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Future Prospects of Power Electronic Converters for Electric Energy Storage, Energy Management, and Peak Power Applications

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The role of battery energy storage as a secondary source (to provide back-up energy) is well documented in literature. Batteries have successfully been demonstrated to back up fuel cells, internal combustion engines, photovoltaic systems, and wind energy systems, just to name a few popular applications. Secondary Lithium-ion (Li-ion) batteries find applications in electric vehicles, distributed energy sources, net-zero energy homes, microgrids, and renewable energy power systems. More recently, hybrid storage systems have been adopted in numerous applications, to combine both energy-dense and power-dense devices. High power-density Ultracapacitors (UCs) have found applications for peak power delivery and fast charging. Such a hybrid storage system lengthens the lifetime of the battery pack in terms of charge/discharge cycles. Hybrid storage applications require smart power electronic energy management systems. The aim of this tutorial is to present such hybrid energy storage systems from a device level characteristic standpoint as well as from an advanced energy management standpoint.

Firstly, practical energy/power storage issues for batteries/ultra-capacitors will be presented. Lithium-ion (Li-ion) batteries, although popularly adopted in various applications, have been highly uneconomic for energy storage, overshooting cost requirements by a large margin. Li-ion batteries provide a respectable solution for energy storage. However, major practical issues with Li-ion batteries include: cycle life, calendar life, energy density, power density, and safety. These issues can be addressed successfully by using a simple approach: an active power electronic cell equalizer. The purpose of the second part of this tutorial is to demonstrate the role of power electronics intensive battery and ultra-capacitor energy management solutions, to reach the cost break-even point of a hybrid energy/power storage system. The design and implementation of both inductor-based as well as switched-capacitor DC/DC converters for Li-ion battery cell-equalization will also be discussed. Finally, the design of a novel, cost-effective DC/DC converter for cell equalization of Li-ion battery cells will be presented.

The presentation will also review current as well as future interfacing methodologies for batteries/ultracapacitors, PV systems, and the AC grid, as an example microgrid environment. The presentation will discuss the modeling, sizing, design, and implementation of a high-efficiency, single-stage, PV/battery/AC grid energy management infrastructure. The novel, single-stage PV/grid/battery infrastructure is universal in nature and smartly adaptable, whereby batteries of different chemistries as well as charging rates can be accommodated in a single power conversion stage. In addition, the designed power electronic interface can also support future DC charging for electric vehicles. Futuristic PV/grid/battery interface using wireless charging will be presented. The design and energy transfer capabilities of a surface charging system, using inductive power transfer, will be presented. Power electronic converter topologies and energy management systems for such an inductive/surface EV/PEV charging infrastructure will be presented.

This tutorial will be useful for engineers and managers with entry-level and/or medium-level knowledge of power electronics. The talk would also be suitable for engineers with entry-level knowledge of power electronics and motor drives applications towards energy storage systems, electric vehicles, and renewable energy systems.

Speaker Biography

Sheldon S. Williamson (S'01–M'06–SM'13) received his Bachelor of Engineering (B.E.) degree in Electrical Engineering with high distinction from University of Mumbai, Mumbai, India, in 1999. He received the Master of Science (M.S.) degree in 2002, and the Doctor of Philosophy (Ph.D.) degree (with Honors) in 2006, both in Electrical Engineering, from the Illinois Institute of Technology, Chicago, IL, specializing in automotive power electronics and motor drives, at the Grainger Power Electronics and Motor Drives Laboratory. Dr. Williamson is an Associate Professor within the Department of Electrical and Computer Engineering, at Concordia University, Montreal, Canada, where he has been working since June 2006. His main research interests include the study and analysis of electric drive trains for electric, hybrid electric, plug-in hybrid electric, and fuel cell vehicles. His research interests also include modeling, analysis, design, and control of power electronic converters and motor drives for land, sea, air, and space vehicles, as well as the power electronic interface and control of renewable energy systems.

Dr. Williamson has offered numerous conference tutorials, invited lectures, and short courses in the areas of automotive power electronics and motor drives. He is the principal author/co-author of over 150 journal and conference papers. He is the principal author of several books and textbooks related to power electronics and motor drives for electric, plug-in hybrid electric, and fuel cell vehicles. He has also contributed to several book chapters related to electric vehicle drivetrains, energy storage systems, and transportation electrification. Dr. Williamson has been selected as the General Chair for the IEEE Transportation Electrification Conference and Exposition-India/Middle East, to be held in Bangalore, India, in Dec. 2015. He is also the General Chair for the IEEE Transportation Electrification Conference and Exposition, to be held in Detroit, Michigan, in June 2014. He currently serves as the Chair of the Technical Committee on Automotive Technology within the IEEE Industrial Electronics Society (IEEE IES). He also serves on the transportation electrification, power electronics, motor drives, and renewable energy technical committees for the IEEE Power Electronics Society (IEEE PELS). In the recent past, Dr. Williamson has consistently served as the Technical Program Chair for various leading IEEE Conferences, including the IEEE Energy Conversion Congress & Expo. (IEEE ECCE), IEEE Applied Power Electronics Conf. and Expo. (IEEE APEC), IEEE Annual Conf. of the IEEE Industrial Electronics Society (IEEE IECON), IEEE Vehicle Power and Propulsion Conference (IEEE VPPC), and the IEEE Canada – Electrical Power & Energy Conf. (IEEE EPEC).

Dr. Williamson is also the beneficiary of numerous awards and recognitions. He was the recipient of the prestigious "Paper of the Year" award, for the year 2006, in the field of Automotive Power Electronics, from the IEEE Vehicular Technology Society (IEEE VTS). In addition, he also received the overall "Best Paper" award at the IEEE PELS and VTS Co-sponsored Vehicle Power and Propulsion Conference, in Sept. 2007. He was awarded the "Best Paper" award at the IEEE Canada Electrical Power and Energy Conference, in Halifax, Nova Scotia, Canada, in Aug. 2010. He was awarded the prestigious Sigma Xi/IIT Award for Excellence in University Research, for the academic year 2005-2006. In 2006, he also received the "Best Research Student" award, Ph.D. category, within the ECE Department, at the Illinois Institute of Technology, Chicago. Dr. Williamson has also served as a consultant to numerous national and international companies as well as Government research laboratories, for his expertise on transportation electrification.

Dr. Williamson is a Senior Member of the IEEE. He currently serves as a Distinguished Lecturer of the IEEE Vehicular Technology Society (VTS). He also serves as Associate Editor for the IEEE Transactions on Industrial Electronics, IEEE Transactions on Power Electronics, and the IEEE Journal of Emerging and Selected Topics in Power Electronics. He also serves as the IEEE Industry Applications Society (IAS) Chapter Chair for the IEEE Montreal section. He is a member of the IEEE PELS, IES, and VTS.