Advances in Intelligent Solid-State DC Substations for Future Interconnected DC Grids

Abstract

The change of the electrical supply system to more environmental-friendly energy sources require the development of a new grid infrastructure. Next to the increasing penetration of large-scale renewable energy sources such as offshore wind farms, the change of consumer behavior in the distribution grids from consumer into producer due to the installation of decentralized generations will result in a bottleneck in the distribution grids. Local or regional balancing between loads and generations is found to be a cost effective solution for the future electrical distribution grids, which can be realized with direct current (DC) technology more efficiently and flexibly.

The tutorial will focus on the latest advances and best practices of intelligent solid-state DC substations for future flexible DC grids, which covers a selection of key enabling technologies from converter topologies, optimized control, hardware-in-the-loop simulation techniques, to the development of megawatt medium-voltage demonstrators. The presented advances are collected from a number of recent and ongoing research projects in the Institute for Power Generation and Storage Systems, which includes the Flexible Electrical Networks (FEN) Research Campus funded by the German Federal Ministry of Education and Research.

Following a general introduction and a technology roadmap of flexible DC grids, the tutorial will elaborate the technologies of bidirectional isolated DC-DC converters for intelligent solid-state DC substations for interconnection of DC grids at different voltage levels. It will start with dual-active bridge (DAB) based DC-DC converter topologies for LVDC-MVDC applications, where advanced modulation and control of DAB converters will also be discussed. This includes the instantaneous flux and current control method as well as the advanced black start-up and fault ride-through strategies for a highly dynamic and robust operation under both normal and fault conditions.

Then, the development and control of an IGCT-based 5 kV, 5 MW DAB DC-DC converter will be presented. This includes the employment of the modified auxiliary-resonant commutated-pole circuit to ensure zero-voltage soft-switching of IGCT devices with snubber capacitors, and a novel anti-saturation detection and compensation methods for medium-frequency transformers.

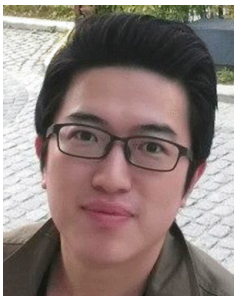
Considering the numerous benefits of the bipolar DC distribution, the tutorial will also present advances in power conversion technologies for bipolar LVDC and MVDC distribution systems. The concept of topological integration is adopted and demonstrated for state-of-the-art AC-DC and DC-DC converters such as MMC and DAB, which enables a full bipolar operation capability on the DC side with a minimum count of additional components.

The last section of the tutorial will deal with the real-time simulation and hardware-in-the-loop test for intelligent DC substations. Different modeling techniques will be discussed and compared with best practices in the real-time environment. A successful example of using the rapid-control-prototyping tool to develop a high-power medium-voltage modular DC-DC converter will be presented as well as the lessons learnt.

Instructor Biography

Rik W. De Doncker (F'01) received the Ph.D. degree in electrical engineering from the Katholieke Universiteit Leuven, Leuven, Belgium, in 1986. In 1987, he was appointed as a Visiting Associate Professor at the University of Wisconsin, Madison. After a short stay as an Adjunct Researcher with Interuniversity Microelectronics Centre, Leuven, he joined, in 1989, the Corporate Research and Development Center, General Electric Company, Schenectady, NY. In 1994, he joined Silicon Power Corporation, a former division of General Electric Inc., as the Vice President of Technology. In 1996, he became a Professor at RWTH Aachen University, Aachen, Germany, where he currently leads the Institute for Power Electronics and Electrical Drives. Since 2006, he has been the Director of the E.ON Energy Research Center, RWTH Aachen University. Dr. De Doncker was the President of the IEEE Power Electronics Society (PELS) in 2005 and 2006. He was the recipient of the IEEE IAS Outstanding Achievement Award in 2002, the IEEE PES Nari Hingorani Custom Power Award in 2008, the IEEE William E. Newell Power Electronics Award in 2013, and the IEEE Medal in Power Engineering in 2020. In 2010, he received an honorary PhD from TU Riga, Latvia.

Jingxin Hu (M'19) received the B.S. degree from Northeastern University, Shenyang, China, in 2010, and the M.Sc. degree and Dr.-Ing. degree both with the highest distinction (summa cum laude) from RWTH Aachen University, Aachen, Germany, in 2013 and 2019, all in electrical engineering. During April 2012 – October 2012, he was an intern research engineer at the ABB Corporate Research Center (ABB-CRC), Baden-Daettwil, Switzerland. From 2013 to 2014, he worked at the High Power Electronics Laboratory at General Electric Global Research Center (GE-GRC), Munich, Germany. Since October 2014, he joined the Institute for Power Generation and Storage System, E.ON Energy Research Center, RWTH Aachen University, Aachen, Germany, where he is currently working as a Senior Scientist to lead research projects. Dr. Hu was the recipient of Second Prize Paper Award of IEEE IPEC (ECCE Asia) in 2018 and the STAWAG Dissertation Prize in 2019. His main research interests include solid-state transformers, renewable power generation and dc microgrids. He was a lecture instructor in 2019 Asia PhD School on Advanced Power Electronics, and a tutorial instructor in IEEE IPEMC 2020 ECCE-Asia and eGrid 2020.



Shenghui Cui (M'19) received the B.S. degree from Tsinghua University, Beijing, China, in 2012, and the M.S. degree from Seoul National University, Seoul, South Korea, in 2014, and the Dr.-Ing. degree with the highest distinction (summa cum laude) from RWTH Aachen University, Aachen, Germany, in 2019, all in electrical engineering. Since March 2015, he joined the Institute for Power Generation and Storage System, E.ON Energy Research Center, RWTH Aachen University, Aachen, Germany, as a research associate, where he is currently working as a senior scientist. Dr. Cui was the recipient of the Second Place Prize Paper Award of the IEEE Transactions on Power Electronics, in 2018, the Second Prize Paper Award of IEEE IPEC (ECCE Asia), in 2018, and the Outstanding Presentation Award of IEEE APEC, in 2014. He was a tutorial instructor in IEEE IPEMC 2020 ECCE-Asia and eGrid 2020.

Johannes Voss (M'19) studied electrical engineering from 2006-2011 at the RWTH Aachen University and joined the Institute for Power Generation and Storage Systems (PGS), E.ON Energy Research Center, RWTH Aachen University, Aachen, Germany, in 2012. In 2011, he received the Diploma degree in electrical engineering from RWTH Aachen University. In 2019, he received the Dr.-Ing. degree with the highest distinction (summa cum laude) from RWTH Aachen University. In 2015, he joined for 8 months the NSF GRid-connected Advanced Power Electronics Systems (GRAPES) at the University of Arkansas as an exchange student. In 2011 he received a ABB award for an excellent Diploma theses and in 2014 he was honored with an Excellent Paper Award at the IEEE International Power Electronics and Application Conference and Exposition. In 2019, he received the STAWAG Dissertation Prize. Dr. Voss is currently Chief Engineer in the Institute for Power Generation and Storage Systems (PGS) at RWTH Aachen University. He was a tutorial instructor in IEEE IPEMC 2020 ECCE-Asia and eGrid 2020.

Philipp Joebges (S'16) completed his Bachelor of Electrical Engineering from RWTH Aachen University, Aachen, Germany, in 2013. He received his M.Sc in Electrical Power Engineering from RWTH Aachen University, Germany, in 2016. Since April 2016, he has been working towards his doctoral degree at the Institute of Power Generation and Storage Systems (PGS), E.ON Energy Research Center, RWTH Aachen University, Aachen, Germany. His research interests include medium-voltage high-power dc-dc converters with focus on control and real-time simulation for control evaluation. Mr. Joebges is currently Chief Engineer in the Institute for Power Generation and Storage Systems (PGS) at RWTH Aachen University. He was a tutorial instructor in IEEE eGrid 2020.