Aalborg University Fosters Multi-Disciplinary Approach To Research In Efficient And Reliable Power Electronics

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Power electronics is one of the strategic areas of study at Aalborg University and the work being conducted in this area is meant to produce new knowledge and candidates for the surrounding society nationally and internationally. It is one of the six research and education sections within the university's Department of Energy Technology. This department has a unique academic combination, since competences in electrical, thermal, fluid power and mechanical energy are placed within the same unit, working collaboratively in the field of power electronics and its applications.

This multi-disciplinary approach benefits a number of research programs as shown in Fig. 1. These programs focus on renewable energy, efficient energy consumption and distribution, conversion technologies and control of energy. Efficient and Reliable Power Electronics is the core power electronics program, together with three programs on Wind Turbine Systems, Photovoltaic Systems and Microgrids, and Automotive and Industrial Drives, where the application of power electronics is intensive. Five other programs are also heavily involved with power electronics activities as shown in the figure.

There are currently seven full-time full professors, as well as associate and assistant professors, in the area of power electronics and its intensive applications, including three IEEE Fellows and two IET Fellows. They are Professors Frede Blaabjerg, Stig Munk-Nielsen, Remus Teodorescu, Zhe Chen, Josep M. Guerrero, Poh Chiang Loh, and Francesco Iannuzzo. In addition to the team, Prof. Philip Kjaer is a part-time professor in medium power electronics and Prof. Eckart Hoene and Prof. Marco Liserre are adjunct professors from Fraunhofer IZM, Germany and Christian-Albrechts-Universität zu Kiel, Germany, respectively. About 60 PhD students, 20 research assistants and postdocs, and 20 visiting scholars and exchange PhD students are actively doing research in the areas of power electronics and its related applications.

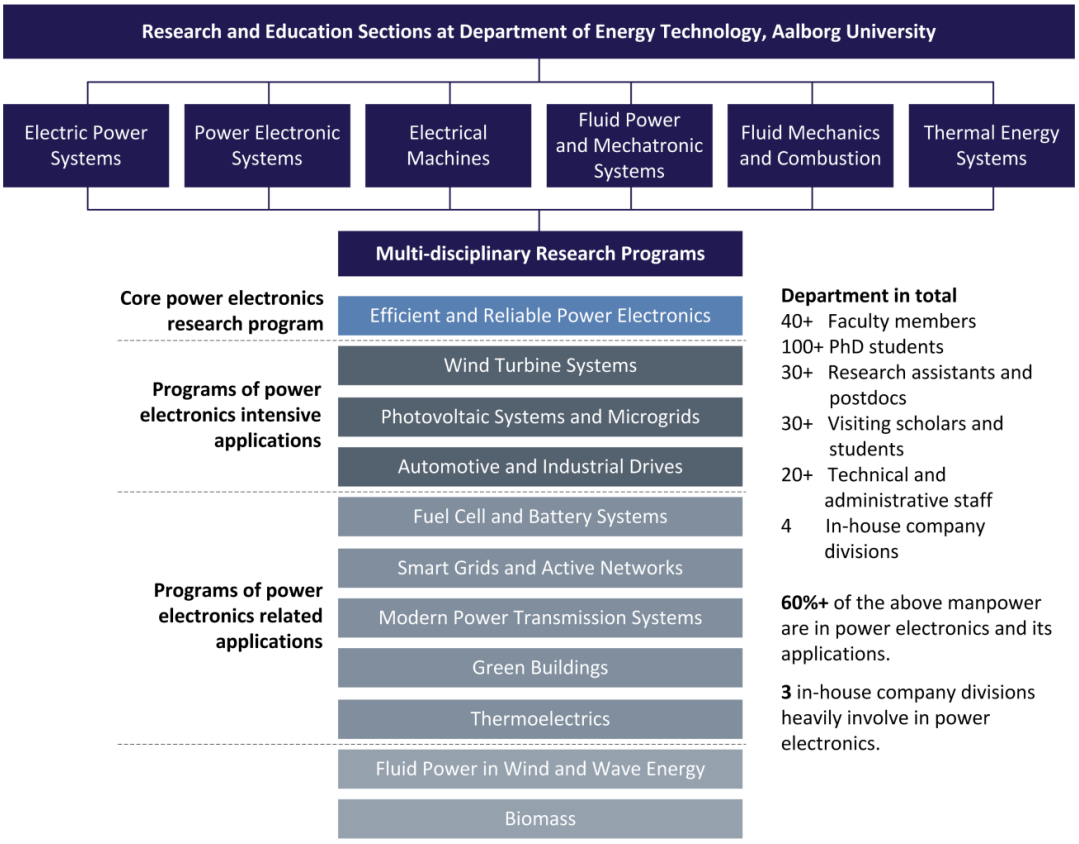


Fig. 1. Multi-disciplinary research programs in the Department of Energy Technology at Aalborg University, Denmark.

Close Industry Collaborations Based On Application-Oriented Research Projects

The power electronics research program at Aalborg University places great emphasis on national and international collaborations with peer universities and companies in industry. In particular, it has a comprehensive collaboration with the industry in both research projects and consulting. It is proud of the fact that a number of world-renowned companies (e.g., Vestas, Danfoss and KK Wind Solutions) have chosen to have in-house divisions at the Department, which contributes to ever closer collaborations. The research program has a long history of collaboration with companies.

In the 1990s, the power electronics research team was responsible for a Danfoss Professor Program from 1997-2000, supported by Danfoss Drives A/S and later also the Ministry of Education, Denmark. The main goal of this program was to attract more students to the discipline of power electronics and drives by offering a world-class curriculum and world-class professors. The research outcomes and graduates from the program have had long-lasting positive impact for both the research group and the company.

In the 2000s, a Vestas Power Program was initiated by Vestas Wind Systems and the power electronics team at Aalborg University, with the financial support of six million Euros from the company from 2008 to 2013. This research initiative has led to a range of breakthroughs that make it possible to manufacture turbines with greater capacity and improved efficiency and functionality, and to develop a crucial precondition for meeting the challenges of the future with regard to increased integration of wind power into electricity grids.

Since the 2010s, two strategic research centers, the Center of Reliable Power Electronics (CORPE) and Intelligent and Efficient Power Electronics (IEPE), have been established in close collaboration with Danfoss, Grundfos and KK Wind Solutions. The total budget allocated to their research is around 25 million Euros for five years of activities, supported by the Danish Council for Strategic Research, the Danish National Advanced Technology Foundation, the four participating companies, the Obel Foundation and Aalborg University.

CORPE focuses on more fundamental research in design for reliability of power electronics. It aims to obtain high-reliability power electronic systems for use in all fields of electrical applications used both in design and operation. In the targeted applications, the main drivers are lower development cost, manufacturing cost, efficiency, reliability, predictability, and lower operational and maintenance costs during the application's lifetime.

IEPE supports each company's research and development of its own products, and initiates future new products by developing demonstrators in wind power converters and adjustable speed drives with the technology integration of efficient components and design, innovative interconnection and intelligent control and monitoring.

Fig. 2 shows the university-industry collaboration platform built on these two research centers. It bridges the fundamental technologies and final system solutions through innovative products, which in the end will enable companies to achieve a stronger global market position.

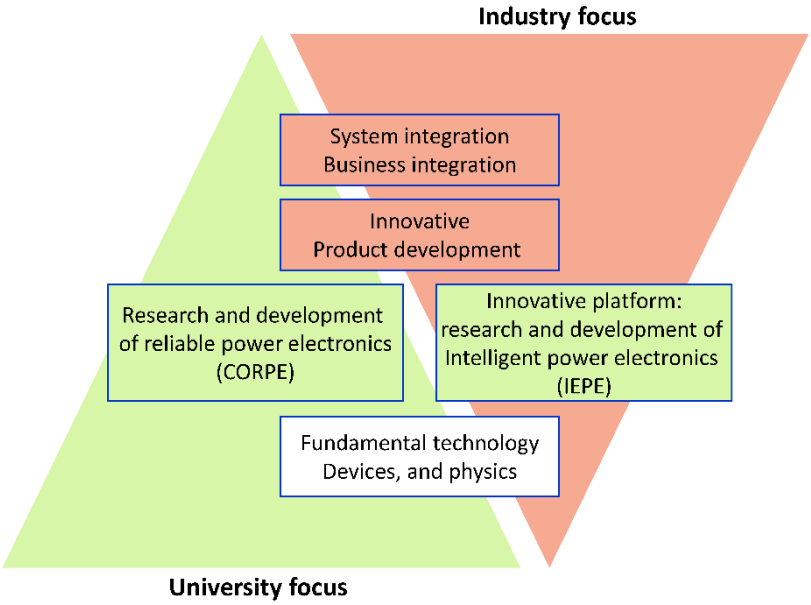


Fig. 2. An example of the university-industry collaboration platform within the Efficient and Reliable Power Electronics program at Aalborg University (CORPE-Center of Reliable Power Electronics; IEPE—Intelligent and Efficient Power Electronics.)

To provide a better overview of the application-oriented research, a list of selected projects in the Efficient and Reliable Power Electronics program is provided as follows:

- HARMONY—Harmonic identification, mitigation and control in power electronics-based power systems (2013-2018, European Research Council Advanced Grant)
- Intelligent and Efficient Power Electronics (IEPE) (2012-2017, Danish National Advanced Technology Foundation)
- Center of Reliable Power Electronics (CORPE) (2011-2016, Danish Council for Strategic Research)
- Reliability of capacitors in power electronic systems (ReliaCap) (2013-2014, Danish Council for Independent Research)
- Highly efficient, low-cost energy generation and actuation using disruptive DEAP technology (2011-2015, Danish National Advanced Technology Foundation)
- Semiconductor Materials for Power Electronics (SEMPEL) (2014-2019, Danish Council for Strategic Research)
- Power-2-Electrolysers (2013-2016, EUDP)
- DSO challenges from introduction of heat pumps (2014-2016, Energinet)
- NHTD—New Harmonic Reduction Techniques for Motor Drives (2014-2017, Højteknologifonden)
- HEART—The Highly Efficient And Reliable smart Transformer, a new Heart for the Electric Distribution System (2014-2019, European Research Consolidator Grant, involved partly in the project with PI of Prof. Marco Liserre)

A Unique Problem-Based Learning (PBL) Education Model And PhD/Industrial Course Portfolio

The power electronics program also strives for the highest excellence in education to produce exceptional candidates who are highly educated in power electronics in a multi-disciplinary way. The education of undergraduate and master students is based on a unique problem-based learning (PBL) model implemented at Aalborg University in the 1970s. Each semester, students work closely with a group of fellow students on a real life, problem-based project assignment, which counts for 50% of the credit hours with the other 50% of credit hours coming from courses. The group work adds an academic and social dimension to the educational program and at the same time, it equips students for a labor market where skills in cooperation are highly valued.

For PhD education and also for the benefit of industrial companies seeking state-of-the-art research results, a number of PhD/industrial courses are established in the areas of power electronics and its intensive applications. The courses are open to PhD students from both Aalborg University and other universities all over the world, as well as engineers and scientists working in industry. Each year, there are regularly 10+ PhD courses in the area of power electronics. Some examples of the PhD courses to be given in 2015 are:

- Reliability in power electronics systems (three days, the very first course anywhere on this topic, given since 2013)
- Reliability, availability, maintainability and safety (three days)
- Modern power semiconductors and their packaging (three days)
- Advanced topics in pulse width modulation for voltage source converters (two days)
- Harmonics in power electronics and power systems (three days)
- Introduction to wind power—generation and integration (four days)
- Recent progress in sensorless control of ac motor drives (two and a half days)

- Photovoltaic power systems (PVPS) (four days)
- AC microgrids (two days)
- DC microgrids (three days)
- Power qualities in microgrids (two days)
- Storage systems based on Li-ion batteries for grid support and automotive applications (three days)

State-of-the-Art Facilities

Different power electronics-related laboratories with world-class facilities have been built up in the last 20 years at Aalborg University. Currently, the department is upgrading its facilities at a cost of more than 20 million Euros. A list of laboratories in power electronics and its applications is given below.

- Advanced Electric Machine and Drive Laboratory
- DC Microgrids Laboratory
- Flexible Drive Systems Laboratory (FDSL)
- Fuel Cell and Battery Systems Laboratory
- Grid Integration Laboratory (GIL)
- Medium Voltage Laboratory (up to 20-kV /2-MVA testing capability, as shown in Fig. 3a)
- Intelligent Microgrid Laboratory (iMGL) (as shown in Fig. 3g)
- Photovoltaic Systems Laboratory (PVLAB)
- RTDS Laboratory
- Smart Energy Systems Laboratory
- Vehicle and HeavyLab
- Reliability Testing Laboratory

In the last four years, intensive reliability-related activities have been going on in CORPE and IEPE research centers. To facilitate the research, some state-of-the-art experimental systems and testing platforms have been added. Figs. 3b through 3f show photos of some of these platforms, which are used for component-level testing of high-power modules (i.e. Fig. 3c and 3e) and capacitors (i.e. Fig. 3d), and system-level testing of high-power stacks (i.e. Fig. 3b.)

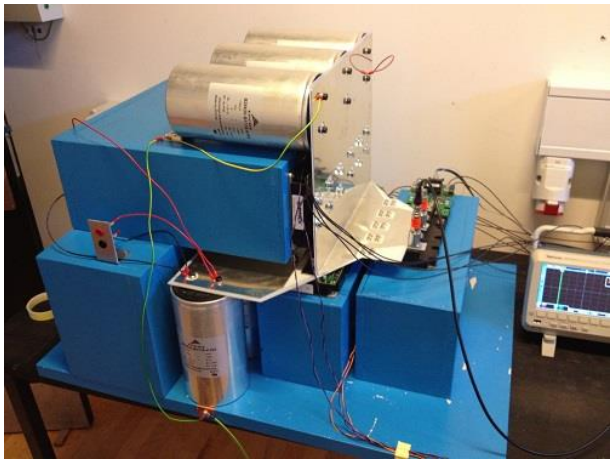
Moreover, a power electronics reliability test center is currently being built up to be able to test from single device up to system level with different reliability stressors like temperature, humidity, vibration, moisture, and grid interfacing. The testing center aims to integrate the following facilities over a five-year period:

- Packaging facilities to make power modules and test new technologies for parallel power chips
- Testing systems for testing for most stressors like temperature, humidity and vibration
- Upgrade of renewable test systems (PV, fuel cell, and wind turbine hardware simulators) in order to better simulate different mission profiles in the systems)
- Facilities for fabrication and test of semiconductor device elements
- Medium-voltage and medium-power electronics test facilities to test the reliability of real industrial power converters
- Small grid facilities for harmonic grid stability

- A high-frequency EMC test facility, both conducted and radiated noise

(a) The Medium Voltage Laboratory for testing of next-generation medium-voltage power converters up to 20 kV/2 MVA in a safe and controlled environment.

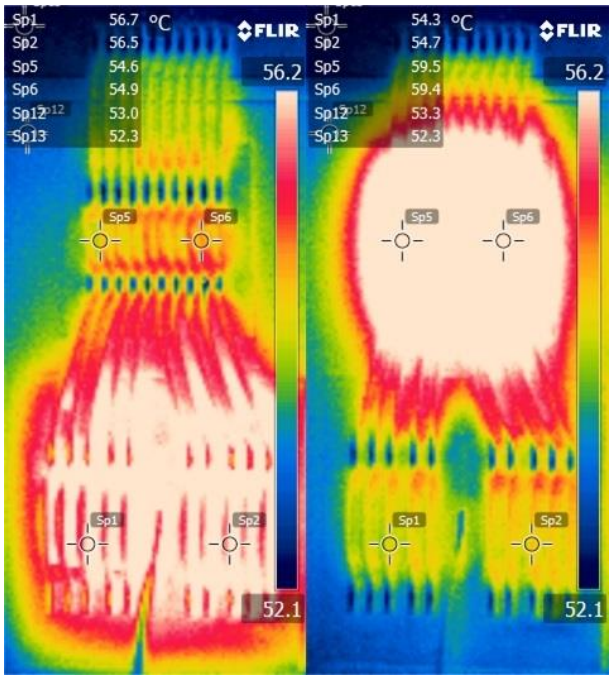
(b) A 1-MW power stack test platform.



(c) A non-destructive short circuit testing system for high-power IGBT modules (up to 6-kA current level.)

(d) A capacitor testing system (up to 2-kV voltage and 100-A ripple current under climatic conditions).

(e) A power cycling testing setup under open module test with infrared camera for direct junction temperature measurement.



(f) Infrared measurement of open module in which an IGBT is conducting (left) and a diode is conducting (right).

(g) The Intelligent Microgrid Laboratory in the Department of Energy Technology.

Fig. 3. Selected lab facilities in power electronics at the Department of Energy Technology, Aalborg University.

For Further Information

For further information about the Efficient and Reliable Power Electronics program at Aalborg University, please visit the websites at the links below:

- CORPE, www.corpe.et.aau.dk/
- IEPE, www.iepe.et.aau.dk/
- HARMONY, www.harmony.et.aau.dk/
- SEMPEL, www.sempel.aau.dk/
- ReliaCap, www.corpe.et.aau.dk/cap and
- Project and Publication Portfolios of Power Electronic Systems Section.

About The Authors

Huai Wang (S'07 - M'12) is currently an assistant professor with the Center of Reliable Power Electronics (CORPE) in the Department of Energy Technology, Aalborg University, Denmark. His current research interests include the reliability of dc-link and ac filter capacitors, reliability of power electronic systems, multi-objective life-cycle performance optimization of power electronic systems, high-voltage dc-dc power converters, time-domain control of converters, and passive components reduction technologies, and their emerging power electronics applications. He has contributed more than 25 journal papers and filed four patents in the above areas.

Wang received his PhD degree from the City University of Hong Kong, Hong Kong, in 2012, and a B. E. Degree from Huazhong University of Science and Technology, China, in 2007. He was a visiting scientist with the ETH Zurich, Zurich, Switzerland, from August to September, 2014 and with the Massachusetts Institute of Technology (MIT), Cambridge, Mass., U.S.A., from September to November, 2013. He was with the ABB Corporate Research Center, Baden, Switzerland, in 2009.

Wang is a recipient of six paper awards and project awards from industry, IEEE, and the Hong Kong Institution of Engineers. He also received the Green Talents Award from the German Federal Ministry of Education and Research in 2014. He serves as the guest associate editor of the IEEE Transactions on Power Electronics and Guest Editorial Board of Microelectronics Reliability on special issue topics relevant to reliability in power electronics.

Frede Blaabjerg (S'86–M'88–SM'97–F'03) is currently a professor with the Department of Energy Technology and the director of the Center of Reliable Power Electronics (CORPE), Aalborg University, Denmark. He received the Ph.D. degree from Aalborg University, Aalborg, Denmark, in 1995.

From 1987 to 1988, Blaabjerg was with ABB-Scandia, Randers, Denmark. In 1992, he joined Aalborg University, where he became an assistant professor and subsequently an associate professor in 1996, and a full professor of power electronics and drives in 1998. He has been a part-time research leader with the Research Center Risoe in wind turbines. From 2006 to 2010, Blaabjerg was the dean of the faculty of Engineering, Science, and Medicine and became a visiting professor with Zhejiang University, Hangzhou, China, in 2009. His current research interests include power electronics and its applications such as in wind turbines, PV systems, reliability, harmonics, and adjustable-speed drives.

Blaabjerg received the 1995 Angelos Award for his contributions to modulation technique and the Annual Teacher Prize at Aalborg University. In 1998, he received the Outstanding Young Power Electronics Engineer Award from the IEEE Power Electronics Society. He has received 15 IEEE Prize Paper Awards and another Prize Paper Award at PELINCEC Poland in 2005. He received the IEEE PELS Distinguished Service Award in 2009, the EPE-PEMC Council Award in 2010 and the IEEE William E. Newell Power Electronics Award 2014. He has also received a number of major research awards in Denmark, including the largest individual Danish research award—Villum Kann Rasmussen Annual Award for Technical and Scientific Research in 2014. He was the editor-in-chief of the IEEE Transactions On Power Electronics from 2006 to 2012. He was a distinguished lecturer of the IEEE Power Electronics Society from 2005 to 2007 and of the IEEE Industry Applications Society from 2010 to 2011. He was the chairman of EPE in 2007 and PEDG, Aalborg, in 2012. Blaabjerg was nominated in 2014 by Thomson Reuters to be among the 250 most-cited researchers in engineering in the world.