Tutorial Title

Emerging Bidirectional Switches and Their Impact on Future AC Power Converters and Applications

Abstract

This tutorial will introduce participants to the emerging technology of monolithic bidirectional (M-BD) power switches and the exciting opportunities they will open for future ac power converter topologies and their applications. Wide-bandgap (WBG) power semiconductor technology has opened the door to the development of long-sought monolithic bidirectional switches that can block voltage and conduct current in both polarities under full gate control in all four quadrants. Prototype versions of these M-BD devices produced in industrial and academic laboratories have been reported with ratings as high as ±1400V and ±100A. A section of this tutorial will be devoted to exposing participants to the underlying semiconductor technology of these M-BD switches including their operating principles, achievable terminal characteristics, technical challenges, and promising M-BD devices reported to date.

Following this introduction to state-of-the-art M-BD switch technology, the tutorial will focus attention on the strong potential this new class of switches holds for having a major disruptive impact on the future of power electronics. In particular, this tutorial will focus on the exciting opportunities that these new switches provide for dramatically improving key performance metrics of future dc-ac and ac-ac power converters, including their power density, efficiency, EMI suppression, and (eventually) cost.

Two of the well-known power converter classes that will be among the biggest beneficiaries of the future availability of M-BD switches are matrix converters (MCs) and current-source inverters (CSIs). While the appealing advantages of matrix converters for direct ac-ac power conversion have long been recognized, the unavailability of M-BD switches has prevented MCs using the baseline 3x3 matrix of ac switches from achieving wide commercial success. After reviewing the basic concepts associated with matrix converters and their control, attention will be focused on the opportunities that M-BD switches open for realizing the full commercial potential of future MCs in applications such as motor drives.

Similarly, the future potential of new M-BD switches to revive long-neglected CSI technology will also be explored. Recent work has revealed a variety of appealing properties of CSI-based motor drives in a wide variety of dimensions including high-temperature operation, EMI suppression, and enhanced fault protection in permanent magnet machine drives. After reviewing the basic concepts of CSI technology for both ac-dc and dc-ac power converters, special attention will be focused on the game-changing potential of M-BD switches in future CSI-based integrated motor drives that combine motors and drives into the same housing.

Finally, opportunities to realize the full potential of M-BD switches in promising new power converter topologies will be explored. One particularly exciting development is their application in a new T-Type switching cell (TT-SC) topology that provides the basis for designing high-performance WBG-based three-level voltage-source inverters that can achieve appealingly high power density and efficiency performance metrics. Other promising power converter applications of M-BD switches will also be reviewed.

Tutorial participants can expect to leave this tutorial with valuable insights into the emerging technology of M-BD switches and the opportunities they open for more fully exploiting wide-bandgap switch technology to revolutionize the power electronics field.

Thomas M. Jahns (M'79–F'93–LF'19) received the S.B., S.M. (1974), and Ph.D. (1978) degrees in electrical engineering from MIT, Cambridge, MA, USA. In 1998, he joined the Department of Electrical and Computer Engineering, University of Wisconsin-Madison, as a Grainger Professor of Power Electronics and Electric Machines, where he is currently the Director of the Wisconsin Electric Machines and Power Electronics Consortium (WEMPEC). Prior to joining UW-Madison, he worked at GE Corporate Research and Development (now GE Global Research Center), Niskayuna, NY, for 15 years. His current research interests include high-performance permanent-magnet synchronous machines, electric propulsion drives, and integrated motor drives. Dr. Jahns received the 2005 IEEE Nikola Tesla Technical Field Award and the IAS Outstanding Achievement Award in 2011. He is a Past President of PELS and served two years as Division II Director on the IEEE Board of Directors (2001-2002). He was elected as a member of the U.S. National Academy of Engineering in 2015.

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Johann W. Kolar (M´89–F´10) received his M.Sc. and Ph.D. degree (summa cum laude) from the University of Technology Vienna, Austria, in 1997 and 1999, respectively. Since 1984, he has been working as an independent researcher and international consultant in close collaboration with the University of Technology Vienna. He has proposed numerous novel PWM converter topologies, modulation and control concepts and has supervised 75+ Ph.D. students. He has published 900+ journal and conference papers, and has filed 200+ patents. Dr. Kolar has received 35+ IEEE Transactions and Conference Prize Paper Awards, the 2014 IEEE R. David Middlebrook Achievement Award, and the 2016 IEEE William E. Newell Power Electronics Award. He served from 2001 through 2013 as an associate editor of the IEEE Transactions on Power Electronics. The focus of his current research includes ultra-compact and ultra-efficient SiC and GaN converter systems, advanced variable speed three-phase motor drives, integrated modular motor drives, ultra-high speed motors, and bearingless motors/ actuators. He was elected to the U.S. National Academy of Engineering as an international member in 2021.

Jonas E. 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, finally (from 2016) as a Post-Doctoral Researcher, 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. In 2017, he joined ABB Switzerland Ltd. as a Power Electronics Development Engineer working on high-power DC-DC converter systems for traction applications. He then returned to the Power Electronic Systems Laboratory, ETH Zurich, as a Senior Researcher in 2020 and has extended his research scope to all types of WBG power semiconductor based ultra-compact / ultra-efficient or highly dynamic converter systems.

Victor Veliadis received the Ph.D. degree in electrical and computer engineering from Johns Hopkins University, Baltimore, MD, USA, in 1995. He was with Nanocrystals Imaging Corporation, Briarcliff Manor, NY, USA, from 1996 to 2000, where he developed quantum-dot phosphors for imaging applications, and high-resolution X-ray imagers. From 2000 to 2003, he was with Lucent Technologies, Boulogne-Billancourt, France, where he designed InP-based tunable photonic integrated circuits for telecommunication applications. In 2003, he was an Adjunct Professor with Ursinus College, Collegeville, PA, USA, and Saint Joseph's University, Philadelphia, PA, USA, where he taught quantum physics and oversaw the physics laboratories. After a brief military service, he joined Northrop Grumman Electronic Systems, Baltimore, MD, USA, in 2004, where he designed, fabricated, and tested SiC JFETs, MOSFETs, thyristors, JBS, Schottky, and PiN diodes in the 1–12-kV range. In 2016, he was named the CTO of PowerAmerica, Raleigh, NC, USA. He has authored or co-authored 105 peer-reviewed technical articles, three book chapters, and has 23 issued and multiple pending patents to his credit.