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Tutorial Title

Z-Source DC Solid-State Circuit Breakers

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Abstract

The utilization of DC interconnection in power systems is becoming increasingly prevalent for various reasons, such as the potential for significant savings in power conversion stages and the ease of interconnecting inherently DC-natured components, such as solar panels, fuel cells, and batteries. DC power systems have become the norm for ship propulsion systems, building electrification, aircraft power systems, electric vehicles, and many other applications. While the power conversion components in these systems are well-known and well-defined, considerable research is still being conducted into the circuit breakers. The primary challenge in breaking a DC circuit is that there is no zero crossing in the current, thus creating a sustained arc that can potentially damage the switch or cause a fire. One solution is to use an oversized AC breaker for the DC application. Other solutions involve hybrid breakers (with a main-path mechanical contactor and auxiliary solid-state components). Another option is the fully solid-state circuit breaker (SSCB). Although the on-state loss is usually higher than that of a mechanical contactor, the SSCB has the advantages of a very rapid response and more controllability. Within the SSCB category, there are a number of variations. The basic design switches off the main-path current and transfers the energy to a metal-oxide varistor (MOV). Other variations involve power converter elements acting as breakers. This version of the SSCB has the benefit of highly controllable behavior. The Z-source circuit breaker is a unique type of SSCB based on the fundamental Z-source LC circuits. Its fundamental operating principle is that a rapid fault at the breaker terminal with an increasing current will result in a decrease in the current of the main path semiconductor. If this semiconductor is a silicon-controlled rectifier (SCR), the device will be automatically shut off when the Z-source circuit forces the device current to reach zero. Consequently, the Z-source breaker is different from other SSCBs in that it automatically deactivates the current path in response to a fault without requiring detection circuitry and technique. Additionally, the Z-source breaker has the benefit of a rapid turn-off due to its solid-state operation, which is usually in the microsecond range. Yet another advantage is the independent operation of multiple breakers in a DC microgrid. Whether the Z-source breakers are connected in a shunt configuration or series (downstream), only the breaker nearest the fault will be disengaged. This tutorial will first review the fundamental Z-source circuits introduced approximately 15 years ago. This includes the coupled inductor Z-source circuits and

utilization of the circuits in the Z-source inverter. Subsequently, the fundamental Z-source breaker idea will be described, followed by a number of variations on the Z-source breaker, including bi-directional topologies. Finally, incorporating the Z-source breaker within DC-DC power converters will be presented. Select examples of Z-source breakers will be utilized throughout the tutorial to illustrate various practical concepts, with simulations of these examples being made available to the tutorial participants.

Instructor Biography

Fang Z. Peng (Fellow, IEEE) received the B.S. degree in electrical engineering from the Wuhan University, Wuhan, China, in 1983, and the M.S. and Ph.D. degrees in electrical engineering from the Nagaoka University of Technology, Nagaoka, Japan, in 1987 and 1990, respectively. From 1990 to 1992, he was a Research Scientist with the Toyo Electric Manufacturing Company, Ltd., Tokyo, Japan, where he was involved in the research and development of active powerfilters, flexible ac transmission system (FACTS) applications, and motor drives. From 1992 to 1994, he was a Research Assistant Professor with the Tokyo Institute of Technology, Tokyo, Japan, where he initiated a multilevel inverter program for FACTS applications and a speed-sensorless vector control project. From 1994 to 1997, he was a Research Assistant Professor with the University of Tennessee, Knoxville, TN, USA. From 1994 to 2000, he was with the Oak Ridge National Laboratory, Oak Ridge, TN, USA, where he was the Lead (Principal) Scientist with the Power Electronics and Electric Machinery Research Center from 1997 to 2000. From 2000 to 2018, he was with the Michigan State University, East Lansing, MI, USA, where he was the University Distinguished Professor with the Department of Electrical and Computer Engineering. He is currently with Florida State University, Tallahassee, FL, USA, where he is a Professor with the Center for Advanced Power Systems.

Keith A. Corzine (Fellow, IEEE) received the Ph.D. degree from the University of Missouri - Rolla, MO, USA, in 1997. He taught at the University of Wisconsin - Milwaukee, Missouri University of Science & Technology, Clemson University, and is currently a Professor with UC Santa Cruz, Santa Cruz, CA, USA. He held 9 Summer appointments at the Naval Surface Warfare Center in Philadelphia. He has authored or coauthored more than 70 refereed journal papers, more than 130 refereed international conference papers, and holds 4 U.S. patents related to power conversion. Dr. Corzine's research interests include power electronics, motor drives, naval ship propulsion systems, and electric machinery. He was the past IAS Chapter Officer for the IEEE Milwaukee Section and past Chair of the IEEE St. Louis Section. He has also been involved in publicity and finance of IEEE conferences and served on the IEEE Region 5 Audit committee. Recently, he served as co-chair of the IEEE Vehicle Power and Propulsion Conference. Dr. Corzine has over 25 years of experience teaching power electronics material; including short courses at the Naval Surface Warfare Center.

Jinyeong Moon (Senior Member, IEEE) received the B.S. degree in electrical engineering and computer science from the Korea Advanced Institute of Science and Technology, Daejeon, South Korea, in 2005, the M.S. degree in electrical engineering from Stanford University, Stanford, CA, USA, in 2007, and the Ph.D. degree in electrical engineering and computer science from the Massachusetts Institute of Technology (MIT), Cambridge, MA, USA, in 2016. He was with Hynix Semiconductor Inc., Icheon, South Korea, from 2007 to 2011 as a Senior Research Engineer, where he was involved in designing analog, digital, and power circuits for DDR4 SDRAM. He was a Postdoctoral Associate with MIT from 2016 to 2017. He was with Maxim Integrated, North Chelmsford, MA, USA, from 2017 to 2018 as a Member of Technical Staff, where he was involved in high efficiency wide bandgap AC-DC converter projects. He is currently an Assistant Professor in the electrical and computer engineering with Florida State University. His research interests include modeling, design, analysis, and measurement of circuits and systems in the fields of power conversion, energy harvesting, electromagnetics, and renewable energy. Dr. Moon was a recipient of two grand prizes in the MIT Clean Energy Prize in 2014. He was also a recipient of the Kwanjeong Scholarship and the Hynix Strategic Patent Award. He holds 17 registered U.S. and international patents. He currently serves as an Associate Editor for Journal of Power Electronics and the Publication Liaison for IEEE Power Electronics Society's Technical Committee 1.