IEEE ENERGY CONVERSION CONGRESS & EXPO Detroit, Michigan, USA Oct. 9-13

Tutorial Title:

Design and Control of Solid-State DC Transformers for DC Transmission and Distribution Grids

Organizer:

Rik W. De Doncker, RWTH Aachen University, dedoncker@rwth-aachen.de

Jingxin Hu, RWTH Aachen University, jhu@eonerc.rwth-aachen.de

Shenghui Cui, Seoul National University, cuish@snu.ac.kr

Subhashish Bhattacharya, North Carolina State University, sbhatta4@ncsu.edu

Abstract:

The transition from a predominantly fossil fuel-based power generation towards renewable power sources, predominantly wind turbines and photovoltaic systems, inevitably leads towards an energy supply system that greatly depends on power electronics to feed the energy in the electrical grid. As all power electronic driven systems are intrinsically DC sources or loads, DC transmission and distribution systems become evident, not only because it is more efficient and cost effective, but also increases the ampacity of cables. The development and commercialization of medium-voltage, multi-megawatt DC-DC converters, also called solid-state DC transformers, is a key enabler to realize flexible and interconnected DC grids. Compared to AC transformers, solid-state DC transformers not only need to transform voltage and control power flow, but also need to offer similar efficiencies (up to 99%) at high switching frequencies, provide the same insulation levels and limit fault currents, that is, offer fault-ride-through capabilities.

In this tutorial, we introduce and describe the latest advances and best practices of galvanically isolated bidirectional DC-DC converters for solid-state DC transformers. It covers a wide selection of key enabling technologies from converter topologies, optimized control, to the design of highly efficient megawatt medium-voltage DC-DC converters based on emerging MV SiC devices.

Following a general introduction and a technology roadmap of DC transmission and distribution grids, the tutorial will elaborate the most promising candidates of bidirectional isolated DC-DC converters for solid-state DC transformers. It will start with a comprehensive comparison between single-phase and three-phase dual-active bridge (DAB) converters for LV and MV DC applications, where the pros. and cons. are clearly underlined. Further, advanced modulation and control of the DAB converter will be presented to overcome two important challenges. First, the trajectory modeling approach and the instantaneous flux and current method are systematically presented to explain and resolve the transformer saturation issue under dynamic conditions. Second, the asymmetrical duty-cycle control method is introduced to enable ultra wide voltage operation of the DAB converter with soft-switching and the fault ride-through capability.

Considering the numerous benefits of the bipolar DC distribution, the tutorial will also present advancements in power conversion technologies for bipolar LVDC and MVDC distribution systems. Several novel converter topologies of DC-DC converters for LVDC and MVDC applications will be addressed, which are inherently capable of bipolar operation. These

topologies are based on the concept of topological integration of voltage balancers, which are required individually for maintaining voltage balance of bipolar DC grids. With such integration technique, bipolar operation capability of dc-link can be obtained with minimum costs and conversion losses.

The last section of the tutorial will focus on the understanding of MV SiC devices (15 kV IGBTs versus 15 kV MOSFETs; 10 kV, 6.5 kV, 3.3 kV MOSFETs) and their applications for the MVDC grid. MVDC grids will be explored with demonstrated and pilot application examples of SST (Solid State Transformer). The roadmap of MV SiC power devices in terms of cost targets, module packaging, and reliability qualification of MV SiC devices will be addressed. Advances in medium frequency magnetics for wide band-gap (WBG) devices based power converters and especially for high power converters, with latest advances in magnetic material qualification and characterization will be included.

Bio:

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. From April 2012 to 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 Best Dissertation Prize of RWTH Aachen University in 2019. His main research interests include solid-state transformers, renewable power generation and dc distribution. He was a tutorial instructor in IEEE IPEMC 2020 ECCE-Asia, eGrid 2020 and ECCE 2021.

Shenghui Cui (M’19) received the B.S. degree from Tsinghua University, Beijing, China, in 2012, 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 September 2021, Dr. Cui is with Department of Electrical and Computer Engineering, Seoul National University, Seoul, South Korea as an assistant professor. From March 2015 to May 2021, he has been with the Institute for Power Generation and Storage Systems, E.ON Energy Research Center, RWTH Aachen University, Aachen, Germany, where he worked as research associate and later on senior scientist. His research interests include interaction of power systems and power converters, power converters in ac/dc utility applications, and applications of wide-band gap power devices. Dr. Cui was the recipient of the STAWAG Best Dissertation Prize from Faculty of Electrical Engineering and Information Technology, RWTH Aachen University in 2019, 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 the IEEE Applied Power Electronics Conference in 2014.

Subhashish Bhattacharya (F’22) received his B.E. from IIT Roorkee, India, M.E. from IISc, India, and Ph.D. from the University of Wisconsin-Madison, all in electrical engineering. He worked in the FACTS and Power Quality group at Westinghouse, which later became part of Siemens Power, from 1998 to 2005. He joined the Department of ECE at NCSU in August 2005, where he is Duke Energy Distinguished Professor and a founding faculty member of NSF ERC FREEDM Systems Center, Advanced Transportation Energy Center [ATEC] and the US DOE initiative on WBG based Manufacturing Innovation Institute – PowerAmerica - at NCSU. His research interests are Solid-State Transformers, Integration of renewable energy resources, MV power converters enabled by HV SiC devices, FACTS, Utility applications of power electronics and power quality issues; DC Microgrids, high-frequency magnetics, active filters, and application of new power semiconductor devices such as SiC and GaN for converter topologies. His research is funded by several industries, NSF, DoE, ARPA-E, US Navy, ONR, NASA. He has over 600 publications and 10 patents with several pending patent applications.