New Trends in Battery Management Systems for Lithium Ion Batteries

Presenters:

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Brief description:

During the last few years, the adoption of lithium ion batteries has become well established in mobile and stationary applications. In order to take full advantage of the superior performance of modern lithium ion batteries, advanced management is mandatory. The major objective of a battery management system (BMS) is to ensure the safest and optimum use of the energy stored in the battery and to extend its lifetime by preventing any risk of damage. This goal is achieved by monitoring and controlling the charging and discharging processes of the battery.

The tutorial aims at presenting current and future trends in the modeling, management and design of a BMS for large-format lithium ion batteries, which consist of several series- and/or parallel connected elementary battery cells. It first provides an overview of the current status and possible evolutions of the battery technology with special regard to electric vehicles and to microgrids. Then, a general view of the various BMS functions is presented. For each function, the major modeling, management, and design challenges for its effective implementation, the available commercial solutions and the research directions are discussed.

Commonly used indicators to define the battery state are the State of Charge (SOC) and State of Health (SOH). However, another important indicator that hasn't been widely discussed is the State of Function (SOF). An overview of the concepts of SOC, SOH and SOF is provided to highlight their importance in estimating the remaining energy stored in the battery, its ability to power a load, and for prognosis and diagnosis. The tutorial discusses the commonly used modeling techniques, i.e., circuit based modeling and electrochemical modeling, their limitations and approach to estimate SOC, SOH and SOF. The speaker then describes his research on bridging the gap between the electrochemical and the circuit based models to develop an appropriate definition of SOH and a strategy that can more accurately estimate the SOC, SOH and SOF of the battery. These techniques are applied for range estimation in electric vehicles using a big data based framework.

This tutorial will then discuss the prominent architectures for BMS hardware partitioning and implementation. In particular, it shows that a distributed hierarchical BMS architecture, which reflects the physical structure of a battery (cell, module, and pack), can result in a very effective partitioning of the BMS functions. This is obtained by delegating the monitoring tasks to the local or slave units, while keeping the estimation tasks in the central or master unit. The concept of smart cell is introduced. Moreover, in this scenario, the master unit is requested to estimate the state of up to one hundred cells. This strongly motivates the adoption of innovative solutions for its implementation, in which the use of an FPGA device may be beneficial. Indeed, state-of-the-art FPGAs provide the advantage of combining high performance processors with programmable logic resources, which may well be used for hardware acceleration of the highly computationally-intensive algorithms, such those for battery state estimation. Fresh research *results are presented and discussed. They include the development of a hardware-in-the-loop platform for assessing the performance of battery state estimators implemented in FPGAs*

The tutorial is sponsored by the IEEE/IES Technical Committees on Energy Storage (ES TC) and on Resilient and Security in Industrial Applications (ReSIA TC). The target audience includes graduate students, researchers and professional engineers interested in gaining an in-depth knowledge of current and future trends in the design of advanced battery management systems for lithium ion batteries, which is mandatory for an effective use of these batteries.

Outline:

- *Tutorial introduction. Overview of battery technology for electric vehicles and for microgrids*
  (Federico Baronti, Mo-Yuen Chow 10 min)
- *BMS functions, requirements, available commercial solutions and research directions for their implementation (Federico Baronti, 10 min)*
- *Battery modeling (Mo-Yuen Chow, 30 min)*
- *Battery state estimation and its application to electric vehicle range prediction (Mo-Yuen Chow, 30 min)*
- *BMS architectures and hardware-in-the-loop simulation platform for the validation of battery state estimators (Federico Baronti, 20 min)*
- *BMS implementation examples (Federico Baronti, 20 min)*

Relevant publications:

1. F. Baronti, M.-Y. Chow, C. Ma, H. Rahimi-Eichi, and R. Saletti, “E-transportation: the role of embedded systems in electric energy transfer from grid to vehicle,” *EURASIP J. Embed. Syst.*, vol. 2016, no. 1, p. 12, Dec. 2016.
2. Balagopal, Bharat; Chow, Mo-Yuen, "Effect of Anode Conductivity Degradation on the Thevenin Circuit Model of Lithium Ion Batteries," Industrial Electronics Society, IECON 2016 – 42nd Annual Conference of the IEEE, Oct. 2016
3. C. S. Huang and M. Y. Chow, "Accurate Thevenin's circuit-based battery model parameter identification," 2016 IEEE 25th International Symposium on Industrial Electronics (ISIE), Santa Clara, CA, USA, 2016, pp. 274-279.
4. R. Morello, F. Baronti, X. Tian, T. Chau, R. Di Rienzo, R. Roncella, B. Jeppesen, W. H. Lin, T. Ikushima, and R. Saletti, “Hardware-in-the-Loop Simulation of FPGA-based State Estimators for Electric Vehicle Batteries,” in *ISIE 2016*, 2016.
5. Bharat Balagopal, and Mo-Yuen Chow, "The State of the Art Approaches to Estimate the State of Health (SOH) and State of Function (SOF) of Lithium Ion Batteries”, 13th IEEE Industrial Conference on Industrial Informatics (INDIN), 22-24 July 2015, Cambridge, UK.
6. H. Rahimi-Eichi, P. B. Jeon, M.-Y. Chow, and T.-J. Yeo, “Incorporating big data analysis in speed profile classification for range estimation,” 13th IEEE Industrial Conference on Industrial Informatics (INDIN), 22-24 July 2015, Cambridge, UK.
7. Rahimi-Eichi, H., Baronti, F., & Chow, M., “Online Adaptive Parameters Identification and State of Charge Co-Estimation for Lithium-Polymer Battery Cells,” IEEE Transactions on Industrial Electronics, 61(4), 2053–2061, 2014.
8. F. Baronti, C. Bernardeschi, L. Cassano, A. Domenici, R. Roncella, and R. Saletti, “Design and Safety Verification of a Distributed Charge Equalizer for Modular Li-Ion Batteries,” *IEEE Trans. Ind. Informatics*, vol. 10, no. 2, pp. 1003–1011, May 2014.
9. H. Rahimi-Eichi, U. Ojha, F. Baronti, and M.-Y. Chow, “Battery Management System: An Overview of Its Application in the Smart Grid and Electric Vehicles,” *IEEE Ind. Electron. Mag.*, vol. 7, no. 2, pp. 4–16, Jun. 2013.
10. F. Baronti, G. Fantechi, R. Roncella, and R. Saletti, “High-Efficiency Digitally Controlled Charge Equalizer for Series-Connected Cells Based on Switching Converter and Super-Capacitor,” *IEEE Trans. Ind. Informatics*, vol. 9, no. 2, pp. 1139–1147, May 2013.

Presenter's biography:

	**Federico Baronti** (M'08, SM'16) received the M.Sc. degree in Electronic Engineering in 2001 and the Ph.D. in 2005 at the University of Pisa, Italy. Since 2011 he is an assistant professor at the same university. He works on the design of innovative systems aiming at improving the performance, safety and comfort of road vehicles. More recent activities concern Li-ion battery modeling and the development of innovative battery management systems. He co-authored 87 publications on international journals and conference proceedings. He is the chair of the IEEE-IES technical committee on "Energy Storage" and associate editor of the IEEE Trans. on Industrial Informatics.
	**Mo-Yuen Chow** (S'81, M'82, SM'93, F'07) earned his degree in Electrical and Computer Engineering from the University of Wisconsin-Madison (B.S., 1982); and Cornell University (M. Eng., 1983; Ph.D., 1987). Dr. Chow joined the Department of Electrical and Computer Engineering at North Carolina State University as an Assistant Professor in 1987, Associate Professor in 1993, and Professor since 1999. Dr. Chow is a Changjiang Scholar and a Visiting Professor at Zhejiang University. Dr. Chow is the founder and the director of the Advanced Diagnosis, Automation, and Control (ADAC) Laboratory at North Carolina State University. His current research focuses on cooperative distributed control and fault management with applications on smart grids, PHEVs, batteries, and mechatronics systems. Dr. Chow has published one book, several book chapters, and over two hundred journal and conference articles related to his research work. He is an IEEE Fellow, the Editor-in-Chief of IEEE Transactions on Industrial Electronics 2010-2012, and has received the IEEE Region-3 Joseph M. Biedenbach Outstanding Engineering Educator Award, the IEEE ENCS Outstanding Engineering Educator Award, and the IEEE ENCS Service Award.