Guest Editorial Special Issue on Advanced Energy Storage Technologies and Safety Management for E-Mobility

I. Introduction

DRIVEN by greenhouse gas emission and resource scarcity, modern transportation is on the verge of a major paradigm shift, witnessed by the proactive penetration of electrified vehicles, vessels, and aircraft. Following this trend, energy storage systems (ESS) like batteries and fuel cells have been experiencing a booming advancement in the last decade. Furthermore, grid technologies related to ESS, such as fast charging, wireless power transfer, and vehicle-to-grid systems, have also received significant interest. However, the pursuit of the utmost user experience risks violating critical physical limits accompanied by unexpected side reactions within the ESS, resulting in efficiency reduction, quick degradation, and even catastrophic safety hazards in the most severe case. Particularly, onboard battery systems have been identified as one of the major contributors to recently reported electric vehicle fire accidents. Moreover, risks can accumulate over the life cycle and eventually spread to the second-life use.

This Special Issue aims to document innovations in a broad range of energy storage technologies, like batteries, fuel cells, supercapacitors, and their grid-tied applications. High-fidelity modeling, new integration architectures, and fault-tolerant management of ESS are specially focused due to their vital roles in future electrified transportation systems. This vision can be facilitated by emerging technologies like ESS design and optimization, ESS-interfaced power electronics, intelligent management, environment-adaptive control, and second-life utilization. This Special Issue seeks to highlight the original works on these advancements with special applications in the field of electric transportation.

This Special Issue begins with a review [A1] by Wei et al. that overviews the recent progress and future trends of data-driven battery management from a multilevel perspective. Following this, a review [A2] by Li et al. is presented focusing on the future utilization of second-life batteries.

Referring to the research works, the Special Issue first presents five articles on state estimation and fault diagnosis to ensure the effective operation of batteries. Advanced algorithms for battery state estimation, fault diagnostics, and health prognostics are presented. This is followed by a large set of eight articles related to the design of hardware and charging strategies for the charge management of batteries. Three articles deal with the narrow but all-important topic of thermal management. These concern thermal runaway management, battery preheating, and thermal safety. The fourth group of articles focuses on fuel cells, covering broad topics of lifespan prediction, control, degradation modeling, hybrid topologies, and so on. The last part of this Special Issue deals with several of these topics in the context of energy management.

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II. State Estimation and Fault Diagnosis

Batteries must be carefully monitored to avoid abusive utilization such as over-(dis)charge. Therefore, state estimation remains an essential topic for the future development of battery storage technology.

In [A3], Zhang et al. present a provably convergent estimation scheme based on a single particle model with electrolyte dynamics. The method can be used to estimate the critical information of batteries, such as the electrode-level states, electrolyte dynamics, and cyclable lithium. In [A4], Ren et al. develop busbar circuits to simulate the cell behavior within a battery module, where the interactions of multiphysics within the battery module, including cells, interconnect resistances, and temperature distributions, are analyzed.

Fault diagnosis and health prognostics are essential for the early-stage isolation and maintenance of batteries to avoid the occurrence of catastrophic failures. Motivated by this, Xie et al. [A5] propose an intelligent diagnostic scheme, where the voltmeter array-based anomaly perception, principal component analysis, and multiclass relevance vector machine are synthesized to diagnose the faults in battery packs. In [A6], Zhang et al. propose an impedance measurement method based on the circuit design and a 2-D Gaussian filter for enhancing the performance of the pseudorandom sequence method. In [A7], Meng et al. propose a hybrid approach for the end-of-life prediction of batteries, combining the Gaussian process regression and Kalman filter for the uncertainty assessment.

III. Charging Management

Fast and safe charging of batteries is a primary challenge for the popularity of EVs. This requires advanced techniques of both charging system hardware and charging strategies.

A. Charging System

Mishra et al. [A8] propose a simple and efficient scheme for an on-board charging configuration for light plug-in electric vehicles, which can realize a dual charging arrangement, i.e., utility grid and solar panel. Milas and Tatakis [A9] present the synchronous rectification bidirectional flyback converter with nonideal elements. This design is further utilized for a high equalization current BMS. In [A10], Wang et al. present a modularized boost converter circuit and the associated control strategy based on the characteristics of vehicle-to-vehicle energy interaction devices. In [A11], Mohamed et al. develop a hierarchical predictive control method for multi-port megawatt-scale charging stations that can realize real-time energy management, decide charging rates, dispatch energy storage systems, and provide grid voltage support. In [A12], Prabowo et al. propose the design guidelines for the single-phase solid-state transformer, based on the zero-voltage switching mode boundary analysis.

B. Charging Strategies

The development of the charging strategy is also one of the important subtopics of battery charging management. In [A12], Wang et al. propose a fractional model-based multi-stage charging strategy using the Moth-flame optimization algorithm, where the charging current is divided into several stages to fulfill multiple physical limitations. In [A14], Wu et al. propose a 5-stage constant current optimization strategy according to the orthogonal experiments. Wei et al. [A15] propose a novel heating-charging synergized strategy. The proposed strategy coordinates the heating and charging mode smartly to improve the cold-charging performance.

IV. Thermal Management

Thermal management is also an important topic for the battery operation. This includes two-fold concerns, i.e., thermal safety at high temperatures and battery preheating in cold climates. Zhu et al. [A16] overview various internal heating methodologies developed in recent years for lithium-ion batteries in. In [A17], Sun et al. propose a hybrid battery thermal management system with both active liquid cooling and passive cooling to prevent thermal runaway propagation in the battery module. In [A18], Chen et al. present an optimal power management strategy for plug-in hybrid electric vehicles based on Pontryagin's Minimum Principle. The battery aging and temperature rise have been considered as important indicators for the optimization of management strategies.

V. Fuel Cells

Fuel cells have already gained widespread acceptance and a growing presence due to their advantages of high energy conversion efficiency, low noise, and zero exhaust emissions. In [A19], Wang et al. propose an aging index based on the dynamic degradation of fuel cell performance under different conditions to predict the performance degradation of proton exchange membrane fuel cells (PEMFCs). In [A20], Li et al. develop a thickness-polarization degradation model based on the experimental polarization curves to explain the degradation of PEMFC. In [A21], Guo et al. propose an economic driving energy management strategy for the fuel cell electric vehicle based on the driving cycle periodicity and the velocity prediction-based energy management strategy. In [A22], Hou et al. present an energy management strategy for a fuel cell electric vehicle by combining offline optimization and online algorithms, which can guarantee optimal control, real-time performance, and high robustness in an unknown route. In [A23], Yi et al. optimize the output torque of the stators and improve the dynamic response of a permanent magnet synchronous motor (PMSM) for the air compressor of a fuel cell via mathematical modeling and multiobjective optimization. In [A24], Li et al. conduct a quantitative comparison of topologies and sensitivity analysis of system parameters of four fuel cell hybrid topologies of electric vehicles.

VI. Energy Management

Energy management is essential for the optimized operation of hybrid electric vehicles, attributed to its potential to improve fuel economy and other relevant vehicle performance.

In [A25], Xing et al. present a deep Q network (DQN)-based thermal constrained energy management strategy for the railway co-phase system integrated with an energy storage system to reduce the reactive power injection into the three-phase power grid. In [A26], Sun et al. develop a model-free bidirectional synchronous rectification control scheme for an LLC-based energy storage system in electric-vehicle energy route to address the limitations such as high cost of current sensing, difficulty of high voltage sensing, narrow operating range, or high computational burden. Li et al. [A27] establish a net power optimization control method based on extremum search and model-free adaptive control of PEMFC power generation systems. In [A28], Zhang et al. propose an adaptive dynamic surface control method with disturbance observers to counteract the adverse effects of external disturbances and improve the control accuracy of hybrid energy source systems. In [A29], Radrizzani et al. propose a co-design optimization method that finds the optimal hybrid battery pack configuration to minimize the race time. In [A30], Strajnikov et al. modify the classical electronic capacitor control structure of grid-connected power converters, suggesting using the dc-link side terminals to emulate a frequency-variant capacitor rather than a constant one.

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APPENDIX: RELATED ARTICLES

[A1] Z. Wei, K. Liu, X. Liu, Y. Li, L. Du, and F. Gao, "Multi-level data-driven battery management: From internal sensing to big data utilization," *IEEE Trans. Transport. Electrific.*, vol. 9, no. 4, pp. 4805–4823, Dec. 2023.

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[A12] Y. Prabowo, S. Sharma, S. Bhattacharya, A. K. Tripathi, and V. Bhavaraju, "ZVS boundary analysis and design guideline of MV grid-compliant solid-state transformer for DC fast charger applications," in *Proc. IEEE Energy Convers. Congr. Expo. (ECCE)*, Oct. 2022, pp. 1–8.

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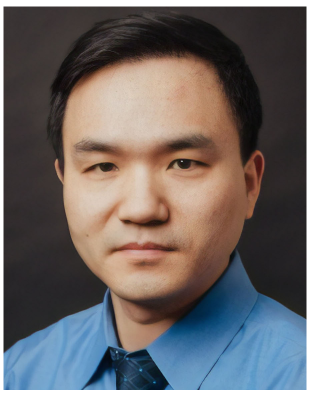

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