Design and Development of Scalable Battery Testers/Emulators and Their Applications for Future Transportation Electrification

Abstract

As electrified transport systems proliferate, batteries are increasingly becoming the critical element in the immediate and long-term technical and commercial success of these programs. Understanding of battery technology and its role in the applications is becoming crucial. While there have been many articles published on battery elements and systems, this tutorial approaches the problem from a user mindset. How do we use the various technology elements of battery models, calculations of charge and health to ensure a successful design outcome? Additionally, this tutorial will discuss how these elements apply to test and validation.

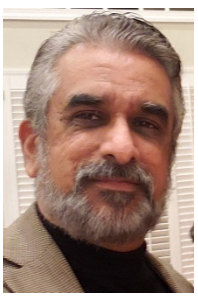
Very few battery cell models are available in literature; most models are very generic or basic. Cell models are either based on equivalent circuit parameters, such as *RC*, *R-RC*, or based on SOC calculation – these are not enough to measure Ah-capacity fade, state-of-health (SOH), and/or end-of-life (EOL). Thermal modeling is used minimally in related literature for testers and emulators. Cell degradation assessment due to varying temperature gradients is not feasible – this is particularly true for fast charging applications; 1C and above. Hence, testers/emulators today are unable to provide boundary testing (near EOL), specifically for applications such as fast chargers and controller validation or BMS validation.

This tutorial will present more realistic and practical electro-chemical and electro-thermal models for emulation and testing purposes. Performance modeling will be presented in order to test advanced machine learning (ML)-based battery management systems (BMS) and charger controllers. Stochastic models of battery cells will also be presented in this tutorial. In addition, SOC/SOH estimation models specific to emulator/tester applications, which affect instantaneous battery performance, will also be presented. Advanced thermal/EOL degradation models, which can be used to test BMS with battery health estimation and energy management, will also be presented for testing applications. Finally, the tutorial will include emulation of custom cell models and health-conscious fast charging algorithms, keeping the effects of temperature gradients in mind. Keeping these aspects in mind, the following key practical aspects will be presented:

- Emulation at cell-level, module level, and pack level (including development of advanced, higher-order thermal models);
- Estimation of SOC and SOH using advanced ML techniques;
- Validation of BMS developmental steps with respect to hardware, firmware, and software;
- Testing of newly developed algorithms (balancing, SOC, SOH, EOL, etc.);
- Development of a new constant-temperature-constant voltage (CT-CV) algorithm;
- Testing of fault cases (over-temperature, over-voltage, etc.);
- Programmable standard and user-owned battery models;
- Bidirectional power supply design (regenerative design) for high-power discharge; Constant-Voltage (CV), Current (CC), Power (CP), Series Resistance (CR) loading;
- Real-time HIL (Simulation of high-voltage batteries at cell/module level; Real-time multi-cell battery simulations; Temperature simulations using isolated analog outputs and advanced models).

Instructor Biographies

Sheldon S. Williamson (S'01–M'06–SM'13–F'20) received his Bachelors of Engineering (B.E.) degree in Electrical Engineering with high distinction from University of Mumbai, Mumbai, India, in 1999. He received the Masters 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. Currently, Dr. Williamson is a Professor at the Smart Transportation Electrification and Energy Research (STEER) group, within the Department of Electrical, Computer, and Software Engineering, at Ontario Tech University, in Oshawa, Ontario, Canada. He also holds the prestigious NSERC Canada Research Chair position in Electric Energy Storage Systems for Transportation Electrification. His main research interests include advanced power electronics and motor drives for transportation electrification, electric energy storage systems, and electric propulsion. Prof. Williamson is a Fellow of the IEEE.



Dr. Uday Deshpande is currently the CTO of D&V Electronics, a maker of special test equipment used in automotive, military, and defense applications for testing electrical systems and EV components. Prior to joining D&V, Dr. Deshpande held global engineering leadership positions in companies such as CNH Industrial, Ingersoll Rand, General Atomics, and Black & Decker. He has worked on projects from electric power steering to electric drivetrain in automotive, on electromagnetic aircraft launch and recovery systems, electrification and autonomy for agriculture equipment, connected products and services. His areas of technical focus are electrical and electromechanical systems and their applications. Dr. Deshpande was the Co-General Chair of ECCE 2011, in Phoenix, AZ. He is the Past Chair of the Industrial Drives Committee of the IEEE IAS and TC3 Motors, Drives & Actuators Technical Committee of the IEEE PELS. He is also an Associate Editor of the IEEE Trans. in Power Electronics. Dr. Deshpande received his B. Tech.(Hons.) degree from the Indian Institute of Technology, Kharagpur, India, and the M.S. and Ph.D. Degrees from the University of Kentucky, Lexington, KY, all in Electrical Engineering. Dr. Deshpande has several patents and publications to his name. He is a Senior Member of the IEEE.