FORTIETH ANNUAL REPORT
OF THE
POWER AFFILIATES PROGRAM

University of Illinois at Urbana-Champaign
Department of Electrical and Computer Engineering
306 N. Wright St.
Urbana, IL 61801

PAP-TR-19-01

May 2019
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FOREWORD

This report provides a summary of Power Affiliates Program (PAP) activities in the Department of Electrical and Computer Engineering at the University of Illinois at Urbana-Champaign for the calendar year 2018. Information listed below is intended to be a progress report to the affiliate companies. The PAP is the foundation of the industrial liaison effort in the power and energy systems area. Current affiliates associated with the PAP are:

Ameren
City Water, Light & Power, Springfield, IL
Continental Automotive
Electrical Manufacturing & Coil Winding Association, Inc.
Exelon
Flanders Electric
G&W Electric
MidAmerican Energy Company
PowerWorld Corporation
S&C Electric Company
Sargent & Lundy Engineers
Professor Emeritus M. A. Pai

2018 was an active year for the PAP and the highlights are covered in this report. We acknowledge the valuable interaction of the Affiliates and are most thankful to these companies for their continued support.

Peter Sauer, Director
Arijit Banerjee
Subhonmesh Bose
Kevin Colravy
Alejandro Dominguez-García
George Gross
Kiruba Haran
Philip Krein
M.A. Pai
1. INTRODUCTION AND SUMMARY

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

- Maintain stimulating, meaningful and high quality undergraduate and graduate programs in electric power engineering.
- Increase university-industrial interaction at all levels of education and research in electric power engineering.

These objectives are as valid today as they were in 1979. The multi-faceted activities in 2018 under the PAP umbrella clearly were in support of these objectives.

Throughout the past 40 years, the PAP has maintained a stable financial base during times of rapid change in the power industry and provided seed money for research. This led to additional funding by other sources and has made it possible for students to be exposed to industrial problems and participate in technical and professional meetings. Given the cyclical nature of funding by government agencies, the PAP is a critically important source of support.

This annual report is organized as follows. The financial statement for the 2018 calendar year is given in Section 2. Section 3 describes how the Power Program fits into the departmental structure. There is no official degree or option associated with the Power Program, but there is a significant level of specialization, which is possible through a set of courses developed and offered by the faculty group who constitute the Power and Energy Systems Area. Section 4 gives a brief description of the courses for specializing in electric power and tabulates the enrollment figures for the most recent offerings. Included in this section is a historical record of the number of graduates who have taken three or more of these courses. Section 5 lists the activities of both the students and the faculty members during the 2018 calendar year. Section 6 gives information about the graduate students in the power area. In addition to personal data and interests, each student has written a brief abstract of his or her research work. Laboratories and other facilities of the power area are discussed in Section 7. The report concludes with a directory in Section 8 and in Section 9 with the 2018 publications list.
2. **FINANCIAL STATEMENT**

The following tabulation of income and expenditures for the calendar year 2018 was prepared from a detailed University statement as of December 31, 2018.

| Income carried over from the 2017 calendar year | $46,753 |
| Total income during Calendar Year 2018 * | $53,787 |
| Total available income during calendar year 2018 | $100,540 |

<table>
<thead>
<tr>
<th>Expenditure</th>
<th>Expenditure Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel</td>
<td>$12,002</td>
</tr>
<tr>
<td>Supplies</td>
<td>$6,421</td>
</tr>
<tr>
<td>Transportation/Travel/Services</td>
<td>$8,656</td>
</tr>
<tr>
<td>Total expenditures</td>
<td>$27,079</td>
</tr>
</tbody>
</table>

**Summary**

| Amount of funds available during calendar year 2018 | $100,540 |
| Amount of expenses during calendar year 2018 | $27,079 |
| Balance as of December 31, 2018 | $73,461 |

* This does not include funds that were received in 2018 but not posted on the university accounting system until 2018.
3. **THE POWER PROGRAM WITHIN THE DEPARTMENT**

Electrical engineering undergraduate students are required to complete 128 hours of course work for a BSEE degree. Detailed descriptions of the undergraduate program and suggested curriculum in Power are on the Department web site. The MEng is a technical degree requiring a minimum of 32 credit hours and includes a professional development requirement. MSEE students are required to complete a minimum of 32 credit hours including a graduate thesis. All PhD students must qualify through a research paper and presentation and complete course and thesis requirements. A detailed description of the graduate programs is given on the Department web site.

The Electrical and Computer Engineering Department is subdivided into eight distinct technical areas as follows:

- Biomedical Imaging, Bioengineering, and Acoustics
- Circuits and Signal Processing
- Communications and Control
- Computer Engineering
- Electromagnetics, Optics and Remote Sensing
- Microelectronics and Photonics
- Nanotechnology
- Power and Energy Systems

While the Department does not have official degree-granting options in these areas, in practice, the eight areas serve as the appropriate grouping of faculty activities and interest. In terms of size, the Power and Energy Systems area represents about 9% of the total active faculty and about 14% of the total student enrollment. The faculty committee in each group has the responsibility for administering courses and research in that group within the Department. The Power and Energy Systems Area Committee and associated faculty for the 2018 – 2019 year together with their fields of interest are:

- **A. Banerjee**
  - Electromechanical energy conversion systems, power electronics, electrical machines and drives, electric propulsion systems, renewable energy, robotic actuators

- **S. Bose**
  - Algorithm and market design for power systems, renewable integration, smart transportation, networked dynamical systems

- **A. Domínguez-García**
  - Power and energy systems, microgrids, grid data analytics, reliability analysis, cyberinfrastructures, decision science

- **G. Gross**
  - Large-scale system analysis and computing, energy economics, effective bio-fuel applications for electricity, electricity planning and analysis

- **K. Haran**
  - Autonomous vehicular technology, UAVs, electric transportation, electrical machines and drive systems, power and energy systems

- **P. T. Krein (Emeritus)**
  - Electric machinery and electromechanics, power and energy systems, power electronics, energy efficient buildings, transportation electrification

- **P. W. Sauer**
  - Electrical machines and drive systems, power and energy systems, cyber security of power system ems, power system stability, dynamic modeling and simulation

3
Two of the primary responsibilities of the Power and Energy Systems Area Committee are to improve, keep current, and staff the courses assigned to the Power and Energy Systems Area. In 2018 those courses were:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECE 298 AB</td>
<td>Solar Car</td>
</tr>
<tr>
<td>ECE 307</td>
<td>Techniques for Engineering Decisions</td>
</tr>
<tr>
<td>ECE 313</td>
<td>Probability with Engineering Applications</td>
</tr>
<tr>
<td>ECE 330</td>
<td>Power Circuits and Electromechanics</td>
</tr>
<tr>
<td>ECE 333</td>
<td>Green Electric Energy</td>
</tr>
<tr>
<td>ECE 431</td>
<td>Electric Machinery</td>
</tr>
<tr>
<td>ECE 432</td>
<td>Advanced Electric Machinery</td>
</tr>
<tr>
<td>ECE 464</td>
<td>Power Electronics</td>
</tr>
<tr>
<td>ECE 469</td>
<td>Power Electronics Laboratory</td>
</tr>
<tr>
<td>ECE 476</td>
<td>Power System Analysis</td>
</tr>
<tr>
<td>ENG 491</td>
<td>Interdisciplinary Design Courses</td>
</tr>
<tr>
<td>ECE 530</td>
<td>Analysis Techniques for Large-Scale Electrical Systems</td>
</tr>
<tr>
<td>ECE 554</td>
<td>Dynamic System Reliability</td>
</tr>
<tr>
<td>ECE 568</td>
<td>Modeling and Control of Electromechanical Systems</td>
</tr>
<tr>
<td>ECE 573</td>
<td>Power Systems Operations and Control</td>
</tr>
<tr>
<td>ECE 576</td>
<td>Power System Dynamics and Stability</td>
</tr>
<tr>
<td>ECE 588</td>
<td>Electricity Resource Planning</td>
</tr>
<tr>
<td>ECE 590 I</td>
<td>Seminar: Power Systems</td>
</tr>
<tr>
<td>ECE 598 AB</td>
<td>Power-Electronic Converter and Control for Electric Machines: Theory and Practice</td>
</tr>
<tr>
<td>ECE 598 SB1</td>
<td>Electricity Markets</td>
</tr>
</tbody>
</table>

The four-hundred level courses are advanced undergraduate or beginning graduate courses, while the five-hundred level courses are graduate. The Power and Energy Systems Area Committee periodically evaluates each course outline for possible revision for future offerings. A brief description of each of these courses, together with the enrollment of the past year, is included in the next section. In addition, the Power Faculty supervises numerous student projects performed in ECE 445. This is the capstone design course for our seniors.
5. COURSES AND ENROLLMENT

As one of seven major areas in Electrical and Computer Engineering, the Power and Energy Systems Area is responsible for the development and offering of a considerable number of courses. Current courses assigned to the power area are described briefly below. Total enrollment for courses offered in the 2018 - 2019 academic year is also given for each course.

ECE 298 AB: Solar Car

The course objective is to show students that a multidisciplinary understanding is essential to create a complex system. UIUC’s own Solar Car “Argo” will be the example. The course will cover high-level aspects of the design, construction, analysis, and economics of solar-powered electric vehicles. Topics will bridge a variety of engineering disciplines integrated with business to present a cohesive overview highlighting complexities of solar-powered vehicles. Students are expected to gain hands-on experience working with the Solar Car Team to build the next solar car. In-class presentations will provide a platform to individuals to convey ideas and contributions to a broad set of multidisciplinary audience. In place of a text are Instructor Notes and Solar Car Wiki. References are Solar Car Primer, by E. F. Thacher and The Leading Edge: Aerodynamic Design of Ultra-streamlined Land Vehicles, by G. Tamai, 1999. The total enrollment for academic year 2018 - 2019 was 14.

ECE 307: Techniques for Engineering Decisions

This three-hour course is concerned with modeling decisions and modeling analysis of models to develop a systematic approach to making decisions. The focus is on developing techniques for solving typical problems faced in making engineering decisions in industry and government. Topics include resource allocation, logistics, scheduling, sequential decision making, siting of facilities, investment decisions and other problems for decision making under uncertainty. Extensive use of case studies gets students involved in real-world decisions. The course has two required texts: Operations Research: Principles and Practice, by A. Ravindran, D. T. Phillips and S. S. Solberg and Making Hard Decisions: An Introduction to Decision Analysis, by R. T. Clemen. The total enrollment for academic year 2018 - 2019 was 14.

ECE 330: Power Circuits and Electromechanics

The goal of this three-hour course is to provide an introduction to three-phase circuits, transformers, and electromechanical systems with an emphasis on analysis and some design insight. The course starts with a review of phasors followed by three-phase power circuits, mutual inductance, magnetic circuits and transformers. Electromechanical systems are analyzed using energy-balance concepts. Introduction to synchronous, induction, dc and small machines is given. The required text is Power Circuits and Electromechanics, by M. A. Pai. The total enrollment for the academic year 2018 - 2019 was 245.
ECE 333: Green Electric Energy
A course on the challenges of meeting future energy needs using renewable resources; this is a three-hour technical elective for engineering introductory-level undergraduate students with a background in electric circuits. The course explores the technical, economic, environmental and policy aspects of renewable and alternative energy systems to provide a comprehensive picture of their role in meeting society’s electricity needs. The upsurge in the worldwide demand for oil-based resources, the restructuring of the electricity industry, advances in engineering technology and the increasing interest in environmental protection are presenting unparalleled challenges to the electric power industry. The role of new energy-resource technologies, the application of power electronics, the use of demand-side management, and the effects of market forces in addressing these challenges are discussed. The course covers the basics of energy production from renewable sources, the relevant thermodynamics background, the structure and nature of the interconnected electric power system and the critical need for environmentally sensitive solutions. In addition, the economic and regulatory policy aspects of electricity and electricity markets are treated. The course has the following texts: Renewable and Efficient Electric Power Systems, 2nd Edition, by G. M. Masters, plus additional lecture material, homework problems (solutions) and other resources posted at http://courses.engr.illinois.edu/ece333/. The total enrollment for academic year 2018 - 2019 was 135.

ECE 365: Data Science and Engineering
Project-based course focused on exploring and understanding how data are collected, represented and stored, and computed/analyzed to arrive at appropriate and meaningful interpretation. Foundations of machine learning are developed and then applied in the context of specific application areas, such as social network analytics, biological data analysis, and auto and video analytics. Course Information: Prerequisite: ECE 313. The total enrollment for academic year 2018 - 2019 was 8.

ECE 431: Electric Machinery
This four-hour course contains a laboratory one-credit hour component, which is an elective in a list of fourteen from which students select two. The fifteen experiments typically include power measurement, power-factor correction, transformer characteristics, three-phase transformer connections, induction motor tests, induction motor torque-speed characteristics, synchronous machine tests, synchronous-machine power characteristics, digital simulation of machine dynamics, motor control, and a written, plus oral project presentation on power and energy system topics. The required text is Electric Machinery, by Fitzgerald, Kingsley, and Umans. The total enrollment for academic year 2018 - 2019 was 56.
ECE 432: Advanced Electric Machinery
This three-hour course contains advanced theory and analysis of rotating and linear machines and drives. It includes power electronic drives for dc and ac motors. The analysis uses $d$-$q$ transformations and related techniques. Emphasis is placed on time-scale modeling of electromechanical devices and on their function in drives. The required text was *Analysis of Electric Machinery and Drive Systems*, by P. C. Krause, O. Wasynczuk and S. D. Sudhoff, IEEE Press. This class was not offered in the 2018 - 2019 academic year.

ECE 464: Power Electronics
This three-hour course is a comprehensive treatment of switching power-conversion systems and the devices used to build them. Concepts of switch control are developed from general switching functions. Phase control, pulse-width modulation, and phase modulation are studied for applications in all types of converters. Converter topologies are introduced along with design concepts for power filters and interfaces. Devices such as diodes, thyristors, bipolar transistors, field effect transistors, capacitors, and magnetic components are examined in the context of high-power switching applications. The required text is *Elements of Power Electronics*, 2nd Edition, by P. T. Krein. The total enrollment for academic year 2018 - 2019 was 70.

ECE 469: Power Electronics Laboratory
This two-hour course, designed to accompany ECE 464, is a laboratory study of circuits and devices used for switching power converters, solid-state motor drives, and power controllers, including dc-dc, ac-dc, and dc-ac converters and applications. It includes high-power measurements for silicon-controlled rectifiers, diodes, capacitors, power transistors and magnetic components. A lab manual by P. T. Krein is used for this course. The total enrollment for the academic year 2018 - 2019 was 40.

ECE 476: Power System Analysis
This three-hour course is the first of two courses on power system analysis. Topics included are transmission-line parameter calculations, equivalent circuits, network analysis, load flow, fault analysis, symmetrical components, unsymmetrical fault analysis, and introduction to economic dispatch. The course is designed to be a stand-alone introduction to the fundamentals of power system analysis and provide the basis for all subsequent courses in the power system analysis. The required text is *Power System Analysis & Design*, 6th Edition, by J. D. Glover, T. J. Overbye and M. S. Sarma. The total enrollment for academic year 2018 - 2019 was 34.
GRADUATE COURSES:

ECE 530: Analysis Techniques for Large-Scale Electrical Systems
This is a four-hour course in modeling power systems in steady-state and dynamic regimes. It includes analysis and simulation techniques for power and power electronics systems as well as computational issues in power systems and power electronics. Topics covered are advanced power flow, sparsity techniques, power-flow control, least-squares and estimation-applications averaging techniques for power electronics systems, numerical integration of differential equations and Krylov subspace applications. The course uses notes by George Gross in lieu of a text. The total enrollment for academic year 2018 - 2019 was 18.

ECE 554: Dynamic System Reliability
This four-hour course offers subjects in new and developing areas of knowledge in electrical and computer engineering intended to augment the existing curriculum. Topics include basic reliability concepts, uncertainty modeling, reliability analysis, system design, fault detection, diagnosis, and applications. Texts are *System Reliability Theory*, by M. Rausand and A. Hoyland, *Uncertain Dynamic Systems*, by F. Schweppe, *Mathematical Theory of Reliability*, by R. Barlow and F. Proschan, and *Fault-Diagnosis Systems*, by R. Isermann. This class was not offered in the 2018 - 2019 academic year.

ECE 568: Modeling and Control of Electromechanical Systems
This four-hour course addresses issues of electrical drives in a modern control and circuit framework. Dynamic models of electric machines are presented. There is special emphasis on field-oriented control methods for ac motors. Power electronics systems for high-performance drives are studied. Nonlinear system methods such as periodic transformations, averaging, geometric control, and feedback linearization are presented. Special topics covered include electrostatic micromachines and permanent magnet machines. The recommended texts are *Control of Electrical Drives*, 2nd edition, by W. Leonard and *Analysis of Electric Machines*, 2nd edition by P. Krause, O. Wasyniczuk and S. Sudhoff. This class was not offered in the 2018 - 2019 academic year.

ECE 573: Power Systems Operations and Control
This four-hour course provides an overview of power system operations and control with major emphasis on security and economics. The role of EMS (energy management system) and principal EMS functions are discussed in depth. Major topics include: optimal power flows; economic dispatch problems; role of reactive power; resource scheduling and commitment; state estimation; observability; bad data identification/detection, analysis and processing; electricity restructuring; competitive electricity markets; market design; congestion management; and ancillary services. The two suggested texts are

ECE 576: Power Systems Dynamics and Stability
This four-hour course includes the dynamic representation of interconnected power systems — electrical plus mechanical, linearized dynamic models of multi-machine systems, methods of coherency identification, order reduction by singular perturbation, time-scale decomposition and aggregation techniques, dynamic equivalents, direct methods of stability analysis and power system stabilizer design. The required text is Power Systems Dynamics and Stability by P. W. Sauer and M. A. Pai. This class was not offered in the 2018 - 2019 academic year.

ECE 588: Electricity Resource Planning
This four-hour course provides coverage of the basic techniques in electricity resource planning including methodologies for reliability evaluation and assessment, production costing, marginal costing, supply-side and demand-side planning and integrated resource planning. Throughout the course, probabilistic approaches are emphasized. In place of a text, notes specifically prepared by George Gross are used. The total enrollment for academic year 2018 - 2019 was 8.

ECE 590 I Seminar: Power Systems
This course is a graduate seminar on advanced topics of current interest. Both faculty and students participate by presenting either current research results or topics of interest in journal publications. Guest speakers from industry and other universities are also scheduled periodically throughout the semester. Approximately 56 students participated in this course for both semesters.

ECE 598 KSH: Electrical Machine Design
Technologies like advanced materials, manufacturing processes and power electronics can open up the design space for new electrical machine solutions aimed at emerging applications in the transportation, energy, and industrial sectors. To take full advantage of these developments, engineers need to be well versed in the multidisciplinary design process for electrical machines, with a good understanding of complex trade-offs that span multiple disciplines. They must also be comfortable with both analytical and numerical tools, and know when to apply these to obtain the best results. The course attempts to prepare electrical and mechanical engineers for this opportunity by focusing on practical design considerations. It builds on fundamentals covered in ECE 330 and 431 and takes students through the design of a variety of electromechanical devices. Fundamental principles of energy conversion applicable to all types of electric machinery are first reviewed. Basic design rules, analytical formulae and the use
of numerical design tools are then introduced, and experience is gained through a hands-on design project. This class was not offered in the 2018 - 2019 academic year.

**ECE 598 AB: Power-Electronic Converter and Control for Electric Machines: Theory and Practice**

This course introduces modeling, analysis, and design of electromechanical energy-conversion systems from a simultaneous perspective of power electronics, electromechanics, and control. We will take a hands-on approach. Theories are discussed in lectures and implemented in real-world laboratory setups. Three-phase power-electronic converters specifically designed for machine drives are introduced. Dynamic models of different types of electrical machines are developed using generalized machine theory. Finally, different control architectures and their impact on the dynamic performance of the drive are discussed. “Real-world” examples from many existing and emerging applications including electric vehicles, renewable energy systems, and high-power and high-performance industrial drives are used to show the need for interdisciplinary understanding from a system perspective. The required text is *Control of Electrical Drives* by W. Leonhard. References include *Vector Control and Dynamics of AC Drives* by D. W. Novotny and T. A. Lipo, *High-Power Converters and AC Drives* by B. Wu and M. Narimani, *Control of Electric Machine Drive Systems* by S. Sul, *Power Electronics and Motor Drives: Advances and Trends* by B. K. Bose and various IEEE papers. Prerequisites: ECE 464 (Power Electronics) and ECE 431 (Electric Machinery). ECE 486 is preferred. The total enrollment for academic year 2018 - 2019 was 24.

**ECE 598 SB1: Mathematical Foundations of Electricity Markets**

Power system operation is linked to the operation of electricity markets. In this course, we study the modeling and analysis of competitive electricity markets that facilitate the balance of demand and supply of electricity across a power network. We leverage tools from optimization theory, microeconomics, and game theory to investigate the rationale behind current market designs, how they operate, and analyze the outcomes, given the strategic behavior of the market participants. The course illustrates the complex interaction of mechanism design with the physics of the underlying grid, a feature that distinguishes electricity markets from traditional marketplaces. While the bulk of the course focuses on wholesale electricity markets in the US, we conclude with current debates on the creation of retail markets to harness the flexibility of demand side resources. The total enrollment for academic year 2018 - 2019 was 13.
## NUMBER OF ELECTRIC POWER AND ENERGY SYSTEM AREA GRADUATES IN RECENT YEARS

### Annual Average Power Area Graduates

<table>
<thead>
<tr>
<th>Period</th>
<th>B.S.E.E.</th>
<th>M.S.E.E.</th>
<th>Ph.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950-1970</td>
<td>25</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>1970-1980</td>
<td>44</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>1980-1990</td>
<td>32</td>
<td>5</td>
<td>2</td>
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<tr>
<td>1990-1995</td>
<td>40</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>1995-2000</td>
<td>35</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>2000-2005</td>
<td>40</td>
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<td>60</td>
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<tr>
<td>2016-2017</td>
<td>65</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td>2017-2018</td>
<td>67</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>2018-2019</td>
<td>70</td>
<td>14</td>
<td>7</td>
</tr>
</tbody>
</table>
5. ACTIVITIES

Faculty and students in the Power and Energy Systems Area participated in a considerable number of special activities during the calendar year 2018. The major events are listed below:

JANUARY

- Alejandro Domínguez-García presented an invited talk at the University of Cyprus in Nicosia, Cyprus.
- Peter Sauer attended the Grid Engineering for Accelerated Renewable Energy Deployment (GEARED) meeting and DistribuTECH Conference & Exposition in San Antonio, TX.
- Peter Sauer attended an Illinois Commerce Commission (ICC) meeting in Chicago, IL.
- Philip Krein began approximately monthly meetings to serve as Executive Dean of the Zhejiang University/University of Illinois at Urbana-Champaign Institute in Haining, China.

FEBRUARY

- Philip Krein presented research seminars about China interaction at Purdue University and the University of Michigan in West Lafayette, IN and Ann Arbor, MI.
- Philip Krein met with IEEE about the “Empowering a Billion Lives” project at the Georgia Institute of Technology in Atlanta, GA.
- Alejandro Domínguez-García attended the Power Systems Engineering Research Center (PSERC) Executive Committee (EC) Retreat in Tempe, AZ.

MARCH

- Philip Krein attended the IEEE Applied Power Electronics Conference (APEC) and IEEE Power Electronics Society (PELS) meetings in San Antonio, TX.
- Peter Sauer attended an ICC meeting in Chicago, IL.
- Alejandro Domínguez-García attended the Annual ARPA-E Program Review in San Diego, CA.
- Peter Sauer attended a meeting at the DOE in Washington, DC.
APRIL

- Philip Krein attended fellow induction events at the National Academy of Inventors (NAI) in Washington, DC.


- Philip Krein presented invited seminars at Huazhong University of Science and Technology in Wuhan, China.

- George Gross presented an invited presentation at the IEEE Power and Energy Systems (PES) Distinguished Lecture Program at the IEEE PES Student Chapter at the Costa Rica Institute of Technology, Cartago, CR.

- George Gross presented an invited presentation at the IEEE PES Distinguished Lecture Program at the IEEE PES Student Chapter at Universidad de Costa Rica, San Jose campus, San Jose, CR.

- George Gross presented an invited presentation at the IEEE PES Distinguished Lecture Program at the IEEE Honduras Section, Tegucigalpa, Honduras.

MAY

- Subhonmesh Bose and Alejandro Dominguez-Garcia attended the PSERC Industry Advisory Board (IAB) Meeting in Wichita, KS.

- George Gross presented an invited talk at the Conference on Offshore Wind (OSW) Transmission in New York, NY.

- Subhonmesh Bose met with the DOE and National Science Foundation (NSF) project directors in Washington, DC.

- Subhonmesh Bose, Alejandro Dominguez-Garcia, George Gross, and Peter Sauer presented at the Mid-America Regional Microgrid Education and Training (MARMET) Consortium short course held at Ameren in Saint Louis, MO.

JUNE

- Philip Krein presented at the IEEE Transportation Electrification Conference (ITEC) in Long Beach, CA.

- George Gross attended the ICC NextGrid: Utility of the Future Study Update and Public Comment Session in Chicago, IL.

- Arijit Banerjee attended the DOE Vehicle Technology Office (VTO) Annual Merit Review 2018 in Washington, DC.
JULY


- Philip Krein participated at the International Advisory Committee (IAC) meeting and presented an invited talk at Beijing Jiaotong University in Beijing, China.

- George Gross participated at the PSERC Summer Workshop held in Salt Lake City, UT.

- Philip Krein served as chief judge, presented an invited talk at the IEEE International Future Energy Challenge (IFEC), and gave an invited lecture at Tsinghua University in Beijing, China.

- Philip Krein attended IEEE PELS Industry Advisory Board meeting in Flemington, NJ.

AUGUST

- George Gross, Kiruba Haran and Peter Sauer participated at the IEEE Power Engineering Society General Meeting (GM) in Portland, OR.

- George Gross gave an invited talk at the Anjan Bose Symposium held in Spokane, WA.

- Peter Sauer attended an ICC project meeting in Carbondale, IL.

- Philip Krein presented an invited short course at the power electronics summer school in Tsukuba, Japan.

- Arijit Banerjee gave an invited talk as part of the IEEE Lecture Series at the Indian Institute of Technology Kharagpur, Kharagpur, India.

SEPTEMBER

- Peter Sauer attended the Cyber Resilient Energy Delivery Consortium (CREDC) Workshop in Boston, MA.

- Kiruba Haran presented an invited talk at Massachusetts Institute of Technology (MIT) and General Electric (GE) Research at Cambridge, MA and Schenectady, NY.

- Subhonmesh Bose attended an ISO New England Incorporated (ISO-NE) meeting in Holyoke, MA.

- Arijit Banerjee and Philip Krein attended IEEE Energy Conversion Congress and Exposition (ECCE) 2018 in Portland, OR, and Philip Krein attended committee meetings of the IEEE PELS there.

- Philip Krein attended the US National Academy of Engineering (NAE) Annual Meeting in Washington, DC.
OCTOBER

- Kiruba Haran attended the Advanced Air Transport Technology (AATT) Hybrid Gas Electric Propulsion NRA Awards Annual Review on Wednesday, October 17, and Thursday, October 18, 2018, at the Ohio Aerospace Institute (OAI) in Cleveland, OH.

- Arijit Banerjee attended the NSF Workshop on Future Trends and Opportunities for Power Electronics in an Electrified Transportation Industry at the University of Maryland, College Park, MD.

- Arijit Banerjee presented an invited talk at EnergyTech 2018 Conference and Expo in Cleveland, OH.

- Kiruba Haran attended the Applied Superconductivity Conference (ASC) in Seattle, WA and an NSF Review Panel in Alexandria, VA.

NOVEMBER

- Subhonmesh Bose participated at the Institute for Operations Research and the Management Sciences (INFORMS) Annual Meeting in Phoenix, AZ.

- Peter Sauer attended the DOE CREDC Review in Washington, DC.

- Kiruba Haran visited United Technologies (UTC) Aerospace Systems - Collins Aerospace in Rockford, IL.

DECEMBER

- Philip Krein participated in a grants review at the Hong Kong University Grants Council in Hong Kong, China.

- George Gross and Subhonmesh Bose participated at the PSERC IAB Meeting in Berkeley, CA.
During the 2018 calendar year, the power area group hosted the following guest speakers:

- Prof. Hsiao-Dong Chiang, School of ECE, Cornell University, “Feasible Region of Optimal Power Flow: Theory, Methods, Bifurcations and Applications,” February.

- Prof. Johanna Mathieu, University of Michigan Electrical Engineering & Computer Science, “Real-Time Energy Disaggregation of a Distribution Feeder’s Demand Using Online Learning,” April.


- Erica Tsypin, Co-Founder, Mobility, Exelorate Growth, Exelon Corporate Innovation, “The Electron as We Know It, is Changing,” October.


- Dr. Alireza Khaligh, Director, Maryland Power Electronics Laboratory, University of Maryland at College Park, “Integrated Onboard Chargers and Advanced Power Electronics for Transportation Electrification,” October.


- Prof. John Donnal, United States Naval Academy, “WATTSWORTH: No Watt Left Behind,” December.
During the 2018 calendar year, the power faculty and students presented the following seminars to our local audiences:

- Samuel Utomi, “Hardware-In-The-Loop Implementation of the Coordination of Distributed Energy Resources to Provide Frequency Regulation Services,” March.
6. STUDENT PROJECTS

This section of the report contains information on the graduate students whose major research efforts were supervised by faculty in the Power and Energy Systems Area. While not all of these students received financial aid from the Power Affiliates Program in terms of Research Assistantships, they were all associated with the program through the active involvement of their respective advisors. Those students supported by the Power Affiliates Program received maximum one-half time Research Assistantships for 11 months. The results of each student's work will be made available to all affiliate companies in the form of technical reports. The following students were associated with the Power and Energy Systems Area and their work is described in the following pages:

Ajala, Olaoluwapo (Ph.D.)
Anderson, Aaron (M.S.)
Arastu, Faraz (Ph.D.)
Balachandran, Thanatheepan (Ph.D.)
Barth, Christopher (Ph.D.)
Brooks, Nathan (M.S.)
Buason, Paprapee (M.S.)
Candan, Enver (Ph.D.)
Chattopadhyay, Abhiroop (M.S.)
Cheng, Leslie (M.S.)
Das, Dipanjan (Ph.D.)
Dasgupta, Sujay (M.S.)
Foulkes, Thomas (Ph.D.)
Galtieri, Jason (Ph.D.)
Hoole, Yovahn (M.S.)
Huynh, Phuc (Ph.D.)
Jin, Austin (M.S.)
Ku, Bonhyun (M.S.)
Liao, Zitao (Ph.D.)
Libbos, Elie (M.S.)
Lima Abrantes, Adriano (Ph.D.)
Madavan, Avinash (M.S.)
Mamalis, Theodoros (M.S.)
Min, Byung Hoon (M.S.)
Ndrio, Mariola (Ph.D.)
Nigam, Siddhartha (Ph.D.)
Pallo, Nathan (M.S.)
Phillips, Desiree (Ph.D.)
Renner, Nathaniel (M.S.)
Sain, Christopher (M.S.)
Shivang (M.S.)
Sirimanna, Samith (Ph.D.)
Stillwell, Andrew (Ph.D.)
Utomi, Samuel (M.S.)
Wang, Yuyao (M.S.)
Winnicki, Anna (M.S.)
Wu, Michael (M.S.)
Xu, Hanchen (Ph.D.)
Yi, Xuan (Ph.D.)
Yoon, Andy (Ph.D.)
Yu, Yangxue (M.S.)
Yurdakul, Ogün (M.S.)
Zatarski, Joseph (M.S.)
Zhang, Xiaolong (Ph.D.)
Zheng, Lijun (M.S.)
Zhlobarysoy, Madi (Ph.D.)
Zhu, Jeffrey (M.S.)
Adriano Lima Abrantes

B.S.: December 2013, University of São Paulo, Brazil
M.S.: August 2016, University of São Paulo, Brazil
Status: Working towards Ph.D. at University of Illinois Urbana-Champaign
Professional Interests: Power System Flexibility, Renewable Integration, Electricity Markets

A Framework for Grid Operational Flexibility Assessment based on Robust Optimization
Adriano Lima Abrantes with Advisor Prof. George Gross
Supported by Power Systems Engineering Research Center (PSERC)

ABSTRACT

The integration of renewable energy resources (RERs) into electric power grids raises concerns regarding the ability of the system to accommodate larger net-load variability and forecast errors. This ability is referred to as grid operational flexibility (GOF). Even though there is growing interest in the quantification of procurable GOF and the design of GOF requirements, a formal definition directly related to a measurable quantity is still lacking. The quantification of GOF is challenging due to its multifaceted nature, as it is connected to multiple time scales, time horizons, operational limitations of generating units, network constraints, RERs uncertain output and grid-operation paradigms. Furthermore, the economic aspects of GOF procurement may not be disregarded. The goals of this project are to propose a framework under which we analyze different GOF metrics and requirements that may provide guidance to power system operations, insights to system planners and policymakers, and enable the comparison of the value of flexibility in different power systems.
Olaoluwapo Ajala

B.S.: December 2010, University of Lagos, Nigeria
M.S.: December 2014, University of Illinois Urbana-Champaign
Ph.D.: December 2018, University of Illinois Urbana-Champaign
Status: Postdoctoral Researcher
Professional Interests: Distributed Energy Resources, Microgrids, Modeling and Control Design

A Hierarchy of Microgrid Models with Some Applications

Olaoluwapo Ajala with Advisers Prof. Alejandro Domínguez-García and Prof. Peter W. Sauer

Supported by the Advanced Research Projects Agency-Energy NODES (ARPA-E NODES)

ABSTRACT

This work proposes a hierarchy of microgrid models that can be utilized for power system analysis and control design purposes. The microgrid models are classified according to time resolution and, consequently, according to complexity and computational cost as well. Our approach involves three key stages: (1) the formulation of high-order models, using existing circuit and control laws in the literature, followed by (2) a systematic reduction of the high-order models to reduced-order models using singular perturbation analysis and, finally (3) a hierarchical classification of the high-order and reduced-order models according to the time scales we propose for which they should be utilized. The resulting hierarchy of microgrid models is comprised of a microgrid high-order model, the microgrid reduced-order model 1, the microgrid reduced-order model 2, and the microgrid reduced-order model 3, the last three of which are developed in this work. Each microgrid model we develop is composed of models for three-phase inverters, microturbines, type-C wind turbine generators, distribution line networks, and generic elements (e.g., loads) connected to the network. We identify the time resolution of the models and analyze their performance using various power system test cases.
Aaron Anderson

B.S.: May 2017, Purdue University
Status: Working towards M.S. at University of Illinois Urbana-Champaign
Professional Interests: Electric Machines and Drives, Electric Vehicles

System Weight Comparison between Motor Topologies for Aircraft Propulsion
Aaron Anderson with Advisor Prof. Kiruba S. Haran
Supported by Grainger CEME

ABSTRACT

An important thrust in current aerospace research is aircraft electrification, including propulsion system electrification. Several system configurations have been explored including partially distributed, fully distributed, and parallel hybrid propulsion schemes in the NASA N3-X, NASA STARC-ABL, and Rolls-Royce Electrically Variable Engine, respectively. For the electric systems to provide net benefits over traditional aircraft, strict system-specific power, power density, and efficiency requirements must be met. This work takes a rigorous approach in comparing electric machine topologies for electric aircraft propulsors while considering tradeoffs in the power electronic, fault-response equipment, and gearbox components. Permanent magnet synchronous machine (PMSM), brushless DC machine (BLDC), switched reluctance machine (SRM), and brushless doubly-fed reluctance machine (BDFRM) topologies are explored. Models are developed using analytical sizing equations calibrated using advanced machines found in the literature and industry trends. Continuation of this work will include modeling each machine in a finite element analysis tool to determine the validity of the design and obtain more accurate efficiencies and weights, and more detailed power electronic models, while carefully considering the impact of system efficiency on thermal management systems, additional energy storage, and airframe size.
Faraz Arastu

B.S.: May 2015, Northeastern University
M.S.: May 2018, University of Illinois, Urbana-Champaign
Status: Working towards Ph.D. at University of Illinois Urbana-Champaign

Electric Motor for a Venus Rover Spacecraft
Faraz Arastu with Advisor Prof. Kiruba S. Haran

ABSTRACT

The power density and ambient operating temperature of electric motors are limited by the temperature rating of their electromagnetic coils. Motors are almost always geared or coupled to hydraulic systems to meet the necessary power requirements. They also need active cooling systems to operate within their rated temperature. Removing the temperature limit of electromagnetic coils will enable extremely lightweight and powerful direct-drive systems with no gearing, hydraulics, or cooling systems. This technology also opens up exciting new possibilities for deep-space exploration, like driving a rover vehicle to explore the surface of Venus.

The proposed project aims to develop an electric motor with ceramic insulation to achieve a maximum operating temperature well beyond the 200 °C limit of traditional motors. To date, we have manufactured and tested magnet wire samples with a dielectric strength of 162 V$_{\text{RMS}}$ at 660 °C. This dielectric performance is several times higher than what is needed for nearly any commercial motor. Current efforts are focused on scaling up magnet wire production to produce full coils for a reluctance motor prototype, which will be tested to determine its rated power at various internal and external operating temperatures.
Thanatheepan Balachandran

B.S.: University of Peradeniya, Sri Lanka.
M.S.: Wichita State University, U.S.A.
Status: Working towards Ph.D. at University of Illinois at Urbana Champaign
Professional Interests: Superconducting Machines, Wind Energy.

Feasibility Study of an Air-Core Fully Superconducting Machine for 10-MW Offshore Wind Turbine
Thanatheepan Balachandran with Advisor Prof. Kiruba S. Haran
Supported by NASA

ABSTRACT

Offshore wind turbines are becoming an integral part of future large-scale renewable generation initiatives. It is envisioned that to upscale offshore wind turbines in the range of 10+ MW power, superconducting (SC) technologies need to be explored. The goal of this project is to investigate the feasibility of a 10-MW air-core fully SC machine for offshore wind turbines. An inside-out synchronous machine topology is proposed with shield coils, which eliminate or reduce the shield iron used in traditional SC machines. The machine is attractive for offshore wind-turbine application due to its high power density and high efficiency compared to a conventional shield-iron design. However, this design uses more SC material than the conventional shield iron design due to the introduced shield coils. Thus, an optimal combination between shield coils and shield iron is studied to minimize the weight and cost. In addition, machine designs with different pole counts are investigated to identify the optimal pole count for low-speed applications. A detailed ac-loss calculation is evaluated for the machine, and the required cryocooler power is evaluated to obtain efficiency. The study will include electromagnetic design, ac-loss calculation, cryocooler design, mechanical design, and nacelle integration.
Christopher Barth

B.S.: December 2012, University of Illinois Urbana-Champaign
M.S.: December 2014, University of Illinois Urbana-Champaign
Status: Working towards Ph.D. at University of Illinois Urbana-Champaign

Design of High Density Inverters for Photovoltaic and Motor Drive Applications

Christopher Barth with Adviser Prof. Robert Pilawa-Podgurski

Supported by Grainger CEME

Abstract

Traditionally, inverters have employed a minimal number of active switching components and used large passive inductors to filter two- or three-level voltages into sinusoidal currents. This results in a relatively simple system with acceptable performance characteristics. Newer inverter designs are seeking to minimize system volume and weight while maintaining or improving efficiency and performance. Because capacitor energy density has been shown to be around two orders of magnitude higher than that of inductors, one method of increasing power density is through using more capacitors as filtering components rather than inductors in inverter designs. Inverters, such as modular multilevel and flying capacitor, use a higher number of active switches and require advanced control strategies. Research is being done in the control of many parallel sub-inverters in order to develop increased reliability. These inverters can be coordinated to partially meet system requirements, even during a failure event of a few of the submodules.
Nathan Brooks

B.S.: May 2016, Rose-Hulman Institute of Technology
M.S.: May 2018, University of Illinois Urbana-Champaign
Professional Interests: Power Electronics

Resonant-Type Architectures for Active Power Decoupling in Grid-Tied Single-Phase Power Electronics
Nathan Brooks with Advisor Prof. Robert Pilawa-Podgurski
Supported by the Grainger Foundation

ABSTRACT

In single-phase power converters, twice-line frequency power-decoupling circuits are used to buffer the instantaneous energy difference between the ac and dc sides of the converter. Active buffer implementations are used to reduce the volume and potentially improve the reliability of the converter by redistributing passive energy-storage requirements with combinations of switches, capacitors, and inductors.

This thesis applies resonant impedance behavior to the operation of a specific dc-side twice-line frequency buffer called a series-stacked buffer (SSB). Utilizing this equivalent impedance model, an appropriate voltage-control scheme is derived and experimentally validated. There is also additional consideration of energy performance metrics in the context of dc-side buffers. Furthermore, the SSB equivalent impedance model is extended, applied, and generalized to the full single-phase converter system. This analysis includes an integrated system control method which imposes phase locking and consistent transient stability. Experimental verification of full system interconnectivity is validated with a 1.5 kW power-factor correction, boost flying-capacitor multilevel converter.
Paprapee Buason

B.S.: May 2016, University of Illinois Urbana-Champaign
Status: Working towards M.S. at University of Illinois Urbana-Champaign

Dynamics and Stability of Microgrid

Paprapee Buason with Advisor Prof. Peter Sauer
Supported by Information Trust Institute and ABB Inc.

ABSTRACT

Microgrids are recently being adopted in distribution systems to increase resiliency in power systems. Modern microgrids rely on sophisticated communication and controls, which lead them to require interactaction with cyber-physical systems. In this research, I present control strategies and approaches for resiliency to attacks against measurements, while increasing system stability and secure communications within microgrids, when microgrids are in islanded mode. The sequence of operations to continuously serve specific critical loads is discussed. Finally, a use case that unifies all concepts is included. This use case serves to mitigate effects of an attack against measurements on a critical load bus. Firstly, the attack is detected by the mean of the detection algorithm. Then, the suspicious DER is tripped off due to the command from COM600, which calculates the preventive algorithm called Reachability Analysis. The appropriate tie line between two microgrids is closed to continuously supply power to the critical load when consensus is reached. Control strategies and communication take action to ensure stability of the new system. Results from real-time simulation are provided to validate the effectiveness of this approach.
Enver Candan

B.S.: June 2012, Istanbul Technical University, Istanbul, Turkey
M.S.: June 2012, Istanbul Technical University, Istanbul, Turkey
M.S.: August 2014, University of Illinois Urbana-Champaign
Ph.D.: August 2018, University of Illinois Urbana-Champaign

Professional Interests: Power Electronics, Converters, Data Center Power Delivery, Differential Power Processing

A Series-Stacked Power-Delivery Architecture for Server Racks
Enver Candan with Advisor Prof. Robert Pilawa-Podgurski
Supported by the National Science Foundation (NSF)

ABSTRACT

Recently, series-stacked power-delivery architectures have been explored to separate the processed power from the power delivered, by processing only the difference in power between a group of series-connected loads, such as photovoltaics, light-emitting diodes and battery management systems. In this research, we seek to leverage the series connection of servers in data-center power-delivery applications. Compared to the conventional ways of delivering power to the servers, the proposed differential power processing (DPP) methodology and the control of the overall power conversion system can increase system-level power conversion and delivery efficiency.

In this research, the server-to-virtual bus architecture of DPP is being adapted. A modular test bed is created to replicate the behavior of a server blade; it consists of 12 V 120 W Dell OptiPlex workstations. Four dual active-bridge dc-dc converters are built as DPP converters. The series-stacked system is tested for steady-state operation of the servers and achieved 99.89% system-level power delivery efficiency. In addition, we have demonstrated hot-swapped operation in the series-stacked system, where one server is disconnected from the series stack while the others are still operational. Recently, unregulated bus operation of the series-stacked system is investigated to integrate battery backup to the system.
Abhiroop Chattopadhyay

B.S.: December 2014, Illinois Institute of Technology, Chicago, IL
Status: Working towards M.S. at University of Illinois Urbana-Champaign
Professional Interests: State Estimation, HVDC Transmission, Power System Operation and Control, Power System Security

Cyber-Attack Resilient High-Voltage Direct Current System
Abhiroop Chattopadhyay with Advisor Prof. George Gross
Supported by PSERC

ABSTRACT

The ability of malicious actors to falsify power-order execution commands creates a potential for destabilization of power system operation. This can be particularly acute in ac networks with HVDC links where power orders executed by the HVDC link can be compromised. This project focuses on threats directed at the communication link between the transmission system operator’s control center and the HVDC converter station. Development of detection and mitigation strategies is being investigated using fast state-estimation techniques utilizing power-transfer distribution factors. A real-time model of a large-scale power system that simulates the complexity and characteristics of the western US grid will be implemented in OPAL-RT to serve as a proxy of a real-world system and generate measurements.
ABSTRACT

Electric vehicles have gained popularity and become prominent in recent years. Small companies, such as Zero Motorcycles, address a niche by producing electric motorcycles. Many electric vehicle designs allow for unconventional choices not possible in gas vehicles, such as Tesla vehicles where the typical engine compartment area is now storage space. However, modern electric motorcycles have a nearly identical layout to gas ones where an electric machine replaces the engine to drive the rear wheel. The addition of a powered front wheel is often omitted due to mechanical complexity for gas motorcycles, but electric motorcycles are not subject to this because a motor could be integrated within the wheel. This work examines and explores the performance of such a machine. Increased acceleration and traction are expected due to an additional source of movement. However, it lacks the gear reductions of the conventional layout. Cooling is also a challenge due to exposure to dirt and debris.
Dipanjan Das

B.S.: July 2013, Indian Institute of Technology, Kharagpur
M.S.: May 2016, University of Illinois Urbana-Champaign
Status: Working towards Ph.D. at University of Illinois Urbana-Champaign
Professional Interests: Power Electronics, Control of Power Electronics, DC-DC Converters

Differential Power Processing for Voltage Regulation of Low Voltage Loads
Dipanjan Das with Advisor Prof. Emeritus Philip T. Krein
Supported by Grainger CEME

ABSTRACT

Power delivery to multi-core processors is becoming increasingly challenging with decreasing transistor sizes and, thereby, their operating voltages. With the expansion in number in each processor, the power requirements tend to remain the same with each new generation of microprocessors, and handling transient performance requirements along with efficiency has become much more difficult at lower voltages. Significant improvement in energy efficiency can be achieved by stacking the processor cores in series and regulating the core voltages by differential power processing (DPP).

However, for practically achieving higher efficiency than the conventional parallel-connected processor core architecture over a wide load range, special importance has to be given to light-load power management of bidirectional DPP converters in such a series-stacked system. Topological and control strategies (bidirectional light-load control, multiphase converters with asymmetric load sharing, phase shedding) for faster transient response as well as converter efficiency improvement over a wide bidirectional power range for DPP converters is being investigated.
Sujay Dasgupta

B.S.: May 2017, Nirma University, Ahmedabad, India
MEng: December 2018, University of Illinois at Urbana-Champaign
Status: Working towards M.S at University of Illinois Urbana-Champaign

Improving Grid Resiliency using HVDC

Sujay Dasgupta with Advisor Prof. Peter Sauer
Supported by Information Trust Institute and ABB Inc.

ABSTRACT

The project scope is securing high voltage direct current (HVDC) systems as these interface to transmission systems. This is based on real-time state estimation of the entire system. As HVDC power injections change, we continuously evaluate the consistency of an HVDC power request, while simultaneously monitoring system stability and the consistency of measurements as a power injection ramps. Comparison of measurements with the estimated state helps us assess whether a valid power order was correctly carried out. While we avoid specifics of any system, we are interested in complex systems comparable to the Western Interconnect with the BPA to LADWP HVDC line. Challenges include estimating the state above some voltage level in the transmission system with sufficient fidelity and using power-transfer distribution factors to find very good approximations. We are looking into protocols such as DNP3 for the power order, and modeling systems such as PowerWorld, MATPOWER, and RTDS for the modeling.
Thomas Foulkes

B.S.: May 2015, Rose-Hulman Institute of Technology
M.S.: May 2017, University of Illinois at Urbana-Champaign
Status: Working towards Ph.D. at University of Illinois Urbana-Champaign
Professional Interests: High Power Density Converter Design, Magnetic and Dielectric Material Analysis, Thermal and EMI Mitigation

Liquid Bridge Confined Boiling for Thermal Management of High Power Density Electronics
Thomas Foulkes with Advisors Prof. Nenad Miljkovic and Prof. Robert Pilawa-Podgurski
Supported by NSF Graduate Research Fellowship, NASA and POETS

ABSTRACT

Increasing electrification of mechanically controlled or driven systems has created a demand for the development of compact, lightweight electronics. Removing waste heat from these high volumetric and gravimetric power-dense assemblies, especially in mobile applications, requires non-traditional thermal management strategies with high heat-flux potential and low integration penalty. To overcome this obstacle, a thermal management technique involving confined, subcooled pool boiling on nanoengineered surfaces was created. This enables self-assembly of liquid bridges capable of high heat-flux dissipation without external pumping. Using high-speed optical imaging coupled with high-fidelity heat-transfer experiments in pure vapor environments, we study the physics of liquid bridge formation, bridge lifetime, and heat transfer. Heat flux dissipations greater than 100 W/cm² were demonstrated from a gallium nitride power transistor residing above a horizontally parallel superhydrophobic nanostructured aluminum cold plate. To understand the confined bridge dynamics, a hydrodynamic droplet-bridging model and design rules were developed capable of predicting the effects of gravity, intrinsic contact angle, contact angle hysteresis, and device heat flux. This work not only demonstrates an ultra-efficient mechanism of heat dissipation and spreading using nanoengineered surfaces coupled to fluid confinement, but also enables the development of three-dimensional integrated electronics.

Jason Galtieri with Advisor Prof. Emeritus Philip T. Krein

Supported by Grainger CEME

ABSTRACT

Maximum power point (MPP) tracking is the standard control scheme for photovoltaic (PV) arrays of all sizes. Inverter tracking algorithms work on second to sub-second time scales and can track most naturally occurring irradiance changes, such as moving cloud coverage. Fast-response tracking imposes large power swings on the grid, which must be absorbed in spinning reverses. As PV penetration increases and replaces traditional spinning generation, there is concern the grid’s voltage and frequency stability could be compromised.

The ability to operate PV panels predictably at set-points away from their MPP opens a wide range of possibilities for PV array control and support. However, off-MPP set-points lose many of the constraints traditional maximum power trackers (MPPT) require to correctly function. This work proposes an off-MPP set-point strategy that uses ripple correlation control (RCC) to quickly find the MPP current and voltage. The MPP data is then fed into a set-point controller, to operate at a reduced set-point. RCC algorithms converge in millisecond timeframes, so the MPP data can be updated several times a second to maintain accuracy. Likewise, the off-MPP converters converge on similar time-scales, so the converters spend most of their time at the reduced set-point.
ABSTRACT

To extract the peak performance from PMSMs, the drive system requires accurate position feedback of the rotor angle in order to align the current vector and achieve maximum torque output. Traditionally, this was fulfilled by the integration of a position transducer with the motor shaft, such as an encoder or resolver, which increases system cost and mechanical complexity. An alternative to the transducers is back emf or high-frequency signal-injection based sensorless methods. However, back emf based methods are unable to estimate rotor position accurately at low speeds due to reduced signal amplitudes, and while signal-injection based methods will work well at low and zero speeds, these rely on either inherent saliency in the machine, or anisotropy due to saturation effects in non-salient machines. The use of linear Hall-effect sensors to measure the external leakage magnetic flux of the rotor provides an alternative that is easier to implement than sensorless methods. These sensors are able to operate at low and zero speeds, and are cheaper than including a position transducer. This work proposes a neural-network algorithm to interpret the signals, obtained from linear Hall-effect sensors located in the rotor fringe field, to replace traditional resolvers. The main objective is to design a cost-effective position-estimation system comparable to encoders and resolvers in functionality and performance, without the limitations of sensorless position-estimation methods.
Phuc Huynh

B.S.: December 2013, University of Minnesota
M.S.: December 2016, University of Illinois Urbana-Champaign
Status: Working towards Ph.D. at University of Illinois Urbana-Champaign
Professional Interests: Electric Machine and Power Electronics Integration, Power System Dynamics and Control

An Integrated Permanent-Magnet-Synchronous-Generator–Rectifier Architecture for Limited-Speed-Range Applications
Phuc Huynh with Advisor Prof. Arijit Banerjee
Supported by NASA

ABSTRACT

Ac-to-dc power conversion is essential in many emerging applications, including wind-power generation and electrified transportation. For example, an intermediate dc bus is often necessary to connect a variable-speed wind-powered generator to the fixed-frequency ac grid. Similarly, future electric ships are envisioned to have a medium-voltage dc grid created from a gas-turbine-driven ac generator. The preferred electrical output of these megawatt-scale mechanical-to-electrical energy conversion systems is a regulated dc bus while the prime movers operate over a limited speed range. The operating speed range is driven by an improved energy-captured-to-cost ratio, as in a wind turbine, or by an increased fuel efficiency, as in a gas-turbine driven generator.

Conventionally, ac-to dc power requires all power being processed on active rectifiers, leading to high investment cost, high loss, and reduced reliability. This project develops an ac-to dc power conversion architecture that integrates power electronics to a multi-port permanent magnet synchronous generator. The architecture relies on series-stacking one active with multiple passive rectifiers. This system achieves high conversion efficiency compared to solutions relying only on actively controlled switches. In addition, overall system reliability could potentially increase at a reduced investment cost.
Austin Jin

B.S.: May 2016, University of Illinois Urbana-Champaign
M.S.: August 2018, University of Illinois Urbana-Champaign

Electromagnetic Fault Analysis for High Specific Power Permanent Magnet Synchronous Machine

Austin Jin with Advisor Prof. Kiruba S. Haran

ABSTRACT

This thesis discusses the electromagnetic fault analyses for a high-specific-power 1 MW permanent magnet synchronous electric machine designed for aerospace applications. The importance of permanent magnet demagnetization and long-term insulation quality is stressed, as the high specific power of 13.3 kW/kg is to be achieved by pushing the design parameters such as mechanical speed, electric current, and temperature. Demagnetization will be quantified using finite element methods, where the effects of permanent magnet material, air gap, and rotor back-yoke material on demagnetization will be explored. Various aging models will be introduced to provide an analytical basis to project the insulation lifetime on real applications. A preliminary aging experimental setup is presented, along with a partial discharge detection setup, since partial discharges are suspected to be one of the main electrical aging mechanisms.
Bonhyun Ku

B.S.: December 2016, University of Texas at Dallas
Status: Working towards M.S. at University of Illinois Urbana-Champaign
Professional Interests: Robotic Actuators, Power Electronics, Electric Machines

Distributed and Scalable Electromechanical Actuation for Agile Systems
Bonhyun Ku with Advisor Prof. Arijit Banerjee
Supported by Kwanjeong Educational Foundation

ABSTRACT

Animal-like robots, such as a cheetah robot, require agile movements, including running and jumping. Even though many animal-like robots have been developed, most of them have stiff bodies. Stiff body structure limits a robot’s balance and agile movements. Actual cheetahs have a flexible spine, which allows them to run very fast. We propose a distributed and scalable electromechanical actuation for agile systems to overcome the limitations of the current robots’ dynamic movements. The system is also able to detect the position of each structure. The proposed electromechanical actuation design can allow animal-like robots to have faster and flexible movements and better balancing.
Elie Libbos

B.S.: American University of Beirut
Status: Working towards M.S. at University of Illinois Urbana-Champaign
Professional Interests: Electric Machines and Drives, Power Electronics, Control

Flexible Induction Machine Drive for Electric Vehicles

Elie Libbos with Advisor Prof. Arijit Banerjee
Supported by ECE Indirect Cost Recovery

ABSTRACT

High power density, high efficiency, and an inexpensive drivetrain operating over a wide speed range are critical attributes for future electric vehicles (EV). Induction machines (IM) offer a cost-effective and reliable alternative to permanent magnet-based solutions. A flexible power electronics drive with individual-slot current control can reconfigure the IM to optimize its performance in the dynamic EV environment. The proposed drive architecture and employment of wide bandgap semi-conductors opens the opportunity to functionally integrate the motor and its power electronics. The wide-speed range requirement of an EV limits the power density of conventional machines. A flexible IM that is reconfigured on the fly creates a new design space to meet the dynamic requirements of an EV.
Zitao Liao

B.S.: May 2015, University of Illinois Urbana-Champaign
M.S.: May 2017, University of Illinois Urbana-Champaign
Status: Working towards Ph.D. University of Illinois Urbana-Champaign
Professional Interests: High Step-up FCML Converter, Electric Vehicle Applications

Analysis and Design of Compact and Efficient High Step-up Flying Capacitor Multilevel Converters
Zitao Liao with Advisor Prof. Robert Pilawa-Podgurski
Supported by Sandia and POETS

ABSTRACT

This thesis explores possibilities to improve the power density (power to volume ratio) and the efficiency of dc-dc boost converters by using flying capacitor multilevel (FCML) converter topology. Dc-dc boost converters are widely used in electrical systems for stepping up the source dc voltage to higher levels. For many applications that are constrained by power consumption and physical space for installation, power converters with high efficiency and power density are preferred. A conventional dc-dc boost converter has many limitations with regard to achieving high power density and efficiency at high voltage gain, such as high switching loss, high voltage stress on main switches and large inductor volume. The FCML converter topology utilizes high energy density capacitors and inductors to store and transfer energy. This brings many inherent properties to overcome limitations of conventional dc-dc boost converters. This thesis will present the analysis and design process for an FCML boost converter hardware prototype.
Avinash N. Madavan

B.S.: July 2016, University of California at San Diego
M.S.: December 2018, University of Illinois Urbana-Champaign
Status: Working towards Ph.D. at University of Illinois at Urbana-Champaign
Professional Interests: Optimization over Large-scale Power Systems under Uncertainty

Scalable Methods for Security-Constrained Optimal Power Flow
Avinash N. Madavan with Advisor Prof. Subhonmesh Bose
Supported by the International Institute for Carbon-Neutral Energy Research (I2CNER)

ABSTRACT

A security-constrained economic dispatch (SCED) problem is regularly solved by system operators in electric power networks that make day-ahead and real-time dispatch decisions. Preventive SCED is conservative and requires dispatch decisions that are secure against any single component failure. Corrective (recourse) actions can significantly reduce operational costs. Even with linear power-flow models, corrective SCED poses significant computational challenges owing to an increase in the dimensionality arising from additional recourse decisions and the number of contingencies to guard against. In this presentation, I will describe a novel risk-sensitive formulation for SCED that captures the tradeoff between cost and reliability. I will also demonstrate an algorithm that tackles the computational challenges of solving the problem at scale through decomposing the problem via a critical-region exploration technique that exploits the problem structure using properties of multi-parametric linear programming.
Theodoros Mamalis

B.S.: December 2016, University of Patras

Status: Working towards M.S. at University of Illinois at Urbana-Champaign

Professional Interests: Vehicle-to-Grid Services, Transportation Networks, Incentive Modeling, Optimization

Electric Vehicles for Grid Services

Theodoros Mamalis with Advisor Prof. Subhonmesh Bose

Supported by ECE Indirect Cost Recovery

ABSTRACT

Electrification of urban transportation is on the rise. In April 2016, Téo Taxi launched a plug-in electric vehicle (PEV) fleet in Montreal followed four months later by Uber in London. PEV enables transportation but adds to the road traffic. When parked, it can act as a controllable storage device either to consume surplus or inject energy to the grid. Hence, managed PEV fleets provide unique opportunities for electric grid support and traffic management. Further, managed PEV fleets include two types. One comprises ridesharing companies with transactional control over vehicles, wherein private drivers respond to monetary incentives. The other comprises car-sharing companies, which directly control their fleet. In this project, we will characterize viable control strategies for the managers to co-optimize their revenues from both transportation services and their grid activities. We will develop profit maximization algorithms of the PEV fleet managers providing such services.
ABSTRACT

HVAC systems consume a major part of the energy in both industrial and domestic buildings. Therefore, compressor motor efficiency has a huge impact on overall compressor motor efficiency. Currently, the industry relies heavily on an induction motor that is cost-effective compared to regular permanent magnet synchronous machines (PMSM) but lower in efficiency. From initial trade-study research, the PM-assisted synchronous reluctance motor (PM assisted SynRM) with a ferrite magnet seemed to be a viable option for compressor usage that can substitute an induction motor for higher efficiency while maintaining lower cost. PM-assisted SynRM uses reluctance torque in addition to regular magnetic torque, allowing usage of low-cost ferrite magnets instead of permanent magnets. However, mechanical stability is affected due to these magnetic barriers. Current research seeks to optimize rotor design for both higher efficiency and mechanical stability for compressor application.
ABSTRACT

Virtual bidding represents a mechanism for buying and selling an electricity product without physically consuming or producing it. Such mechanisms are employed in centralized wholesale electricity markets as instruments to achieve price convergence between day-ahead and real-time electricity prices as well as in the determination of electric-power interchange between independently operated grids. An example of the latter is coordinated transaction scheduling (CTS) that is implemented among independent system operators (ISOs) in the northeast interconnection to set the interface schedules among areas that exhibit price spreads at the border nodes. My research focuses on the modeling and analysis of the strategic interactions of virtual bidders in CTS markets via the utilization of game-theoretic methods. More specifically, we develop a framework that yields the equilibria of the strategic interactions among CTS players and the market outcomes in both static and dynamic settings. Our analysis indicates that under uncertainty and when CTS players have better forecasts on system conditions than the ISO, the CTS outcome is closer to the real optimal interface schedule than the one computed by the ISO alone.
ABSTRACT

Any collection of interconnected generators and loads capable of islanded operation is generally considered a microgrid. It follows, then, that there are no formal restrictions on generator type in a microgrid; however, like the prototypical example of a neighborhood comprising homes with rooftop-mounted photovoltaic arrays, microgrids are typically envisaged to consist entirely of generators interfaced through power electronics. Consequently, without the spinning mass inherent in traditional synchronous generators, this class of microgrid has little to no effective inertia, thus making frequency regulation one of the key operational challenges. In this work, we describe the implementation and testing of a centralized and a distributed frequency-regulation controller for islanded inertia-less ac microgrids. For the centralized frequency-regulation architecture, we use the NI cRIO-9068 microcontroller as the centralized controller to regulate the frequency of the inertia-less ac microgrid. We model the microgrid using the Typhoon HIL, which emulates the real-time microgrid operations. The centralized controller monitors the ac microgrid to detect and compute the average frequency error in the microgrid due to load changes. The controller then fixes the set points of the inverter-based generator sources to remove the average frequency error. This process takes place continuously in a closed loop regulating the microgrid frequency. For the distributed frequency-regulation architecture, we use six Arduino-based microcontrollers to run a ratio consensus algorithm to compute, in a distributed fashion, the average frequency error in the system due to load changes. Based on the consensus results that provide the average frequency error, the frequency controllers of each inverter-based generation resource fix the set points to match the generation and load and thus regulate the system frequency.
Nathan Pallo

B.S.: 2011, Massachusetts Institute of Technology
M.S.: May 2018, University of Illinois Urbana-Champaign

Overcoming Electro-Thermal Barriers to Achieve Extreme Performance Power Conversion for More Electric Aircraft
Nathan Pallo with Advisor Prof. Robert Pilawa-Podgurski
Supported by POETS

ABSTRACT

The National Aeronautics and Space Administration (NASA), in addition to an increasing number of privately funded ventures, has demonstrated growing interest in more electric aircraft (MEA) - flight vehicles where propulsion is partially or totally supplied by electric motors. While hybrid or turbo-electric MEA concepts would still rely on a jet-engine power plant to provide electrical power to these electric motors, NASA studies indicate these concepts can result in cleaner, quieter, and more fuel-efficient flight compared to current best-in-class passenger jet aircraft.

To achieve this new paradigm in flight, major engineering challenges must be overcome to improve the thermal management, efficiency and power density of the propulsion electronics as well as ensure the high reliability necessary for aviation. This thesis focuses on these challenges in the scope of one block of this electrical system: a high-performance dc-ac converter designed to drive the type of electric machine engineered for electric flight from a high-voltage dc bus that would be present on some MEA concepts. The flying capacitor multilevel topology is demonstrated as an enabling technology for simultaneously achieving high efficiency and high power density, with specific consideration given to packaging and implementation. Reliability of the converter is addressed through discussion of on-line health management by a real-time hardware-in-the-loop (HIL) observer.
Desiree Phillips

B.S.: May 2012, Rensselaer Polytechnic Institute, Troy, New York
M.S.: May 2014, University of Illinois at Urbana-Champaign
Ph.D.: June 2018, University of Illinois Urbana-Champaign
Professional Interests: Power Systems Operation, System Reliability, Computational Techniques

Toward Joint Water-Power Electric Grid Modeling
Desiree Phillips with Advisor Prof. Emeritus Thomas J. Overbye
Supported by the Institute for Sustainability, Energy, and Environment (ISEE)

ABSTRACT

The water-energy nexus refers to the relationship between how much water is used to generate and transmit energy, and how much energy it takes to collect, clean, move, store, and dispose of water. The dependence of the electric power grid on water varies based on generation technology (i.e., prime mover), fuel source, cooling technology, and climate. By one estimate, 49% of all U.S. water withdrawals are used for thermoelectric cooling, with the state of Illinois ranking second overall in terms of thermoelectric-cooling withdrawal. This work proposes the introduction of water-dependency variables into existing electric grid analysis, specifically for the state of Illinois. The goal is to examine how the changes in water use and availability affect electric grid operation and reliability.
Nathaniel Renner

B.S.: May 2016, University of Illinois at Urbana-Champaign
M.S.: April 2018, University of Illinois Urbana-Champaign
Professional Interests: Electric Vehicles, Electric Machines, Manufacturing, Systems Integration

Development, Manufacture, and Qualification of Stator Components for a High-Speed Electric Machine Intended for Aerospace Applications
Nathaniel Renner with Advisor Prof. Kiruba S. Haran
Supported by NASA, Rolls-Royce and the Power Affiliates

ABSTRACT

In recent years, advances in power electronics and materials have enabled innovative electric machine (EM) designs. At the same time, the environments and applications in which these electric machines are being used are becoming more and more demanding. For example, electric vehicles require electric motors that do not consume a large amount of space or weight, while still providing high power and efficiency. As a result, much research has been done to improve the specific power (kW/kg) and power density (kW/m3) of these devices. Due to the steady increase in air transportation, electric propulsion systems are now being explored as a way to reduce the energy consumption of long-distance travel. Studies have shown that EM-specific powers of greater than 13 kW/kg are necessary to enable this type of propulsion.

This thesis provides an overview of the current progress related to electric aircraft configurations followed by an in-depth analysis of machine topology selection. Ultimately, an outside rotor permanent magnet synchronous machine (PMSM) designed to produce 1 MW at 96% efficiency with a specific power of 13 kW/kg is selected. This thesis then shifts focus to the development, manufacturing, qualification, and assembly of the PMSM’s armature windings. The innovative winding design that is addressed is a key enabler to the machine’s performance due to its ability to push electric loading to 40,000 A/m, while using only forced air-cooling. Finally, the thesis concludes with a summary of findings and suggestions for future work.
Christopher Sain

B.S.: 2017, New Mexico Institute of Mining & Technology
M.S.: Working towards University of Illinois Urbana-Champaign
Professional Interests: Reliability and Planning in Infrastructure

**An OpenDSS Implementation of a Generic Municipal Microgrid for Co-Simulation**

Christopher Sain with Advisor Prof. Peter Sauer

Supported by the Grainger Foundation

**ABSTRACT**

Many power system research problems may be solved via deployment simulations. However, for real-world problems the computational efforts for detailed dynamic modeling may be impractical or excessive. OpenDSS provides a framework within which a model of a small- or large-scale system may be implemented without the representation dynamics, with extensive co-simulation capabilities. We model a generic 8-bus microgrid that consists of 200 residential loads plus an additional load for the local control building, three-generation resources – solar, wind, and gas – and a battery-storage resource. We use actual environmental data from Decatur, IL together with realistic consumer load shapes to analyze the simulation studies of various unbalanced and quasi-balanced situations. In addition, we apply the model in co-simulation studies with hardware-in-the-loop to evaluate various potential scenarios.
Shivang

B.S.: May 2016, Indian Institute of Technology (IIT), Kharagpur, India
Status: Working towards M.S. at University of Illinois Urbana-Champaign
Professional Interests: Doubly-fed Machines, Electric Drives

Brushless Doubly-Fed Reluctance Machines for Turboelectric Distributed Propulsion Systems
Shivang with Advisor Prof. Arijit Banerjee
Supported by NASA and ECE Indirect Cost Recovery

ABSTRACT

Turboelectric propulsion systems are considered a critical enabler for low-carbon emission in the aircraft industry. Unlike hybrid-electric and all-electric systems, these systems do not use batteries for propulsive energy during any phase of flight. Since batteries with high power capacity and specific power required for commercial aircraft are unlikely to be developed within the next 30 years, turboelectric systems are the only feasible option at this point of time.

Out of several motors available for driving the distributed propeller fans, brushless doubly-fed reluctance machines (BDFRM) are seen as one of the more attractive, primarily for use of a partially rated power converter, brushless operation and low rotor losses. Our research focuses on designing a BDFRM and the necessary drive required for this megawatt-class application. A switched-drive architecture has also been proposed for machine control. It reconfigures the stator excitation on the fly, enabling a wide-speed range operation while preserving the benefit of fractionally rated power electronics.
Samith Sirimanna

B.S.: April 2016, University of Moratuwa, Sri Lanka
Status: Working towards M.S. at University of Illinois Urbana-Champaign

High Efficiency, Low Cost Motor for Compressor Applications
Samith Sirimanna with Advisor Prof. Kiruba S. Haran
Supported by Johnson Controls International and ECE Indirect Cost Recovery

ABSTRACT

Compressors use a substantial amount of energy in most industrial or household applications, from refrigerators or HVAC to general manufacturing. As a result, compressors present a huge opportunity for reducing energy. Traditionally, compressors use induction or synchronous motors coupled with a mechanical shaft that drives a variety of compressor types. The availability of the high-speed, high-power density synchronous machine with slot-less stator design provides an opportunity to take a significant step towards an efficiency increase. The trade-offs between these designs are being analyzed to adopt the optimum motor topology. Motor integration is an important factor in overall compressor efficiency. Different topologies of motor integration are being examined to continue the study.
Andrew Stillwell

B.S.: 2005, University of Missouri
M.S.: August 2015, University of Illinois Urbana-Champaign
Status: Working towards Ph.D. at University of Illinois Urbana-Champaign
Professional Interests: High Power Density Power Converters, Renewable Energy

Design Optimization of a 1500 V GaN-Based Solar Inverter Using Flying Capacitor Multi-Level Converter Stages
Andrew Stillwell with Advisor Prof. Robert Pilawa-Podgurski
Supported by DOE Sunshot Project and Grainger CEME

ABSTRACT

Utility-scale solar installations are adopting 1500 V solar inverters with reduced cabling and installation costs. Flying capacitor multi-level (FCML) inverters with 650 V transistors offer unique system benefits, leading to lower volume and weight while improving system efficiency. In this work, we develop the design optimization of FCML inverters for 1500 V with considerations of different switches, number of levels, switching frequency and passive components. The optimization informed the design of a 5-level FCML with 650-V GaN switches which was demonstrated successfully in hardware.
ABSTRACT

New operational challenges have emerged with the proliferation of distributed energy resources (DERs) in the power grid. By effectively coordinating the DERs, one can provide services to mitigate these effects. One such service important to maintaining grid stability is frequency regulation on ancillary services provided in the open-market grid management. This thesis presents a hardware-in-the-loop platform for testing the effectiveness of different coordination schemes for providing frequency regulation services. While this is usually done in a centralized manner, in our testbed we aim to show the effectiveness of distributed control algorithms, which are used along with local controls to coordinate these DERs and achieve the frequency regulation objective. We first elaborate on frequency regulation and the provision process and then present an overview of our hardware testbed. We then present the various parts that make up this testbed on both the hardware and software level, describing in detail the distributed algorithm used and how it is developed on our software platform. Finally, we present various experiments and results that showcase the use of our hardware testbed.
The introduction of hybrid-electric and fully-electric vehicles in the automotive industry has led to various improved performance aspects in commercially available vehicles. This trend is expected to be replicated in the aerospace industry, with NASA studies on hybrid, turboelectric and fully-electric aircraft propulsion indicating significant improvements in efficiency and fuel consumption. An alternative possibility in electric air transportation is the use of a fully-electric multi-propeller, vertical takeoff and landing configuration for short-distance transportation of a few passengers. Component selection and system-design considerations will need to balance the tradeoff between performance and system weight, while ensuring that the vehicle is safe and robust.
Michael Wu

B.S.: May 2018, University of Illinois
Status: Working towards M.S. at University of Illinois Urbana-Champaign
Professional Interests: Power Electronics Applications in Consumer Electronics

Research on Intelligent Technology of IGBT Drive
Michael Wu with Prof. Arijit Banerjee
Supported by CRRC China

ABSTRACT

Today, insulated-gate bipolar transistors (IGBT) have become increasingly popular for their high voltage and current capabilities. These applications range from transport to renewables. However, IGBT’s are some of the more delicate components in these high-power systems, and IGBT failure can have severe economic implications. Therefore, it is important to develop an online health-monitoring framework to ensure proper operation of IGBT power modules and predict the remaining life of a power module. This work aims to create a thermal model of an IGBT power module in a 3-phase, 2-level inverter that can accurately estimate junction temperature, which provides useful information in evaluating both current health and remaining power module life. This model will require the development of hardware that can withstand voltages and currents that can accurately measure on-state saturation voltage and collector current to calculate power dissipation in the power module. Additional hardware will be developed for the storage of such measurements for fault analysis. This will allow a user the ability to observe various electrical signals at and around the time of failure.
Hanchen Xu

B.S.: July 2012, Tsinghua University, Beijing, China
M.S.: July 2014, Tsinghua University, Beijing, China
Status: Working towards Ph.D. at University of Illinois Urbana-Champaign
Professional Interests: Data-driven Control, Grid Data Analytics, Voltage Control

Data-driven Voltage Regulation in Radial Power Distribution Systems
Hanchen Xu with Advisors Prof. Alejandro Dominguez-Garcia and Prof. Peter Sauer
Supported by ARPA-E

ABSTRACT

My research focuses on developing a data-driven voltage regulation framework for distributed energy resources (DERs) in a balanced radial power distribution system. The objective is to determine optimal DER power injections that minimize the voltage deviations from a desirable voltage range without knowing a complete power-distribution system model a priori. The nonlinear relationship between the voltage magnitudes and the power injections in the power distribution system is approximated by a linear model, the parameters of which—referred to as the voltage sensitivities—can be computed directly using information on the topology and the line parameters. Assuming the knowledge of feasible topology configurations and distribution line resistance-to-reactance ratios, the true topology configuration and corresponding line parameters can be effectively estimated using a few measurement sets on voltage magnitudes and power injections. Using the estimated voltage sensitivities, the optimal DER power injections can be readily determined by solving a convex optimization problem. The proposed framework is intrinsically adaptive to changes in system conditions, such as unknown topology reconfiguration due to its data-driven nature. The effectiveness of the proposed framework is validated via numerical simulations on the IEEE 123-bus distribution test feeder.
ABSTRACT

The current aviation industry demands environmentally friendly and fuel-efficient aircraft to be sustainable. It has been theoretically proven that superconducting machines can power electric airplanes to carry hundreds of people. These machines apply superconducting technology to produce dramatically high-flux density and high-current density, and thus can significantly reduce weight/volume. Conventional machines for aircraft application must reach a power density of eight hp/lb (four times more than the existing state-of-art) to produce similar results. In this project, a non-cryogenic, high-frequency, high-pole-count and high-speed air-core permanent magnet motor is proposed to meet this requirement. In addition, an efficient multi-physics optimization method that can accurately predict electric and thermal performance of such a machine is developed and verified with finite element analysis. Optimum machine sizing is obtained by using a genetic algorithm coupled with an established multi-physics model. The final step will validate the proposed analytical model and optimization method with our 1 MW prototype machine full-power tests at UTRC and POETS facilities.
Andy K. Yoon

B.S.: May 2013, University of Illinois at Urbana-Champaign
M.S.: December 2016, University of Illinois at Urbana-Champaign
Status: Working towards Ph.D. at University of Illinois Urbana-Champaign
Professional Interests: Electric Machines, Electromechanics, Electric Transportation Systems

Experimental Validation of High Specific Power Electric Machine

Andy Yoon with Advisor Prof. Kiruba S. Haran

Supported by NASA

ABSTRACT

A 1 MW electric motor has been designed at a rated speed of 15,000 rpm and has a projected specific power of 13kW/kg. Such a design is appropriate for aerospace applications for its flight-weight and low-volume characteristics. Current plans include experimental validation of the motor assembly to retire thermal, mechanical, electrical, and magnetic risks associated with the design. The testing will take place at Collins Aerospace facility in Rockford. The test facility will allow the device to be tested as a generator up to rated power of 1 MW. The device will also be tested as a motor to study its interaction with a typical aerospace inverter drive.
Yangxue Yu

B.S.: May 2018, University of Illinois Urbana-Champaign
Status: Working towards M.S. at University of Illinois Urbana-Champaign
Professional Interests: Electric Machines, Electromechanics, and Electromagnetics

Trunnion Effect on a PMSM with External Rotor Design
Yangxue Yu with Advisor Prof. Kiruba S. Haran
Supported by ZJU and JCI

ABSTRACT

To predict and improve the performance of a motor, it is important to understand the rotor dynamics and correctly capture the critical rotor frequencies. For an external rotor design, the presence of the trunnion effect, which is modeled as a rotational stiffness at the hub of the trunnion plate, may shift the first critical speed of the rotor downward. When the first critical speed falls within the range of operation, the system will experience vibration and may lead to severe damage if the system is not well balanced. Therefore, it is crucial to identify the critical speed due to the trunnion effect before testing. In this study, the rotational stiffness is calculated from a base model, and XLrotor is used to simulate the rotor free-free mode. A ping test is performed on the rotor to determine the frequency of the trunnion effect. By comparing the simulation and ping-test result, the base model is calibrated and applied to the rotor dynamics simulation of the entire drive train.
Ogün Yurdakul

B.S.: June 2016, Boğaziçi University, Istanbul, Turkey
M.S.: May 2018, University of Illinois Urbana-Champaign
Professional Interests: Energy Storage Resources, Optimization, Economics, Electricity Markets

Analysis and Performance Evaluation of Coordinated Transaction Scheduling
Ogün Yurdakul with Advisor Prof. George Gross
Supported by the Fulbright Program

ABSTRACT

In this thesis, we focus on coordinated transaction scheduling (CTS), an interchange evaluation methodology that has been deployed by the New York Independent System Operator (NY ISO) and Independent System Operator-New England (ISO-NE) since December 15, 2015. The analysis and the quantification of the performance of any interchange evaluation methodology require the explicit representation of the physical and economic aspects, the steps of the coordination procedure, and all the interactions among them. In order to consider the required representation and tools in a unified structure, we construct a framework. This framework is general and comprehensive, and can be used as a consistent basis that allows side-by-side comparison of any two-interchange evaluation methodologies. In order to illustrate the execution of the CTS procedural steps, we use various data sets and evaluate the interface exchange and the total payments for each data set. We conduct sensitivity analyses, and examine the dependence of the interface exchange and the total payments on a change in the internal offers or the interface offers.
Joseph Zatarski

B.S.: May 2018, University of Illinois at Urbana-Champaign
Status: Working towards M.S. at University of Illinois Urbana-Champaign
Professional Interests: Power Electronics

Silicon-Carbide MOSFET Health Monitoring and Diagnosis
Joseph Zatarski with Advisor Prof. Arijit Banerjee
Supported by the Navy and ECE Indirect Cost Recovery

ABSTRACT

The objective of this project is to predict failures and remaining useful life in power electronic building blocks (PEBBs) comprising Silicon Carbide (SiC) devices. Silicon Carbide devices are relatively new in the industry, so it is important to create health monitoring techniques for high-reliability applications. The condition-based maintenance algorithms will be demonstrated on a dc/dc high frequency transformer made using 1.7 kV SiC devices. The project will be in collaboration with Dr. John S. Donnal, who has pioneered non-intrusive load-monitoring technology, from the United States Naval Academy (USNA).
Xiaolong Zhang

B.S.: June 2011, Huazhong University of Science and Technology, China
M.S.: June 2014, Huazhong University of Science and Technology, China
Status: Working towards Ph.D. at University of Illinois Urbana-Champaign
Professional Interests: Motor Drives and Control, Permanent Magnet Synchronous Machines, Power Electronics

Study of Dynamic Response Performance and Stability in a High-Speed PM Machine Drive
Xiaolong Zhang with Advisor Prof. Kiruba S. Haran
Supported by NASA

ABSTRACT

Electric propulsion has been proposed for large commercial aircraft to achieve benefits similar to those seen in hybrid-/all electric ground-based and marine vehicles. A high-power, high-speed permanent magnet synchronous machine (PMSM) drive system is being developed to meet the stringent weight requirements in the aircraft application. The dynamic response performance and stability of the inner current control loop in such a system is of great importance to its reliable and efficient operation. An analytical tool based on complex state variables has been developed to predict the dynamic response and stability. This tool includes four different $dq$ decoupling design options and practical effects caused by sampling delay. This tool reduces the computation time from around 30 minutes with the conventional method, i.e., numerical modeling under Simulink, to just a few seconds, while maintaining similar accuracy. The optimal tuning of the proportional-integral-differential current controllers can be done efficiently with the developed tool.
Lijun Zheng

B.S.: May 2016, University of Illinois at Urbana-Champaign
M.S.: April 2018, University of Illinois at Urbana-Champaign
Professional Interests: Renewable Energy, Electric Machines, and Electromechanics

Mechanical Design and Validation of 1 Mw Permanent Magnet Synchronous Machine
Lijun Zheng with Advisor Prof. Kiruba S. Haran
Supported by Grainger CEME

ABSTRACT

This thesis focuses on a high-frequency, high-power density (8 hp/lb), 1 MW power-output electric motor design to double the power density of electric machines, bringing us closer to electrified propulsion. This thesis focuses on the mechanical analysis and design for a specially designed 1 MW permanent magnet synchronous electric machine (PMSM).

First, the design intention or design topology will be explained. A high-speed, high-frequency, PMSM is designed. An inside-out configuration was chosen for its high peak efficiency and large tip speed. There are also other innovative designs such as Halbach array magnets and air gap windings. Combining these designs imposes challenges for the motors mechanical design. Not only does mechanical integrity strength need to be considered, but dynamic performance, vibration and thermal performance would also face challenges when it comes to actual operation. The thesis will first go over some trade-off studies and analysis before we introduce our design. The thesis mainly addresses analysis for rotor dynamics as well as fan performance. Design challenges are analyzed by analytical equations, numerical methods like finite element analysis, and finally test results.
Madi Zholbaryssov

B.S.: December 2011, University of Illinois Urbana-Champaign
M.S.: May 2014, University of Illinois Urbana-Champaign
Status: Working towards Ph.D. at University of Illinois Urbana-Champaign
Professional Interests: Distributed Energy Resources, Microgrids, Distributed Control and Optimization

Fast Distributed Optimal Generation Dispatch Over Time-Varying Communication Networks
Madi Zholbaryssov with Advisor Prof. Alejandro Domínguez-García
Supported by ARPA-E NODES

ABSTRACT

The goal of the project is to develop fast distributed algorithms for coordinating the response of distributed energy resources in ac microgrids to minimize electrical line losses and generation cost, and to ensure that the microgrid network constraints are satisfied. The proposed algorithm can be utilized as a tertiary controller for economic optimization of microgrids, or to coordinate distributed energy resources for providing ancillary services to the bulk grid when the microgrid is in grid-connected mode. Such coordination is also required to be resilient against communication delays and random data-packet losses and to have geometric convergence speed, a desirable feature for ensuring fast performance.
Jeffrey Zhu

B.S.: May 2017, University of Illinois at Urbana-Champaign
Status: Working towards M.S. at University of Illinois Urbana-Champaign
Professional Interests: Power system stability and control

Compensating for the Reduction in Synchronous Inertia Caused by Greater RES Penetration with VSGS
Jeffrey Zhu with Advisor Prof. Peter Sauer
Supported by ECE Indirect Cost Recovery

ABSTRACT

The traditional power grid has been dominated by large synchronous generators, which have offered not only power supply but also frequency stability through their inertia and frequency controls. As more renewable energy sources (RESs), such as wind and solar, are integrated into the grid, they displace synchronous generation units. Many of these RES units do not inherently contribute inertia to the system, so the net effect is a decrease in the aggregate inertia of the power grid. Low inertia threatens the grid with fast frequency dynamics that can trigger under-frequency load shedding or anti-islanding relays in the event of a disturbance. In light of that reality, the frequency support that is traditionally provided by synchronous generators must be found elsewhere. This paper investigates the virtual synchronous generator (VSG) as a solution. The VSG is a controls-based system that mimics the frequency dynamics and response of a synchronous generator. Through simulation, this paper seeks to identify those requirements on the minimum synchronous inertia, virtual inertia, and VSG response time that will maintain the frequency at a safe level and rate of change following a disturbance.
7. LABORATORY FACILITIES

The Power Area has assembled some of the nation's finest facilities for experimental and computer-based research and teaching. Both undergraduate and graduate students can take advantage of these facilities.

The Grainger Power Engineering Software Laboratory is located in room 4076 ECEB (Electrical and Computer Engineering Building). The Software Laboratory has nine advanced personal computers. All stations are connected to the campus network and Internet.

A major objective of the laboratory is to develop an extensive library of commercial software and large-scale databases for power area applications. Software is based on Windows 7. Some of the commercial software packages currently in use include:

- Mathematica / Wolfram (advanced symbolic mathematics, fully integrated technical computing)
- Mathcad / PTC (industry standard for engineering calculations)
- MATLAB / MathWorks (MATrix LAB, technical computing)
- Simulink (Matlab package, graphical simulation, model based design, dynamic and embedded)
- SimElectronics (Simulink Toolbox, model and simulate electronic and electromechanical systems)
- SimPowerSystems (Simulink Toolbox, modeling and simulating electric power systems)
- xPC Target (Simulink, rapid control prototyping and hardware-in-the-loop)
- PLECS (Simulink, fast simulation of electrical and power electronic circuits)
- acslX(treme) / AEgis (general-purpose simulation environment)
- LabVIEW (visual programming language, lab bench dynamometer control program & Gui)
- PSS/E / Siemens PTI (power system simulator for engineering, electrical transmission)
- RISKSYM / Henwood (package for energy market analysis)
- PowerWorld (power systems analysis, power market analysis, locational marginal price analysis)
- Power System Tool Box (PST Version 2.0)
- Dymola / Dassault (Dynamic Modeling Lab, multi-engineering modeling and simulation)
- ANSYS / Ansoft (finite element analysis modeling)
- Maxwell (ANSYS, EM Field Simulation for high-performance electromechanical design)
- RMxprt (ANSYS, design software for electric machines)
- Simplorer (ANSYS, simulation of electrical, electromechanical, electromagnetic, power, thermal)
- Flux / Magsoft / Cedrat (electromagnetic and thermal physics simulation)
- OrCAD / Cadence (schematic capture and PCB design)
• Eagle / CadSoft (schematic capture and PCB design)
• SAM / NREL (System Advisor Model, PV Photovoltaic system cost estimation)
• Altera Quartus & DSP Builder (FPGA software & Digital Signal Processing tool)
• Agilent VEE (graphical programming environment for measurement and analysis)
• Xilinx ISE (synthesis and analysis of HDL hardware description language design)
• MPLAB IDE / Microchip (Integrated Development Environment for PIC programming)
• SPEED / STAR-CCM+ / CD-adapco / Siemens (design and analysis of electric machines)

A secondary objective of this laboratory is the use of this space as a hardware-in-the-loop (HIL) testbed to test the effectiveness of distributed algorithms in coordinating a group of distributed energy resources modeled in the Typhoon HIL Platform. The hardware that comprises this testbed includes:

• A set of Arduino Due microcontrollers, each coupled with a W5100 Ethernet shield and XBee module
• Typhoon HIL 402
• Typhoon HIL 603
• National Instruments cRIO 9068 with NI PS-15 power supply
• 24 Port Gigabit Switch

This comes with a set of software packages installed on two advanced personal computers as listed below:

• Arduino IDE Software
• Processing 3.3.7
• LabVIEW 2017
• Typhoon HIL testing software
• MATLAB R2017a

The Grainger Electrical Machinery Laboratory is located in 4024 ECEB (Electrical and Computer Engineering Building). This facility is primarily for undergraduate teaching and is used for ECE 431 (Electric Machinery), ECE 469 (Power Electronics), and Engineering Open House (EOH) Power & Energy demonstrations. With many power and energy teaching labs cutting back on hardware and machines, or going totally to software or virtual experiments, the Grainger lab has been able to maintain and increase our large inventory of test machines and equipment. Ten self-contained machinery workstations are available. Each has a two-horsepower machine set with a servo-based dynamometer. The lab benches were updated with new equipment for the academic year (2013 - 2014) including new digital wattmeters, oscilloscopes, signal generators, power supplies, and
speed/torque displays. The equipment is suitable for the study of induction, synchronous, and dc machines. Small portable machine sets are used to introduce stepper motors and brushless dc machines. Transformers, resistor boxes, capacitor boxes, SCR, and power FET units are provided to support a full range of experiments in all aspects of power and power electronics. The facility has a dedicated three-phase supply 120/208 Vac (150 kVA) and 240 Vdc (+/- 120 Vdc) 80 A rectifier. In 2015, we added a new set of synchronous machines.

The Power and Energy Systems group has Advanced Power Applications Labs in 4020 and 4026 ECEB. These research labs have motor test benches with precision dynamometers and a third new high-horsepower test bed. These benches can access 208 Vac 3-phase, 480 Vac 3-phase, and 240 Vdc. These labs serve as a research facility for all hardware aspects of power electronics, machines, and power systems. Additional equipment is available for the study of harmonic effects, high-performance switching converters, and digitally controlled converters / drives. Computers are available throughout the laboratory for automation of experiments using LabVIEW and Matlab / Simulink / Real-Time Toolbox. This fourth floor lab has direct access to the roof to allow for solar panel, wind turbine, and weather station placement.
8. DIRECTORY

THE UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
COLLEGE OF ENGINEERING

Rashid Bashir, Dean
(217) 333 2150
rbashir@illinois.edu

Philippe Geubelle, Executive Associate Dean
(217) 244 7648
geubelle@illinois.edu

Dale Wright, Associate Dean for Advancement
(217) 244-0604
dlwright@illinois.edu

Michael J Devocelle, Associate Dean for Finance and Administration
(217) 333-2151
mdevocel@illinois.edu

Jennifer Bernhard, Associate Dean for Research
(217) 333-0293
jbernhar@illinois.edu

Jonathan Makela, Associated Dean for Undergraduate Programs
(217) 333-2280
ravaioli@illinois.edu

Harry Dankowicz, Associate Dean for Graduate, Professional and Online Programs
(217) 244-1231
danko@illinois.edu

Address: University of Illinois College of Engineering
306 Engineering Hall
1308 W. Green St
Urbana, IL 61801
Fax: (217) 244-7705
www.engr.illinois.edu
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
ADMINISTRATION

Wen-mei Hwu, Acting Department Head
(217) 244-8270
w-hwu@illinois.edu

Michael Oelze, Associate Head Graduate Affairs
(217) 333-9226
oelze@illinois.edu

Erhan Kudeki, Associate Head for Undergraduate Affairs/Chief Advisor
(217) 265-0128
erhan@illinois.edu

Catherine Somers, Assistant Head for Administration
(217) 244-1783
csomers@illinois.edu

Heather Vazquez, Senior Director of Advancement
(217) 333-2517
hfv@illinois.edu

Nikki Slack, Alumni and Donor Relations Coordinator
(217) 265-4317
nslack@illinois.edu

Address: University of Illinois at Urbana-Champaign
Department of Electrical and Computer Engineering
Electrical and Computer Engineering Building
306 N. Wright Street, MC-702
Urbana, IL 61801
Fax: 217-333-1162
www.ece.illinois.edu
POWERS AND ENERGY SYSTEMS AREA

Robin Smith, Office Manager  
(217) 333-6592  
rsmth@illinois.edu  
Prof. George Gross  
(217) 244-1228  
gross@illinois.edu

Prof. Peter W. Sauer  
Director of the Power Affiliates Program  
(217) 333-0394  
psauer@illinois.edu  
Prof. Kiruba Haran  
(217) 244-1838  
kharan@illinois.edu

Prof. Arijit Banerjee  
(217)300-5319  
arijit@illinois.edu  
Prof. Emeritus Philip T. Krein  
(217) 333-4732  
krein@illinois.edu

Prof. Subhonmesh Bose  
(217) 244-2101  
boeses@illinois.edu  
Prof. Emeritus M. A. Pai  
(217) 333-6790  
mapai@illinois.edu

Prof. Alejandro Domínguez-Garcia  
(217) 333-3953  
aledan@illinois.edu  
Kevin Colravy, Research Engineer  
(217) 333-1056  
colravy@illinois.edu

Address:  
University of Illinois at Urbana-Champaign  
Department of Electrical and Computer Engineering  
Electrical and Computer Engineering Building  
306 N. Wright Street, MC-702  
Urbana, IL 61801  
Fax: (217) 333-1162  
www.energy.ece.illinois.edu
AMEREN
Mr. George Mues
Ameren Services
1901 Chouteau Avenue
P.O. Box 66149
St. Louis, MO 63166
Gmues@ameren.com

CITY WATER, LIGHT AND POWER, SPRINGFIELD, IL
Mr. Shaun Anders
City Water, Light and Power
1008 E. Miller Street
Springfield, IL 62702
(217) 789-2120
Shaun.Anders@cwlp.com

CONTINENTAL AUTOMOTIVE
Mr. Dennis Stephens
21440 Lake Cook Road
Deer Park, IL 60010
(847) 862-2757
dennis.stephens@continental-corporation.com

ELECTRICAL MANUFACTURING AND COIL WINDING ASSOCIATION, INC.
Mr. Charles E. Thurman
EMCWA
P.O. Box 278
Imperial Beach, CA 91933
(619) 575-4191
cthurman@emcwa.org

EXELON
Ms. Jennifer Sterling
Exelon
Two Lincoln Centre
Oakbrook Terrace, IL 60181
(630) 437-2764
jennifer.sterling@exeloncorp.com

Mr. Tom Kay
Exelon
Two Lincoln Centre
Oakbrook Terrace, IL 60181
(630) 437-2758
thomas.kay@exeloncorp.com
FLANDERS, INC.

Mr. Stan Mann
Flanders Electric
8101 Baumgart Rd.
Evansville, IN 47725
smann@flanderselectric.com

G&W ELECTRIC

Mr. James Solari
G&W Electric
305 W. Crossroads Pkwy
Bolingbrook, IL 60440
jsolari@gwelec.com

MIDAMERICAN ENERGY COMPANY

Mr. Richard W. Polesky
MidAmerican Energy
One River Center Place
106 E. Second Street
P.O. Box 4350
Davenport, IA 52801
(319) 333-8187
rupolesky@midamerican.com

POWERWORLD CORPORATION

Dr. Mark Laufenberg
PowerWorld Corporation
2001 S. First Street
Champaign, IL 61820
(217) 384-6330
lauf@powerworld.com

Dr. James Weber
PowerWorld Corporation
2001 S. First Street
Champaign, IL 61820
(217)384-6330
weber@powerworld.com

S&C ELECTRIC COMPANY

Dr. Michael G. Ennis
S&C Electric Company
6601 North Ridge Boulevard
Chicago, IL 60626-3997
(773) 338-1000
mennis@sandc.com
SARGENT & LUNGY ENGINEERS

Ms. Carol Talaronek
Sargent & Lundy Engineers
55 East Monroe Street
Chicago, IL  60603
(312) 269-3578
caroltalaronek@sargentlundy.com
Or contact
Linda Kelnosky
linda.e.kelnosky@sargentlundy.com

Mr. Robert M. Dahlgren
Sargent & Lundy Engineers
55 East Monroe Street
Chicago, IL  60603
robert.m.dahlgren@sargentlundy.com

PROFESSOR EMERITUS M.A. PAI

Prof. Emeritus M. A. Pai
33 Rockwood
Irvine, CA. 92614
mapai@illinois.edu
9. REFERENCES AND PUBLICATIONS


