INDUSTRIAL ELECTRONICS FOR SUSTAINABLE ENERGY SYSTEMS

IEEE International Conference on Industrial Electronics for Sustainable Energy Systems (IESES 2023)

Tutorial Proposal

Tutorial Title: Second-Life EV Batteries for Renewable and Smart Grid Storage Applications

Presenter(s): Dr. Chris Mi, Fellow of IEEE & SAE, Distinguished Professor, Electrical and Computer Engineer

Brief description: The number of electric vehicles (EVs) on roads is growing rapidly. EV batteries today, almost exclusively lithium-ion based, can last about 10 years before they can no longer provide the required performance such as power and range. They cost heavily in both production and recycling. So economically dealing with retired EV batteries is an important topic. It is estimated that the first huge wave of EV battery retirement will hit in 2025, and more retired batteries will be available each year thereafter.

On the other hand, renewable energy, such as solar photovoltaic (PV) and wind, also enjoy a high rate of penetration. To buffer the volatile nature of the energy output of renewable energy systems, battery energy storage systems (BESSs) are frequently incorporated to balance out the variability in power generation, efficiently manage the dynamics of demand and supply, mitigate the potential failure of the grid due to over generation, provide power during a power outage, and enable cost savings by shifting the peak use and reduce demand charge. However, the high cost of new batteries in renewable and grid storage systems is a major concern for potential home and business owners.

Batteries in EVs degrade gradually over the lifetime of the vehicle and will reach the point that it is no longer able to provide the required performance, such as range and acceleration. Second-life EV batteries include not only the batteries that are discarded from EVs due to degraded conditions; but also in-warranty replacements; road accidents; test vehicle batteries; and unsold batteries. Second-life EV batteries, though no longer roadworthy in the vehicle, still have considerable capacity for renewable energy and smart grid applications where the requirement for energy and power density is not as stringent in vehicles. The use of second-life EV batteries in grid BESS extends the life cycle of batteries after their first life in EVs, improves the environment, reduces EV ownership cost by selling them for second-life use, and reduces the cost of BESS in renewable energy systems.

However, there are a number of barriers to overcome in the deployment of second-life EV batteries, including how to properly remove them from vehicles, transport, store, test, and select second-life batteries for storage applications; how to quickly, and accurately identify the battery health conditions of every cell before and after deployment in grid storage; how to dynamically manage them so as to minimize degradation and optimize usage; and how to meet various standards related to fire hazardous mitigation/prevention, certification, permit, and safety.

This tutorial will holistically look at these issues and address how second-life EV batteries can be used in renewable energy and smart grid applications. The tutorial will include storage system design, battery management, battery balancing, size optimization, and system control and optimization for demand charge management and peak shaving. It will also look at the various testing requirements for identifying the conditions of used EV batteries. The aging mechanism of second-life EV batteries will be presented. Various topologies for storage applications, as well as safety and permit-related issues, will also be discussed.

Duration: 3 hours

Outline:

1. Energy Storage Options and Second-Life EV Batteries Basics (15 min)
    - Battery parameters – capacity, SOC, discharge rate, internal impedance
    - Battery characteristics
    - Lithium-ion batteries
    - EV battery systems
    - Logistics of second-life EV batteries
2. Battery Management Systems in EVs and energy storage systems (30 min)
    - Current monitoring
    - Voltage monitoring
    - Temperature monitoring and cooling system control
    - SOC calculation
    - SOH - concepts, method, measurements
    - Cell balancing
3. Energy Storage System Design (45 min)
    - Energy storage system paired with s solar PV system
    - Major components of the system
    - Optimization of control to reduce demand charge and shift usage to super-off-peak
    - Storage system sizing optimizations
    - Economics of the second-life battery storage system
    - Container design
    - Thermal and cooling system design
4. Battery Aging Test, Aging Mechanism, Safety (45min)
    - Cell, module, and pack testing
    - Battery aging mechanism
    - Battery hazards, sources, facts, and risks

- Causes of battery hazards and prevention of battery hazards

5. Role of Power Electronics in Second-life EV Battery applications (30 min)
   - Bidirectional DC-DC converter
   - Bidirectional DC-AC inverters
   - Grid isolation
   - Topologies that are applicable to second-life EV battery energy storage systems
     a. Disassembled battery cells and modules
     b. Series-connected packs for high voltage applications
     c. Parallel-connected packs for residential and low power systems
     d. Multi-level converter for improved cost, reconfigurability, and energy efficiency
6. Codes, Regulations, and Standards in deploying second-life EV Batteries (15 min)
   - NFPA 1, Fire Code (Also applicable: California Fire Code 2019)
   - NFPA 855 – Installation of Stationary Energy Storage Systems
   - NFPA 70 – National Electric Code (NEC)
   - UL 9540 – Energy Storage Systems and Equipment
   - UL 9540A – Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
   - UL 1974 - Creating a Safe Second Life for Electric Vehicle Batteries
7. Summary, wrap up, and discussion (15 min)

Motivation and Focus: See abstract above.

The number of electric vehicles (EVs) on roads is growing rapidly. EV batteries today, almost exclusively lithium-ion based, can last about 10 years before they can no longer provide the required performance such as power and range. They cost heavily in both production and recycling. So economically dealing with retired EV batteries is an important topic. It is estimated that the first huge wave of EV battery retirement will hit in 2025, and more retired batteries will be available each year thereafter.

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Brief CV: Photo, name, email, and short resume (relevant to the proposal).

Bio: Dr. Mi is the distinguished Professor of Electrical and Computer Engineering at San Diego State University. He is a Fellow of IEEE (Institute of Electrical and Electronics Engineers) and SAE (Society of Automotive Engineers). He is also the Director of the US Department of Energy-funded Graduate Automotive Technology Education (GATE) Center for Electric Drive Transportation at SDSU. He was previously a faculty member at the University of Michigan-Dearborn from 2001 to 2015, and an Electrical Engineer with General Electric from 2000 to 2001. He also served as the CTO of 1Power Solutions from 2008 to 2011 and is currently the CTO of EV Safe Charge, Inc. Dr. Mi received his Ph. D from the University of Toronto, Canada, in 2001.

Dr. Mi has published five books, 204 journal papers, 126 conference papers, and 25 issued and pending patents. He served as Editor-in-Chief, Area Editor, Guest Editor, and Associate Editor of multiple IEEE Transactions and international journals, as well as the General Chair of over ten IEEE international conferences. Dr. Mi has won numerous awards, including the “Distinguished Teaching Award” and “Distinguished Research Award” from the University of Michigan-Dearborn, IEEE Region 4 “Outstanding Engineer Award,” IEEE Southeastern Michigan Section “Outstanding Professional Award,” and SAE “Environmental Excellence in Transportation (E2T) Award.” He is the recipient of three Best Paper Awards from IEEE Transactions on Power Electronics and the 2017 ECCE Student Demonstration Award. In 2019, he received the Inaugural IEEE Power Electronics Emerging Technology Award. In 2022, he received the Albert W. Johnson Research Lectureship and named the Distinguished Professor, the highest honor given to a SDSU faculty member and only one award is given each year.

Dr. Mi was the Chair (2008-2009) and Vice-Chair (2006-2007) of the IEEE Southeastern Michigan Section. Dr. Mi was the General Chair of the 5th IEEE Vehicle Power and Propulsion Conference, Area Editor of IEEE Transactions on Vehicular Technology, associate editor of IEEE Transactions on Power Electronics, Associate Editor of IEEE Transactions on Industry Applications. He is the topic chair for the 2011 IEEE International Future Energy Challenge and the General Chair for the 2013 IEEE International Future Energy Challenge. Dr. Chris Mi is a Distinguished Lecturer (DL) of the IEEE Vehicular Technology Society.

He is Guest Editor-in-Chief of IEEE Journal of Emerging and Selected Topics in Power Electronics - Special Issue on WPT, Guest Co-Editor-in-Chief of IEEE Transactions on Power Electronics Special Issue on WPT, Guest Editor of IEEE Transactions on Industrial Electronics - Special Issue on dynamic wireless power transfer, and steering committee member of the IEEE Transportation Electrification Conference (ITEC- Asian). He is Program Chair or General Chair of a number of international conferences, including Workshop on Wireless Power Transfer (WoW), IEEE International Electric Vehicle Conference (IEVC), and IEEE International Transportation Electrification Conference – Asia-Pacific. He is the Guest Editor of a Special Issue of the Proceedings of the IEEE - Electric and Hybrid Vehicles.

Relevant publications: Up to 5 publications including edited books

Jufeng Yang, Xin Li, Xiaodong Sun, Yingfeng Cai, and C. Mi, "An efficient and robust method for lithium-ion battery capacity estimation using constant-voltage charging time," Energy, 263 (2023) 125743, https://doi.org/10.1016/j.energy.2022.125743. October 2022.

Mina Ma, Xiaoyu Li, Wei Gao, Jinhua Sun, Weigang Zhao, C. Mi, and Qingsong Wang, "Multi-Fault Diagnosis for Series-Connected Lithium-ion Battery Pack with Reconstruction-Based Contribution Based on Parallel PCA-KPCA," Applied Energy. Volume 324, 15, doi.org/10.1016/j.apenergy.2022.119678, October 2022, 119678.

H. S. Lam, H. Yuan, S. C. Tan, C. Mi, J. Pou, and S.Y.R. Hui, "Bidirectional AC-DC Modular Multilevel Converter with Electric Spring Functions for Stabilizing Renewable AC Power Grid at the Distribution Voltage Level," Journal of Emerging and Selected Topics in Power Electronics, 10.1109/JESTPE.2022.3173809. vol. 10, no. 6, pp. 7589-7600, December 2022.

Jufeng Yang, Yingfeng Cai, and C. Mi, "State-of-health estimation for lithium-ion batteries based on decoupled dynamic characteristic of constant-voltage charging current," 10.1109/TTE.2021.3125932, IEEE Transactions on Transportation Electrification, vol. 8, no. 2, pp. 2070-2079, Jun 2022.

Zhimin Xi, Rui Wang, Yuhong Fu, and C. Mi, "Accurate and Reliable State of Charge Estimation of Lithium-Ion Batteries Using Time-Delayed Recurrent Neural Networks through the Identification of Overexcited Neurons," Journal of Applied Energy. https://doi.org/10.1016/j.apenergy.2021.117962, vol. 305, 117962, pp. 1-9, January 2022.

Wei Gao, Xiaoyu Li, Mina Ma, Yuhong Fu, Jiuchun Jiang, and C. Mi, "Case Study of an Electric Vehicle Battery Thermal Runaway and Online Internal Short Circuit Detection," IEEE Transactions on Power Electronics - Letters. Doi: 10.1109/TPEL.2020.3013191, vol. 36, no 3, pp. 2452-2455, Mar 2021.

Deadlines:

Full paper submission:	Feb. 5, 2023
Paper acceptance notification:	Apr. 15, 2023
Camera-ready paper submission:	May 15, 2023

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