity between supply and demand of power engineers appeared to be widening in the early 1980's.

At Purdue, power engineering captures about 5.5% of the bachelors level students in Electrical Engineering. In the graduate program, we capture about 2% of the MS plus PhD level students. It is clear from these statistics that an effort to increase the number of students — perhaps to double the number of students — should be a prime objective. Dr. W.L. Weeks set this as a goal in 1987 in his presentation at the PEPC annual meeting. His talk was appropriately entitled "Stopping the Erosion."

Considering that PEPC is the base of support in power, one would expect that a prime effort in increasing the educational program should come from PEPC. Support from PEPC is not the only resource sought to enhance the program, however. We have had modest success in attracting research support from The National Science Foundation, The Electric Power Research Institute and others. The logic in increasing the research program is to increase the graduate program. This is expected to have a strong positive effect on the senior and junior level class enrollments. A related goal is the increase of the number of sponsors of the PEPC program.

The chairman of the committee has set as a goal the establishment of a PEPC directory and data base for use by the sponsors. This should be useful in recruiting efforts. A copy of the directory of students is supplied to each sponsor.

The School of Electrical Engineering at Purdue celebrates its centennial in 1988. Part of the celebration will relate to power engineering including
i. The north American Power Symposium to be held at Purdue, September 26-27, 1988.


As part of the centennial celebration, a new wing of the Electrical Engineering Building will be dedicated in October, 1988. This addition, the first in 40 years, will increase the space available to the department by about 40%.
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.

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), EE 635 (Optimization and Economic Operation of Electric...
Power Systems), and EE 432 (Elements of Electric Power Systems).

Dr. Heydt is a member of Eta Kappa Nu, Sigma Xi, ACM, and representative to the American Power Conference. He 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'Ecuyl (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
2.3 Visiting faculty

This year, Mr. Zhaoxu Liu spent a sabbatical leave at Purdue. Mr. Liu is from the Chinese Electric Power Research Institute, Beijing, PRC. Mr. Liu worked in the area of power system state estimation (with Dr. Heydt). Upon the expiration of his leave, he renewed his stay in the United States for one additional year. He is spending that year at Howard University, Washington, DC.

Professor S.S. Chen of Tsinghua University, Beijing, China completed his one-year sabbatical leave at Purdue in January, 1987. He is presently teaching in China. Professor Chen worked with Dr. C-M. Ong in the area of HVDC systems.
III. The Students in Power Engineering

3.1 Graduate students supported by PEPC

FADI ABDAL is from Damascus, Syria. He just began work on a project in rotating machinery 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 Co, and the United States Army. He is interested in power system devices and instrumentation. He recently began a research project on lightning arrestors with Dr. W. L. Weeks.

WILLIAM BUTLER is from Muncie, Indiana. Bill completed the MSEE in May, 1987 working with Dr. Heydt in the area of harmonics in power systems. He is presently with Emerson Electric Co., Saint Louis, MO.

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

JEFFREY MAYER is from St. Louis, Missouri. He joined the PEPC group in September, 1987 and he is in the early stages of a project under the direction of Dr. O. Wasynczuk.

BILL MCCOY is from Texas. He holds a Bachelors degree in Interdisciplinary Engineering from Purdue. He will complete the BSEE 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.
MICHAEL MEROW is from Laporte, Indiana. Mike was supported by PEPC and he completed the MSEE in May, 1987. He worked in the area of state estimation in power systems. He is presently employed by the American Electric Power Co., Columbus, OH.

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.

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.

DAVID REDDING is from Cincinnati, Ohio. He served as the PEPC coordinator for the last two years. Dave completed the MSEE in May, 1987 working with Dr. Heydt on harmonic signals produced by PWM converters. He is presently with the General Electric Co., Cincinnati, OH.

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.

3.2 Other power engineering graduate students

AHMED BESENOUCI is from Algeria. He is completing the PhD program under the direction of Dr. Ong. Area of interest: power system simulation.

JOHN CHIMINSKI is from Detroit and he holds a BSEE from Michigan State University. Dr. Stanislaw Zak serves as his advisor. Area of interest: automatic control.
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.

CHEN-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 late in 1987 and he has plans to teach in Taiwan. Dr. Ong is his advisor. Area of interest: power system theory.

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.

J. P. STEINER is from West Lafayette, Indiana. 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.

WARREN SUWANWISOOT is from Thailand. He is in the MSEE program under Dr. Ong's direction. Area of interest: HVDC.

3.3 Undergraduate students

It is difficult to firmly identify undergraduate students in power engineering. Forty three undergraduates wished to be listed as in power engineering — about 60% are juniors, 40% are seniors. It is estimated that an additional 20-40 students are in power electronics or a field closely related to power engineering. Using these figures, one finds that about 6% of our total of 1230 undergraduate EE students are in power engineering. Approximately 8% of our 375 seniors in EE are in power engineering. These students primarily come from Indiana (75%) or the surrounding states (10%). An additional 10% come from Eastern states, and the remaining 5% from Western states. There are presently no foreign nationals in the undergraduate power program.
An appendix to this report contains a directory of undergraduate students.
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 (el.).  
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 converter supplied electromechanical drive systems.

EE 625 Analysis of Electromechanical Systems II Class 3, cr. 3. Prerequisite: EE 525 (C.1)

Extension of EE 525 Electric propulsion systems including presentation of cyclo-converter 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. (C,1)

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 (C, 1)

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. (C, 1)

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 Waszczyk 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 Wasylczuk 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 including one in the area of superconductivity.

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.

Professors Krause and Wasylczuk are offering an experimental course, EE 495, in the area of electromechanical motion control.

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 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.

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.

An Optimal Power Flow Technique for AC-DC Power System

Chan-Nan Lu and C. M. Ong

Mathematical optimization techniques, such as linear, nonlinear, integer, quadratic and dynamic programming, have been applied to achieve economic and reliable operation of power systems. One such problem is known as the optimal power flow; it may be defined as the best power flow corresponding to some specified criteria subject to specified constraints. The typical criteria used are minimum production cost and minimum network losses. The usual constraints are those of the network, ratings of components, and those from considerations affecting stability and reliability.
The objective of this research is to establish a suitable mathematical formulation and solution procedure for the large scale ac-dc optimal power flow problem and to examine the economic and security impact of dc power scheduling on the operation of such a power system.

**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 horsepower. 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.

Operating Strategy for Multiterminal DC System without Fast Communication Link

Cheng-Tsung Liu, D. P. Carroll, and C. M. Ong

Although there is no multiterminal hvdc system in operation as yet, there are several possible control schemes for such a system. A simple approach is to extend the current margin control scheme for two-terminal to the multiterminal case, using one of the terminals to determine the dc voltage while the other terminals control their currents or powers. But the implementation of such a scheme requires a fast and reliable communication system to coordinate the current references. A similar requirement applies to the voltage-margin scheme. In recent years, a number of alternate operating schemes with less dependence on the communication system has been proposed. In this
project we will evaluate the merits of some of these new schemes and to explore ways of further refining some of these. The objective is to develop a control strategy that utilizes the best of two or more schemes in an adaptive manner.

**Fast Power Flow Studies Using the Pseudoinverse**

*Michael Merow, G. T. Heydt*

Supported in part by the Purdue Electric Power Center

The electric power flow problem has been reformulated as a state estimation problem in which measurements and system data are used in a linearized set of equations of the form $AX = B$. The $A$-matrix is rectangular and the mean square solution involves the pseudoinverse, $A^+$. Input data includes line flow and bus voltage telemetered data. The lossless model gives good accuracy for the IEEE 31 bus test system.

At this time, solution error and a modified lossy model is being examined. The former is approached from a study of the singular values of $A$. Consideration of losses is being made by modifying the linearization of the power balance equations.

Results of initial tests of the pseudoinverse approach to the power flow problem are very encouraging. We believe that 3% (worst) error levels are attainable with a non-iterative, no-inversion, sparse coded method whose speed is an order of magnitude or more faster than the Newton-Raphson method. The consequences of such an algorithm include real-time supervisory control and data acquisition applications, on-line power flow studies for system operations, and other high speed applications.

**The Harmonic Impact of Converters Serviced by Non-Standard Three Phase Connections**

*William Butler, Craig Pinneo, G. T. Heydt*

Supported by the Purdue Electric Power Center

Most rectifiers and inverters (i.e., converters) rated at 10 kW and above are three phase units. The harmonic impact in the AC system caused by such units has been
studied for standard three-phase connections in the converter transformer. Non-standard connections, however, have not been well covered in the literature. In this study, the open wye, open delta, Scott and LeBlanc connections are considered. These connections offer some potential for reduced transformer cost as well as lower harmonic impact. In this context, harmonic impact may be measured by

- total harmonic distortion (THD)
- telephone influence factor (TIF) or KIT-product
- total negative sequence content.

The accompanying figure shows the four connections under study and a few of the interphase relations.

The Design of Active Filters for HVDC Converter Systems

Daniel Hart*, G. T. Heydt

Supported in part by the Electric Power Research Institute, Contract RP-2444.

*Dr. Hart is presently with Valparaiso University.

Dr. Hart has completed a Ph.D. thesis on the design of active filters for HVDC systems. The filter controls rely on parameters obtained from the harmonic power flow study. The configuration of the active filter is essentially coupling of out-of-phase signals to cancel eleventh and thirteenth harmonics (the predominant signals for a twelve pulse converter). The study includes

- Optimal filter design
- Optimal operation (including fundamental frequency voltage limits)
- Effects of the AC network on filter design
- Typical cost figures
- Recommendations for actual implementation
Figure 4.1 An eight pulse converter bridge with Scott and LeBlanc connected transformer.
The Harmonic Impact of PWM Converters

David Redding, G. T. Heydt

Supported in part by the Purdue Electric Power Center

From a frequency viewpoint, a pulse width modulator (PWM) is a device which shifts frequency to higher spectrum locations. In this study, a PWM device is used in connection with a rectifier or inverter (i.e., converter) to shift AC-side harmonics to higher frequencies. In this way, the harmonic impact of the converter has the potential of being more easily filtered.

The essence of the project is to systematically catalog, control, and design a PWM strategy to mitigate harmonic impact. This impact is measured primarily as total harmonic distortion but “telephone influence factor”, or TIF will also be considered.

The significance of this work is that PWM converters offer the possibility of lower harmonic impact over conventional converters because the converter transformer offers greater isolation at higher frequencies.

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. Waszczuk, 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.

A Self Commutated Power Converter for Stabilizing Torsional Interactions

O. Wasynczuk, N. A. Anwah and C. Chen

Subsynchronous resonance (SSR) occurs when a resonant frequency of a series compensated transmission system interacts with a natural frequency of a steam turbine generator. This form of SSR is referred to as torsional interaction and in some cases may become self excited. If self excitation occurs, significant turbine damage may occur unless corrective action is taken. A new method of counteracting SSR has recently been developed. This method, referred to as transmission current feedback, involves the measurement of the transmission system currents from which the subsynchronous components that cause torsional interactions are extracted. Once extracted, these are suitably amplified by a controllable power source and injected into the generator bus of the affected steam turbine canceling the original subsynchronous components that would otherwise produce torsional interactions.

An important aspect of this approach is the power source used to supply the required subsynchronous currents. A controllable power source suitable for multimegawatt applications with a response bandwidth that includes the complete range of subsynchronous frequencies has recently been proposed. This source consists of a voltage fed, self commutated, switching converter which provides independent control of the injected real and reactive power. Analytical relationships that relate the converter output currents to the controlling variables have been derived and a suitable control strategy has been formulated. The effectiveness of this approach has been demonstrated using a detailed computer simulation of a benchmark system known to be affected by
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.
APPENDIX

Directory of Faculty and Students in

Power Engineering
<table>
<thead>
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<th>Name</th>
<th>Department</th>
<th>Login</th>
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<td>Hamsa Shad</td>
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<td>Scott Shephard</td>
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<td>900 David Ross Rd</td>
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### Interest Area

- **C** Controls
- **E** Electrical Contracting
- **G** Management
- **M** Manufacturing
- **N** Nuclear power
- **R** Robotics
- **S** Solid State Devices
- **U** Communications