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Tutorial Title:

Solid-State Transformers – Fundamentals, Industrial Applications, Challenges

Organizer:

Johann W. Kolar, ETH, Zurich, kolar@lem.ee.ethz.ch

Jonas Huber, ETH, Zurich, huber@lem.ee.ethz.ch

Abstract:

Solid-State Transformers (SSTs) provide isolation and power flow control between medium-voltage (MV) and low-voltage (LV) AC or DC systems and are formed by input- and output-side power electronic converters, which are linked through a medium-frequency transformer (MFT). Accordingly, SSTs are expected to show high power density and offer full controllability of the terminal currents and/or the transferred power and, in case of AC voltages, the reactive power at the input and the output side. Therefore, SSTs are considered for replacing bulky low-frequency transformers (LFTs) of high-power EV charging stations, datacenters, or traction vehicles, and are in general seen as key elements of future smart microgrids. However, the connection to MV and the thus necessary overvoltage protection, the high overall complexity, the relatively high realization costs, and the potentially lower efficiency in case of AC-AC conversion are still major challenges for practical applications.

The tutorial starts with a brief review of transformer scaling laws and then identifies the motivation, requirements, and challenges associated with SST applications. Next, we discuss the most important conceptual and design aspects of SSTs such as single-cell vs. multi-cell topologies using Si or SiC semiconductors, isolated front-end vs. isolated back-end converter architectures, reliability of multi-cell converters, MFT realization, and protection concepts. In this context, we also present latest results of research at ETH Zurich, which currently targets advanced air-core medium-frequency transformer designs considering close similarities to high-power wireless power transfer systems.

The second half of the tutorial then provides comprehensive application-oriented evaluations of industrial SST demonstrator systems in their application context, whereby a focus lies on emerging applications such as MVAC-LVDC interfaces for future datacenters or high-power EV charging stations. For each example, we fairly assess advantages and drawbacks compared to alternative solutions (e.g., based on LFTs and high-efficiency LV SiC converters), regarding relevant performance metrics such as power conversion efficiency, power density, cost, complexity, robustness, and reliability/availability.

We close the tutorial by distilling these comparative evaluation results into the identification of the most promising future SST applications and concepts but also of the remaining key challenges such as robustness, protection, and cost, which need to be addressed in the course of future research for SST technology to enable a breakthrough.

The tutorial is tailored to serve the interests of a broad audience with academic or industrial backgrounds.

Bio:

Johann W. Kolar (M'89–F'10) is a Fellow of the IEEE, an International Member of the US NAE and a Full Professor and Head of the Power Electronic Systems Laboratory at the Swiss Federal Institute of Technology (ETH) Zurich. He has proposed numerous novel converter concepts incl. the Vienna Rectifier, has spearheaded the development of x-million rpm motors and has pioneered fully automated multi-objective power electronics design procedures. He has graduated 80+ Ph.D. students, has published 900+ research papers, 4 book chapters, and has filed 200+ patents. He has served as IEEE PELS Distinguished Lecturer from 2012 - 2016. He has received 40+ IEEE Transactions and Conference Prize Paper Awards, the 2014 IEEE Power Electronics Society R. David Middlebrook Achievement Award, the 2016 IEEE PEMC Council Award, the 2016 IEEE William E. Newell Power Electronics Award, the 2021 EPE Outstanding Achievement Award and 2 ETH Zurich Golden Owl Awards for excellence in teaching. The focus of his current research is on ultra-compact/efficient WBG PFC rectifier and inverter systems, ultra-high BW switch-mode power amplifiers, multi-port converters, Solid-State Transformers, multi-functional actuators, ultra-high speed / motor-integrated drives, bearingless motors, ANN-based multi-objective design optimization and sustainable systems.

Jonas Huber (S'11–M'16) received the MSc (with distinction) degree and the PhD degree from the Swiss Federal Institute of Technology (ETH) Zurich, Switzerland, in 2012 and 2016, respectively. Since 2012, he has been with the Power Electronic Systems Laboratory, ETH Zurich and became a Post-Doctoral Fellow, focusing his research interests on the field of solid-state transformers, specifically on the analysis, optimization, and design of high-power multi-cell converter systems, reliability considerations, control strategies, and applicability aspects. From 2017, he was with ABB Switzerland Ltd. as an R&D Engineer designing high-power DC-DC converter systems for traction applications, and later with a Swiss utility company as a Business Development Manager. He then returned to the Power Electronic Systems Laboratory as a Senior Researcher in 2020, extending his research scope to all types of WBG-semiconductor-based ultra-compact, ultra-efficient or highly dynamic converter systems. Since 2015, he has co-presented 9 tutorials at major IEEE conferences (e.g., ECCE, APEC).