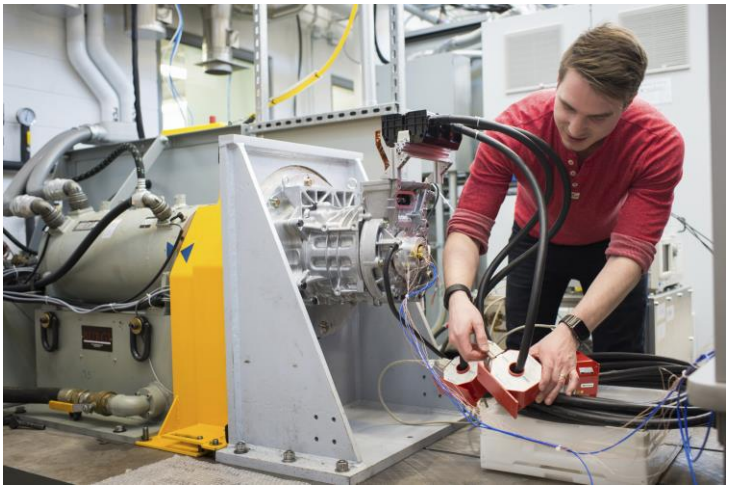
WEMPEC Celebrates 35 Years Of Research And Education In Power Electronics And Motors

by James Sember, WEMPEC Executive Director, Madison, Wisc.

The applications for motor design, power electronics, and controls in electric vehicles, wind and solar power are growing exponentially. As it celebrates its 35th anniversary this year, the Wisconsin Electric Machines and Power Electronics Consortium (WEMPEC) continues to research these areas in ways that are still unparalleled at any other university or industry consortium. WEMPEC is combining research and education in the areas of motor design, power electronic converter design, and motor control.

WEMPEC's Background And Current Research Priorities

Some of WEMPEC's most important research is being done in advanced machines, power converter topologies and controls and sensor technology. WEMPEC focuses on electric machines because of the critical role they play in producing and using electric energy. Electric machine research at WEMPEC has earned an international reputation for its history of ground-breaking innovations ranging from axial-airgap machines to double-airgap machines and, more recently, flux switching machines, variable flux permanent magnet machines, and electrostatic machines.



In the area of converter topologies, WEMPEC pioneered the use of semiconductor power switching devices to create a wide variety of motor drive and power converter topologies. Ongoing work includes introducing a new approach for high-frequency dc-dc power conversion using capacitor coupling to replace transformer coupling and the introduction of Stored Energy Modulation, or SEM. Applying SEM to drive applications reduces the dc link capacitance from thousands of microfarads to just fractions of a microfarad.

Meanwhile, early work on the development of matrix and multilevel converters laid the foundation for more recent work in vector switching ac-ac converters and modular multilevel converters. These have led to optimized topologies and various design-oriented models for applying reactive components to achieve robust performance.

Research in advanced controls constitutes the third major thrust of the WEMPEC program that ties together advanced machines and power converters. In the early days, WEMPEC faculty led the way in education and application of flux vector control and in development of flux observer and current regulator technologies. The concept of "form follows function" has inspired the adoption and integration of goals for self-sensing based control, dynamic loss minimization control, dynamic loss partitioning control, and integration of these control methods with next-generation electric machine design.

Other areas of research include:

- Utility grid applications
- Energy storage
- Wireless power transfer
- Power device dynamic thermal sensing & control.

Combining Theory And Hands-On Experience In Education

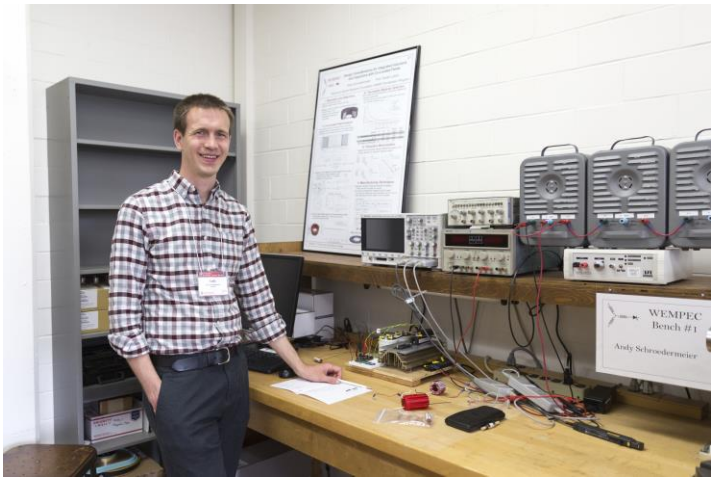
WEMPEC grad students typically have very busy schedules that combine classes, research, and teaching assistant responsibilities. The WEMPEC student body is large, consisting of approximately 75 students at any one time. Their research always includes a combination of theory and hands-on experience. Our students collaborate in the lab, and they meet in research groups once a week together with their faculty advisers to encourage more learning from each other.

WEMPEC has awarded 399 masters degrees and 148 PhDs in electric machines, power electronics and controls. Currently, 27 masters degree students and 46 PhD students are on campus, with 23 off-campus graduate students active in the online graduate degree program, and another 26 off-campus students enrolled in an online capstone certificate program.

The program also provides continuing education to engineers in industry through an extensive program of short courses. As an example, we have a new course taught by professor Bulent Sarlioglu, a WEMPEC faculty member and program director in the UW-Madison Department of Engineering Professional Development.

To be held this June at UW-Madison, professor Sarlioglu's three-day Hybrid Electric Vehicle Bootcamp offers instruction on the latest technology for electric and self-driving vehicles. This course emphasizes electric on-road and off-road vehicles, hybrids, vehicle dynamics, and performance requirements, and much more. In addition to WEMPEC faculty, instructors will include technical professionals from General Motors, Fiat Chrysler, and Oak Ridge National Lab.

Other courses taught by WEMPEC faculty include:



- Permanent Magnet Machine Design Bootcamp, which provides essential information on the various types of PM machines used in traction motors, industrial motors, aerospace motors, appliance motors and generator designs.
- Dynamics and Control of AC Drives, which covers the fundamentals of power conversion and ac machine theory, including the principles of modern ac drives including PM, induction PM and reluctance machines.
- Introduction to Electromagnetic Interference and Compatibility and Best Practices, which covers coupling mechanisms, circuit board layout, conducted and radiated emissions, susceptibility, bonding, grounding and lightning.
- Introduction to Power Electronics, which provides an overview of the growing power electronics field through applications and hands-on demonstrations.

Sponsorships Fund Groundbreaking Research

Approximately half of WEMPEC's funding comes from industry sponsors for basic research. The number of industry sponsors has been quite stable in the vicinity of 90 for the past several years.

Because the sponsorship funds are used primarily to fund basic research, there is not a need for our faculty to constantly seek funding from, for example, government agencies. This allows them to work on research that may take five years or more to provide fruitful results. It also allows them to carry projects over from one student to another. During our 35-year history, WEMPEC has resulted in significant ground-breaking research in more than three dozen distinct areas.

A Distinguished Faculty

WEMPEC was founded by (now emeritus) professors Don Novotny and Tom Lipo. Research is led by WEMPEC co-directors, professors Bob Lorenz and Tom Jahns, in collaboration with three associate directors: professor Giri Venkataramanan and assistant professors Dan Ludois and Bulent Sarlioglu.

Donald Novotny

Since 1961, Donald W. Novotny has been a member of the faculty at the UW–Madison, where he is currently Grainger Professor Emeritus of Power Electronics and co-founder and former co-director of WEMPEC. He retired from full-time activity in 1996 but continues teaching part-time. From 1976 to 1980, he served as chairman of the Department of Electrical and Computer Engineering. He also served as an associate director of the University-Industry Research Program from 1972 to 1974 and from 1980 to 1993.

Novotny has been active as a consultant to many organizations and a visiting professor at Montana State University; the Technical University of Eindhoven, Eindhoven, Netherlands; the Catholic University of Leuven, Leuven, Belgium; and a Fulbright Lecturer at the University of Ghent, Ghent, Belgium. Novotny, who is an IEEE Fellow, received his BS and MS degrees in electrical engineering from the Illinois Institute of Technology, Chicago, in 1956 and 1957, and his PhD degree from the UW–Madison in 1961.

Thomas Lipo

Thomas A. Lipo is a native of Milwaukee, Wisc. Lipo has spent his entire career in the technical field of solid-state ac motor drives. From 1969 to 1979, he was an electrical engineer in the Power Electronics Laboratory, Corporate Research and Development at General Electric in Schenectady, N.Y. where he participated in some of the earliest work in this field. In 1979, he left GE to take a position as a full professor at Purdue University.

In 1981, he joined UW-Madison where he co-founded the industry consortium WEMPEC and served for 28 years as its co-director and as the W. W. Grainger Professor for Power Electronics and Electrical Machines. He also served simultaneously for five years (2009-2013) as World Class Professor at Hanyang University in Ansan, South Korea. He has briefly held positions at Sydney University, Sydney Australia; Cambridge University, Cambridge, England; Monash University, Melbourne, Australia; and Harbin Institute of Technology, Harbin, China. Lipo was also a Fulbright Fellow at the Norwegian University of Science and Technology, Trondheim, Norway in 2008. Presently he is both an emeritus professor at UW-Madison and research professor at Florida State University. Lipo has BEE and MSEE degrees from Marquette University and a PhD from UW-Madison.

Robert Lorenz

Since 1984, Robert D. Lorenz has been a member of the faculty of UW-Madison, where he is the Elmer R. and Janet A. Kaiser Chair and the Consolidated Papers Foundation Professor of Controls Engineering in Mechanical Engineering. He has been co-director of WEMPEC since 1997 after having been associate director since 1985.

Lorenz's research interests include design of motors/actuators for self-sensing and loss minimizing control, power electronic device junction temperature estimation and real-time control of thermo-mechanical strain in power electronic modules, deadbeat-direct torque and flux control for loss manipulation without compromising torque dynamics. Other interests include wireless power transfer technologies, fast signal processing and estimation techniques, precision multi-axis motion control, and ac drive and high precision machine control technologies.

Lorenz has authored more than 300 published technical papers, has won 32 IEEE prize paper awards, and holds 26 patents. An IEEE Life Fellow, Lorenz received his BS, MS, and PhD from the University of Wisconsin-Madison and an MBA from the University of Rochester in Rochester, N.Y.

Thomas Jahns

Thomas M. Jahns joined the faculty at UW-Madison in 1998 as Grainger Professor of Power Electronics and Electric Machines in the Department of Electrical and Computer Engineering. He is a co-director of WEMPEC and the Wisconsin Power Electronics Research Center (WisPERC). Prior to coming to UW-Madison, Jahns worked for 15 years in GE Corporate Research and Development (now GE Global Research Center) in Niskayuna, N.Y., where he pioneered the development of high-performance interior PM machines and drives in a variety of research and management positions.

From 1996 to 1998, he conducted a research sabbatical at MIT, working on advanced automotive electrical systems. An IEEE Fellow, Jahns received his BS, MS, and PhD ('78) degrees from MIT, all in electrical engineering.

Giri Venkataramanan has been a faculty member at UW–Madison since 1999 where he has played a leading role in expanding and modernizing the laboratory infrastructure, while continuing to direct research in various areas of power conversion. He has been actively conducting research in the areas of power converter topologies, microgrids, wind power systems, grid interface for electric vehicles and utility scale power electronic systems. Prior to this, Venkataramanan spent seven years at Montana State University–Bozeman where he taught electrical engineering, developed several courses, and designed and commissioned power electronics, electric machines and drives lab.

Giri Venkataramanan

Venkataramanan studied electrical engineering at the Government College of Technology, Coimbatore, India, and received his BS from the University of Madras, India. Subsequently, He moved to the United States to continue his studies and obtained his MS and PhD from the California Institute of Technology and UW-Madison, respectively.

Bulent Sarlioglu joined UW-Madison as an assistant professor in 2011. Sarlioglu's interests include electric machines and power electronics. Current research includes novel flux switching permanent magnet machines and characterization and control of internal permanent magnet machines. His research team also focuses on design and optimization of high-speed machines.

In the power electronics area, his research team exploits the wide bandgap devices for use in power electronic converters and addresses many new challenges including EMI/EMC and gate-drive design. His research is currently funded by NSF, DOE and industry. Most recently, he received the best paper award at the 2015 IEEE ITEC conference and the best presentation recognition at the 2014 IEEE IECON conference.

Bulent Sarlioglu

Sarlioglu holds a PhD from the University of Wisconsin–Madison, an MS degree from the University of Missouri–Columbia, and a BS degree from Istanbul Technical University, all in electrical engineering. His research advisors were Thomas Lipo for PhD and Richard Hoft for MS.

Daniel C. Ludois is an assistant professor in the Department of Electrical and Computer Engineering. As a WEMPEC faculty member, Ludois's research focus has been on broadening the horizons of capacitive coupling via new dielectric materials and high-frequency power electronics. Applications include compact wireless power transfer for mobile and rotating equipment, brushless electric machine bearing current mitigation, electrostatic (e-field) machinery, and dual energy cores for integrated inductor-capacitors.

Daniel Ludois

Ludois has a PhD in applied physics from UW-Madison. While he was a student at UW-Madison, he won the Climate Leadership Challenge Grand Prize, IEEE President's Change the World Competition Outstanding Student Humanitarian Award, UW Engineering Expo, Burrill Business Plan among others garnering more than $135,000 and research incubator space to advance his ideas.

After graduation in 2011, Ludois and his partners used the winnings to cofound Madison start-up C-Motive Technologies, a company that focuses on electrostatically coupled (capacitive) power conversion solutions, mainly for machines. In 2012, Ludois completed the Weinert Applied Ventures in Entrepreneurship (WAVE) certificate within the UW MBA program, received a WARF Innovation Award for his electrostatic machinery patent, and C-Motive placed second in the Wisconsin Governor's Business Plan Contest.

In 2013, Ludois returned to UW-Madison as an assistant professor in the ECE department and WEMPEC with an affiliate appointment in the Engineering Physics Department. Since returning to UW, he holds an advisory role with C-Motive as chief science officer, with day-to-day running of the company in the hands of his cofounder and full-time engineering team.

For more information about WEMPEC, see "35 Years of Collaboration and Innovation 1981-2016" or visit www.wempec.wisc.edu. For more information about UW-Madison Engineering Professional Development, visit https://epd.wisc.edu/.

About The Author

Jim Sember has worked in the power electronics and power systems arena for more than 35 years. Jim has been associated with WEMPEC for the majority of his career as a sponsor. In 2013, he joined WEMPEC as its first executive director, while continuing to remain active with battery energy storage with a focus on lithium-ion batteries and systems. Power electronics is an intriguing and challenging combination of circuit design, power systems, machine design, machine control, analog and digital electronics, digital signal processing, and real-time embedded system control. Jim has done engineering work in all of these areas. He holds nine U.S. patents.

After obtaining his BSEE from Cornell University, he spent 15 years working on ac drive development engineering and engineering management. Jim gained extensive experience with controls and power electronics development and held an engineering leadership position in a multi-national and cross-cultural product development environment. Subsequently, he led product development for

generators, automatic transfer switches, and generator paralleling switchgear. He obtained an executive MBA in 2002, after which he led a business division supplying medium-voltage UPS, multi-megawatt-scale grid-connected energy storage, and power electronics for reactive power compensation. Jim grew the business at a compound annual growth rate of 27% over five years and achieved profitability. He also developed many state-of-the-art applications for grid-connected energy storage with a variety of battery energy storage technologies.