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

Tutorial Title:

Advanced Control of Power Electronics Systems

Organizer:

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Abstract:

This tutorial provides a fundamentally different perspective to multi-scale control of switching power electronic systems along with plurality of practical experimental results and is expected to be of great interest to the power electronic system engineers, professionals, educators, and students. Many new materials are planned for this tutorial with several recent developments. The tutorial will start with basics for researchers, engineers, professionals, and students and gradually working its way through to intricacies in advanced control concepts, realizations, and practical implementations for advance control realizations on new topologies and control platforms.

It is based on controlling the time evolution of the switching states (i.e., switching sequences) as well as controlling the switching transition of the power semiconductor device of the solid state electronic system. The former – i.e., switching sequence based control yields rapid response under transient condition, optimal equilibrium response, and yields seamless transition between the two states of dynamics. The first part of the tutorial will primarily focus on switching sequence based control for power electronics systems. By enabling integration of modulation and control, switching sequence based control precludes the need for ad-hoc offline modulation synthesis. In other words, an optimal switching sequence for the power converter is generated dynamically without the need for prior determination of any modulation scheme (which generates a pre-determined switching sequence) in typical conventional approaches. One of the fundamental distinctions between switching sequence based control and conventional model predictive control is that the former ensures optimal determination of the switching sequence of the power converter under stability bound. The tutorial will provide the mechanism to carry out switching sequence based control and model predictive control syntheses and demonstrate the differences between the two optimal control schemes. Several device, converter, and network level implementations (e.g., microinverter, solar inverter, pulsed-power systems, microgrid, parallel inverters, multilevel converter, aircraft power system) of the switching sequence based control will be provided encompassing author's multiple years of project experience encompassing leading advanced defense and energy industries. Finally, the tutorial will focus on switching transition control. The primary objective of this control is to demonstrate how key power electronic system parameters including dv/dt and di/dt stress, switching loss, and electromagnetic noise emission can be controlled dynamically by modulating the dynamics of the power semiconductor devices. Both electrical and newly developed optical control mechanisms

to achieve switching transition control will be demonstrated. In the context of the latter, mechanisms for monolithic integration of switching sequence control as well as switching transition control will be outlined and the revolutionary impact of such a novel integration on system performance will be demonstrated with numerous recent and ongoing practical applications.

The second part of the tutorial reviews control methods that fully exploit the performance potential of high-power converters, by ensuring fast control at very low switching frequencies and low harmonic distortions. To achieve this, the control and modulation problem is addressed in one computational stage. Long prediction horizons are required for the MPC controllers to achieve excellent steady-state performance. The resulting optimization problem is computationally challenging, but can be solved in real time by branch and bound methods. Alternatively, the optimal switching sequence to be applied during steady-state operation—so-called optimized pulse pattern (OPP)—can be pre-computed offline and refined online to achieve fast closed-loop control. To this end, the research vision is to combine the benefits of deadbeat control methods (such as direct torque control) with the optimal steady-state performance of OPPs, by resolving the antagonism between the two. Two such MPC methods are presented in detail.

Bio:

Sudip K. Mazumder received his Ph.D. degree from Virginia Tech in 2001. Since 2001, he serves as a Professor at the University of Illinois Chicago (UIC) and the Director of the Laboratory for Energy and Switching-Electronic Systems. He also serves as the President of NextWatt LLC since 2008. He has around 30 years of professional experience encompassing academia and leading industries. He was named a Fellow of the American Association for the Advancement of Science (AAAS) in 2020 and a Fellow of the Institute of Electrical and Electronics Engineers (IEEE) in 2016 for distinguished contributions related to the field of multi-scale control and analysis of power-electronic systems. He served as a Distinguished Lecturer for the IEEE Power Electronics Society (PELS) between 2016-2019 and currently serves as a PELS Regional Distinguished Lecturer for the US region. He is the current Editor-at-Large for IEEE Transactions on Power Electronics. He is the recipient of UIC's highest awards: Distinguished Researcher of the Year (2020), Inventor of the Year (2014), University Scholar (2013). He is also the recipient of several IEEE awards, U.S. ONR Young Investigator Award (2005) and U.S. NSF CAREER Award (2003). Currently, he is also a PELS AdCoM Member and Member at Large and was the Chair for PELS TC on Sustainable Energy Systems for 6 years.

Tobias Geyer recently joined ABB Medium-Voltage Drives in Switzerland as the R&D platform manager of the ACS6080. He is also an extraordinary Professor at Stellenbosch University, South Africa. Dr. Geyer received the Dipl.-Ing. degree in electrical engineering, the Ph.D. in control engineering and the Habilitation degree in power electronics from ETH Zurich in the years 2000, 2005 and 2017, respectively. He is the author of 35 patent families and the book "Model predictive control of high power converters and industrial drives" (Wiley, 2016). He teaches a regular course on model predictive control at ETH Zurich. His research interests include medium-voltage and low-voltage drives, utility-scale power converters, optimized pulse patterns and model predictive control. Dr. Geyer received the Semikron Innovation Award and the Nagamori Award, both in 2021. He is also the recipient of the 2017 First Place Prize Paper Award in the Transactions on Power Electronics, the 2014 Third Place Prize Paper Award in the Transactions on Industry Applications, and of two Prize Paper Awards at conferences. He is a former Associate Editor for the Transactions on Industry Applications (from 2011 until 2014) and the Transactions on Power Electronics (from 2013 until 2019). He was an international program committee vice chair of the IFAC conference on Nonlinear Model Predictive Control in Madison, WI, USA, in 2018. Dr. Geyer is a Fellow of the IEEE and a Distinguished Lecturer of the Power Electronics Society from the year 2020 until 2023.

Debanjan Chatterjee received the B.E. degree in electrical engineering from Jadavpur University, Kolkata, India, in 2015, and received his PhD in Electrical and Computer Engineering at The University of Illinois Chicago (UIC), Chicago, IL, USA in 2021. He is with ABB US Corporate Research Center (USCRC), Raleigh, in June 2021, where he is employed as a Research Scientist. At USCRC, he is working on solid state circuit breakers and power converters for a variety of industry applications, including firmware development, gate driver design, and EMI/EMC analysis. His research interests encompass model predictive, switching sequence and switching transition controllers for wideband gap power electronic systems. He is a reviewer for IEEE Transactions on Power Electronics and IEEE Transactions on Industrial Electronics and serves as a technical committee member for top IEEE conferences.