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Tutorial Title

Bidirectional WBG Power Switches and the Applications They Enable

Instructor Team

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Abstract

There are numerous mass volume power applications where it is necessary to control the flow of bidirectional power, including electric vehicles (vehicle to grid, vehicle to home, and vehicle to vehicle), distributed and grid-tie power systems using regenerated energy and/or energy storage components, and solid-state circuit breaker protection. Silicon carbide (SiC) and gallium nitride (GaN) based bidirectional power switches can enable these applications with their compelling advantages of high efficiency, high blocking voltage capability, and low system weight and volume. In particular, monolithic switches that allow for bidirectional symmetric conduction and voltage blocking with a chip area close to that of a similarly rated unidirectional switch are ideally suited to fuel a revolution in power electronics technology. Today, monolithic bidirectional (MBD) power semiconductor switches are not commercially available. Instead, back-to-back (anti-series) connection schemes of unidirectional power MOSFETs or IGBTs are typically used, resulting in a 4X penalty in chip area and high cost. However, various types of SiC and GaN bidirectional concepts are being investigated including bonded-wafer bidirectional IGBTs, monolithic dual-gate bidirectional GaN switches, and monolithic back-to-back connected SiC MOSFETs and JFETs. In the first section of this tutorial, the semiconductor technology of SiC and GaN bidirectional switches will be reviewed including their operating principles, and their lateral and vertical geometry configurations. The performance advantages of MBD switches will be highlighted and promising MBD devices reported to date will be analyzed. As SiC and GaN devices approach mass commercialization propelled by insertion in electric vehicles and consumer electronics, respectively, fabrication of SiC/GaN MBD switches is becoming economically viable enabling their wide adoption. The second section will focus on key volume applications and power converter topologies that will benefit from BD switches. The world is full of opportunities for integrated motor drives that combine the motor and power electronics in the same housing. Some of the most promising power converter topologies for these applications such as matrix converters, current-source inverters, Vienna rectifiers, and T-cell converters will benefit greatly from the availability of WBG-based BD switches. In fact, some of these promising topologies such as the matrix converter and PWM current source inverter have been blocked from the marketplace for many years because of the commercial unavailability of BD switches. In recognition of the compelling advantages of SiC and GaN bidirectional power switches, the second section of the tutorial will focus on several specific applications and circuit topologies to explore the transformative impact the availability of WBG-based BD switches is destined to have on the practicality and future potential of these topologies in commercial applications. These examples will be carefully chosen to highlight the breadth of applications and topologies that are likely to benefit significantly from the commercial availability of BD switches, as

well as some of the practical engineering issues that will be encountered in the process of applying them. Finally, attention will be devoted to how the applications benefiting from BD switches will grow as the voltage and current ratings of commercialized BD switches expand in the future.

Instructor Team Biographies

Dr. Victor Veliadis is Executive Director & CTO of PowerAmerica, a member-driven consortium of industry, universities, and national labs accelerating the commercialization of SiC and GaN power semiconductor chips and electronics. At PowerAmerica, he has managed a budget of $156M that he strategically allocated to over 210 industrial and University projects to catalyze SiC and GaN chip and power electronics manufacturing. His educational activities have trained 430 full-time students, and engaged over 7000 attendees in tutorials, short courses, and webinars. He is currently negotiating a $64M DOE renewal to further catalyze WBG power technologies.
He is an ECE Professor at NC State, and an IEEE Fellow and EDS Distinguished Lecturer. He has 27 issued U.S. patents, 6 book chapters, and over 150 peer-reviewed publications to his credit. He has given over 150 keynote/tutorial/invited presentations including keynotes at ICSCRM, APEC, ECCE, and WiPDA. Prior to taking an executive position at Power America in 2016, he spent 21 years post-PhD in the semiconductor industry where his work included design, fabrication, and testing of SiC devices, GaN devices for military radar systems, and financials and operations of a commercial semiconductor fab. He has a Ph.D. degree in ECE from John Hopkins University (1995).

Dr. Thomas M. Jahns received his Ph.D. degree in Electrical Engineering from MIT (1978) and worked at GE Corporate Research and Development for 15 years prior to becoming a Professor at the University of Wisconsin-Madison. He is an Emeritus Professor at UW-Madison and a Past Director of the Wisconsin Electric Machines and Power Electronics Consortium (WEMPEC). Following his retirement from the active faculty in 2021, Dr. Jahns is continuing to pursue research as a Grainger Emeritus Professor in the areas of high-performance permanent magnet synchronous machine drives using wide-bandgap power switches, and integrated motor drives using modular topologies. 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 and was awarded the IEEE Medal in Power Engineering in 2022.

Dr. Jin Wang received his Ph.D. degree from Michigan State University in 2005 in electrical engineering. From September 2005 to August 2007, he worked at Ford Motor Company, Dearborn, MI, USA, as a Core Power Electronics Engineer. He joined The Ohio State University, Columbus, OH, USA, in 2007, and was promoted to Full Professor in 2017. His research interests include wide bandgap power devices and their applications, high-voltage, high power converter/inverters, integration of renewable energy sources, and transportation electrification. Dr. Wang has over 200 peer-reviewed journal/conference publications and 9 patents. He received the IEEE Power Electronics Society Richard Bass Young Engineer Award in 2011, the National Science Foundation's CAREER Award in 2011, and the Nagamori Award in 2020. He served as an Associate Editor for the IEEE Transactions on Industry Applications from 2008 to 2014. Currently, he serves an Associate Editor for the IEEE Transactions on Power Electronics and the IEEE Journal on Emerging and Selected Topics in Power Electronics.