Tutorial 1: System level modelling and simulation of MVDC distribution grids featuring solid-state transformers

August 5th, 8:30-11:30 Lexington A Room

Abstract and outline:

The rapid development of solid-state transformers (SST) enables a future for microgrids that features the connection of various sources, loads, and storage elements to a common MVDC bus. The simulation of such systems presents various challenges due to growing complexity caused by the large amount of connected power converters and diversification of sources and loads. Quick benchmarking in booming MVDC areas requires simulation models that feature superior speed with a dynamic response that fits real hardware. Within this context and objective in mind, a simulation tool has been developed with system level average models of elementary SST cells for DC grids. The implemented models are built with controlled current/voltage sources which embody dynamic behaviors of real SST systems. They may be arranged in various modular configurations, and they feature a basic failure mechanism that allows bypassing failed cells to study their impact on the full power system.

This tutorial aims to provide both intuitive and practical understanding of the issues related to the control of MVDC grids featuring modular SSTs with various loads and storage elements. The implementation of dedicated control on the power converter side along with a careful identification of possible perturbations is illustrated via design and simulation examples supported by industrial experience and academic approach.

- DC grid basics: modeling, strength, disturbances, and standards
- Power converters: control basics, handling of DC systems
- Modeling of MVDC grids: system level model of an elementary SST cell and cells in parallel, dc bus and other elements
- Simulation of an example model of a typical MVDC grid for renewable systems: Python scripts for running the model

Instructor:

Daniel Siemaszko received the M.Sc. degree from EPFL, Lausanne, Switzerland in 2005 and the PhD degree at the Industrial Electronics Laboratory (EPFL-LEI) in 2009 under the supervision of Prof. Alfred Rufer. Following this, he worked as a postdoctoral researcher with Prof. Hans-Peter Nee at Royal Institute of Technology (KTH-EME), Stockholm. He later joined CERN, Geneva, Switzerland, as a fellow researcher working on the powering strategies of a future linear collider. He also worked on control of AFE with ABB MV-Drives, Switzerland. In 2014, he founded PESC-CH, a consultancy company in power electronics in Geneva, specialized in DC substation energy recovery and modular BESS solutions for the medium voltage range. He also undertook teaching power electronics at the University of Applied Sciences of Western Switzerland in Yverdon (HEIG-VD) and collaborated with Prof. Mauro Carpita. In 2020, he joined Hitachi Energy as a senior R&D engineer working on SST for MVDC and e-mobility.

Tutorial 2: Hybrid modular multilevel converters: a compact, efficient and cost-effective solution for medium-voltage applications

August 5th, 8:30-11:30 Lexington B Room

Abstract and outline:

Power-electronic converters face significant challenges in keeping up with ever-evolving demands for higher power density, wider operation range, and lower costs. The economies of scale and ease of repair further promote converters that are both modular and scalable. While no single converter for high/medium-voltage applications meets all criteria, modular multilevel converter (MMC) emerges as the frontrunner.

MMCs are developed using multiple smaller units known as submodules (SMs), constructed using fast-switching low-voltage semiconductors combined with energy storage components like capacitors. This allows for high modularity and scalability. Their operating range also makes them suitable for applications like high-voltage direct current (HVDC) transmission. However, the use of bulky capacitors contributes to lower power density compared to other voltage source converters (VSCs). Moreover, employment of more switches in MMCs compared to conventional two-level VSCs increases costs and losses. These challenges have hindered the adoption of MMCs within medium-voltage systems.

In response to these challenges, hybrid modular multilevel converters (HMMCs) have emerged as a viable solution. HMMCs replace a few SMs in MMCs with fewer medium-voltage switches reducing the number of components which, when coupled with intelligent control, also decreases costs and losses. This tutorial aims to delineate the application focus of state-of-the art topologies, showcasing their advantages and limitations. It will also delve into the modeling, control and fault-handling capability of HMMCs, demonstrating their technological readiness.

- Modular multilevel converters
- Topological development of HMMCs: alternate arm converter, HMMC-1/2/3, hybrid modular multilevel rectifier (HMMR)-1/3, flying capacitor hybrid multilevel converter
- Converter evaluation and applications spanning energy storage systems, electric-vehicle charging-stations, motor-drives, and datacenters
- Converter modeling, control, and fault-handling study example: HMMC-3

Lead instructor:

Jayesh K. Motwani received the Integrated Dual Degree (B.Tech. in electrical engineering and M.Tech. in power electronics) from the Department of Electrical Engineering, Indian Institute of Technology (B.H.U.), Varanasi, India, in 2020. He is currently working toward a Ph.D. degree in electrical engineering with the Center for Power Electronics Systems, Virginia Tech, Blacksburg, VA, USA. During 2018 and 2019, he was a Visiting Scholar with the Politecnico di Milano, Milan, Italy, and Duke University, Durham, NC, USA, where he worked on modular converters. His research interests include modeling large power-electronic systems, control of modular power converters, integration of renewable energy systems, and wide-bandgap semiconductor applications.

Other instructors:

Dong Dong received the B.S. degree from Tsinghua University, Beijing, China, in 2007, and the M.S. and Ph.D. degrees from Virginia Tech, Blacksburg, VA, USA, in 2009 and 2012, all in electrical engineering. From 2012 to 2018, he was with GE Global Research Center, Niskayuna, NY, USA, as an Electrical Engineer. At GE, he participated in and led multiple technology programs including MV/HV dc power distribution and power delivery, SiC high-frequency high-power conversion systems, solid-state transformers, and energy storage system. Since 2018, he has been with the Bradley Department of Electrical and Computer Engineering, Virginia Tech. He has authored or coauthored more than 45 referred journal publications and more than 100 IEEE conference publications. He currently holds 34 granted US patents. His research interests include wide-band-gap power semiconductor-based high frequency power conversion, soft-switching and resonant converters, high-frequency transformers, and MV and HV power conversion system for grid, renewable, and transportation applications.

Di Zhang received the B.S. and M.S. degrees from Tsinghua University, Beijing, China, in 2004 and 2006, respectively, and the Ph.D. degree from Virginia Tech, Blacksburg, VA, USA, in 2010, all in electrical engineering. From 2010 to 2018, he worked as a Senior Research Engineer with GE Global Research Center. He is currently an Associate Professor with Naval Postgraduate School, Monterey, CA, USA. His research interests include the modeling and design of medium to high voltage power converters, SiC-based high performance power conversion, and power conversion system for grid, renewable, and aviation applications.

Tutorial 3: Partial power energy processing – a new toolbox for efficient DC microgrids

August 5th, 1 pm to 3 pm Lexington B Room

Abstract and outline:

In recent years, interest in the partial and differential power processing approaches has increased among both academic and industrial researchers. This technology was demonstrated in a broad range of applications, including but not limited to photovoltaic (PV) systems, both string and PV module levels, battery energy storage systems, dc data centers, electric vehicle (EV) charging stations, etc. However, despite the rising number of publications and availability of several review papers, the literature stays ignorant of many practical issues in the application of this technology. Therefore, this tutorial provides a comprehensive overview of the existing solutions, compares them with regards to their practical applications, and discusses critical issues like protection and controllability. The tutorial is based on numerous practical examples of how partial power processing could be applied in dc microgrids.

- Fundamentals of partial power processing: a short history of the topic, main concepts, its implications on converter power rating and system-level efficiency, practical implementation issues
- Applications of differential power processing: PV module level converters for global maximum power point tracking, series cascading of servers in dc datacenters, application in data storage systems, battery charge balancing applications; etc.
- Application of partial power converter in photovoltaic systems, battery energy storage and EV charging systems
- Emerging topologies and control of partial power converters

Instructor:

Andrii Chub received the B.Sc. and M.Sc. degrees in Electronic Systems from Chernihiv State Technological University, Ukraine, in 2008 and 2009, respectively, and the Ph.D. degree in Electrical Engineering from the Tallinn University of Technology, Estonia, in 2016. He was a Visiting Research Fellow with Kiel University in 2017 and a Postdoctoral Researcher with Federico Santa Maria Technical University from 2018 to 2019. He is currently a Senior Researcher with the Power Electronics Group, Department of Electrical Power Engineering and Mechatronics, Tallinn University of Technology. He has co-authored over 200 articles and several book chapters on power electronics and applications and holds several patents and utility models. His research interests include advanced dc-dc converter topologies, renewable energy conversion systems, energy-efficient buildings, reliability, and fault-tolerance of power electronic converters.

Tutorial 4: A comprehensive guide to digital twin design, integration, and applications in DC microgrids

August 5th, 1 pm to 3 pm Lexington A Room

Abstract and outline:

In this tutorial session, the audience will be introduced to the concept of digital twins, its categories and ongoing standardization efforts. The instructors will discuss the following items:

- Representation techniques such as physics-based modeling, AI methods, etc. and underlying structures and architectures used in digital twins
- Cyber physical layers and communication between the physical and digital realms
- Practical applications and case studies
- Interactive and advanced features such as human-in-the-loop decision-making processes and activation of diverse functionalities, to consider the dynamic nature of systems
- Hands-on experience and direct engagement opportunities using a MATLAB-Simulink-based example of a digitally twinned electric aircraft

Lead instructor:

Dr. Kristen Booth is an Assistant Professor of Electrical Engineering at the University of South Carolina. As an NSF Graduate Research Fellow, Dr. Booth completed her Ph.D. degree from North Carolina State University in 2019. Dr. Booth's research interests include resiliency and reliability of power electronics converters, AI-integrated power electronics, and digital twins for grid modernization and security.

Other instructors:

Kerry Sado is a PhD Candidate, advised by Dr. Booth, at the University of South Carolina. His dissertation is regarding the development of digital twin framework and standardization for DC microgrids.

Dr. Austin Downey is an Associate Professor of Mechanical Engineering at the University of South Carolina. His research areas include real-time multi-domain data assimilation and battery prognostics.

Tutorial 5: Supercapacitor assisted converters and protection techniques for DC microgrids and DC homes

August 5th, 3.30 pm to 5.30 pm Lexington A Room

Abstract and outline:

Supercapacitor assisted (SCA) techniques provide a new design direction for high performance power converters and protection systems, based on supercapacitor assisted loss management (SCALoM) theory. In this tutorial, successful applications of SCA techniques are discussed: (i) an extra low frequency DC-DC converter based on linear low dropout (LDO) regulators and with similar efficiency to switch-mode converters. This eliminates the need for RFI/EMI filtering and also provides built-in DC-UPS capability within the converter, (ii) SCA-surge absorber (SCASA) that uses a low cost, small supercapacitor to develop a high-performance surge protector adhering to UL 1449 3rd Ed test standard, (iii) DC LED lighting based on supercapacitor energy recovery/buffer useful in renewable systems. Several other applications of the SCA technique under development such as for DC circuit breakers, rapid heat transfer systems and efficiency improvement in renewable energy inverter systems are also discussed.

- An introduction on supercapacitors
- Supercapacitor as a lossless component to improve efficiency of linear regulators
- Supercapacitor assisted low dropout regulator (SCALDO Technique) – fundamentals and generalized theory
- Supercapacitor assisted surge absorber (SCASA)
- SCA-temperature modification application (SCATMA) – for rapid water heating
- Generalized theory behind SCA techniques- the concept of loss management
- SCA-LED technique for DC microgrid applications
- Other applications

Instructor:

Nihal Kularatna is an Associate Professor in the School of Engineering at the University of Waikato, New Zealand. He is an electrical engineering graduate, a Fellow of the IET (London), a Fellow of Engineering NZ and a Senior Member of IEEE (USA). He is currently active in research in non-traditional supercapacitor applications, power supply topologies, transient propagation and renewable energy, with a contribution of over 175 papers to learned journals and international conferences. His research on supercapacitor assisted (SCA) techniques culminated in numerous US, NZ and PCT patents.