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EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: BATTERY ENERGY STORAGE AND MANAGEMENT SYSTEMS

Battery energy storage and management systems constitute an enabling technology for more sustainable transportation and power grid systems. On the one hand, emerging materials and chemistries of batteries are being actively synthesized to continually improve their energy density, power density, cycle life, charging rate, etc. On the other hand, advanced battery management systems (BMSs) are being intensively developed to guarantee the safety, reliability, efficiency, and cost-effectiveness of batteries in realistic operations, as well as their integration with mechatronics. Owing to their multi-physics nature, designing high-performance batteries and their management systems requires multidisciplinary approaches, with an ever-increasing synergy of electrochemical, material, mechatronics, computer, and control disciplines.

The overarching purpose of this Special Section on ''Battery energy storage and management systems'' is to collect and illustrate the recent results of research and development endeavors to advance the research fields of batteries, their management systems, and their integration into smart grids and electrified vehicles. This Special Section has gained an enthusiastic response from academia and industry. We received 61 article submissions from different research teams worldwide, with a number of interesting design/control perspectives. According to the IEEE ACCESS policy, a considered, rigorous examination of these articles by expert reviewers was conducted, and ultimately, 19 high-caliber articles were chosen to compose this Special Section. It is believed that these articles impressively demonstrate state-of-the-art characterization, modeling, state estimation, and control methods of battery systems. We have organized these 19 articles into the following five categories: 1) Battery state-of-charge (SOC) estimation; 2) Battery health modeling and management; 3) Battery thermal modeling and charger modeling/control; 4) Energy storage integration into electrified vehicles; 5) Energy storage integration into smart grids.

Accurate battery SOC estimation is vital for safe, high-efficiency, and cost-effective battery operations, through effectively avoiding over-charge and over-discharge. As a core functionality in BMSs, various estimation algorithms have been proposed to continually improve the accuracy and robustness of SOC estimation in complicated operational conditions.

In ''State of charge estimation of battery energy storage systems based on adaptive unscented Kalman Filter with a noise statistics estimator,'' by Peng *et al.*, based on a noise statistical estimator, a new SOC estimation approach using adaptive unscented kalman filtering (AUKF) is developed. When the noise statistics of battery energy storage systems (BESSs) are unknown or inaccurate, the developed method can be used to adaptively estimate the noise statistics in the iterative process of the AUKF. The simulation and experimental results of the proposed method are compared with those of the unscented kalman filtering (UKF) and extended kalman filtering (EKF) methods.

In ''Critical review on the battery state of charge estimation methods for electric vehicles,'' by Xiong *et al.*, a taxonomy of existing SOC estimation approaches is reported. Challenges for the SOC estimation for battery packs are discussed. The review also presents some key feedback factors which are indispensable for accurate battery SOC estimation, and some possible recommendations for the development of next-generation, smarter SOC estimation algorithms.

In ''Real-time estimation of battery state of charge with metabolic grey model and LabVIEW platform,'' by Zheng *et al.*, the authors develop a battery SOC estimation method for electric vehicles based on a grey model. The metabolic grey model (MGM) introduces metabolism mechanisms to adjust the model parameters against varying conditions. The analog acquisition, communication system, and SOC estimation algorithms were hard-coded within a LabVIEW platform. The experimental results indicate that the MGM can realize battery SOC estimation in real-time, with a maximum error of 4% under various loading conditions.

In ''Robustness evaluation of extended and unscented Kalman Filter for battery state of charge estimation,'' by Huang *et al.*, the robustness of several model-based SOC estimation observers, i.e., EKF and UKF, against unknown initial SOC, current noise, and temperature effects, is examined. To better evaluate the performance of EKF and UKF, two battery models, the first-order resistor-capacitor equivalent circuit and combined models, are considered. The experimental results show that UKF generally outperforms EKF in terms of estimation accuracy and convergence rate for either battery model. Moreover, the advantages of UKF over EKF using the combined model are not as significant as the case of using the equivalent circuit model. Both EKF and UKF demonstrate strong robustness against current noise. Updating model parameters to adapt to operational temperatures increases the SOC estimation accuracy for both models.

Battery health degrades in real-world applications, in terms of capacity and power fade. A key technological challenge for developing more advanced BMSs is being able to accurately model, monitor, and manage battery health status, resulting in a prosperous, promising field of research.

In "Capacity prognostics of lithium-ion batteries using EMD denoising and multiple kernel RVM," by Zhang *et al.*, a battery capacity prognostic method, based on empirical mode decomposition (EMD) denoising and multiple kernel relevance vector machine (MKRVM) is devised. The EMD denoising is used to analyze the measured capacity data to produce noise-free capacity data, and then the battery capacity prediction model using MKRVM is created, where the MKRVM's kernel diversity is ensured by means of a multiple heterogeneous kernel learning method. The battery capacity prediction experiments unveil that the proposed MKRVM approach can forecast the battery capacity evolution accurately.

In "A comparison of online electrochemical spectroscopy impedance estimation of batteries," by Varnosfaderani *et al.*, the authors compare some methods of conducting on-line electrochemical impedance spectroscopy that has been published in the available literature. A taxonomy of such methods is introduced. This article studies the theoretical assessment of the circuits and control techniques, and then a number of simulation and experimental results are provided for battery systems.

In "remaining useful life prediction for lithium-ion batteries based on exponential model and particle filter," by Zhang *et al.*, the authors propose an algorithm based on an exponential model and particle filtering for predicting the remaining useful life of lithium-ion batteries. The US NASA prognostics center of excellence (PCoE) battery test data are processed to generate a large number of scenarios. Each scenario is exploited to predict average degradation path and final life probability distribution. The prediction results demonstrate that the proposed algorithm exhibits quite good forecasting outcomes.

Battery thermal management systems play a crucial role in maintaining a reasonably safe temperature range and enough small temperature variances for battery packs. A prerequisite for developing an efficient thermal management system is a sufficiently accurate and robust thermal model. Therefore, battery thermal modeling has been gaining attention from the community of battery energy storage and management systems. In addition, to address entrenched issues in battery charging, increasing numbers of researchers are dedicated to modeling, control, implementation, and application of high-performance battery chargers.

In "Finite element thermal model and simulation for a cylindrical Li-ion battery," by Wang *et al.*, to predict the thermal behavior of a cylindrical Li-ion battery, a finite element thermal model is established. Several simplification assumptions are made to reduce the model complexity and increase the computational efficiency. Theoretical analysis and experiments are utilized to identify the boundary conditions and thermal parameters of the battery components. The results substantiate that the error between the simulated and measured temperatures is around 10% at different ambient temperatures and discharge rates.

In "An overview on thermal safety issues of lithium-ion batteries for electric vehicle application," by Zhang *et al.*, the authors present a comprehensive review on thermal safety issues of lithium-ion batteries, from standpoints of thermal behavior and thermal runaway modeling/tests for battery cells, and safety management strategies for battery packs. Heat generation, dissipation, and accumulation mechanisms inside a battery cell are explained. Triggering factors of thermal runaway are summarized as well. Thermal runaway detection and prevention strategies are also introduced, including diverse engineering approaches.

In "Modeling and controller design of a bidirectional resonant converter battery charger," by Dalala *et al.*, a charger controller design is presented for a CLLLC-type bidirectional resonant converter with increased overall system efficiency. The controller accounts for dynamic behavior due to load variations. The controller stability is examined in the entire range of operating switching frequency. Moreover, both battery charging and regeneration modes are described and analyzed. To prove the stability and effectiveness of the controller design, a 3.5-kW converter is devised to show a stable step response, with the appropriate output voltage and current loop controllers.

Battery energy storage systems have emerged as important power sources to facilitate the deployment and penetration of electrified vehicles. The integration of battery systems into electrified powertrains is a nontrivial task that needs a holistic approach to account for mechanical, electronic, control, and information aspects.

In "Hybrid modeling of strategic loading of a marine hybrid power plant with experimental validation," by Miyazaki *et al.*, considering the energy storage device switching behavior, a hybrid simulation framework is demonstrated as an appropriate dynamic modeling tool for proper design and verification of control strategies for hybrid power plants. The developed hybrid model is validated using experiments at the Hybrid Machinery Laboratory, Norwegian University of Science and Technology. The effects that are analyzed in this study include the steady-state, transient behaviors, and losses. The transient behaviors include Generator-set dynamics and load ramps. The validation results showcase good agreement between the hybrid model and the experiments. The error in fuel consumption estimation is reported to be below 3% for all 15 tested cases, with a less than 9% deviation for the nitrogen oxide gas emissions estimation.

In "Handling stability improvement for a four-axle hybrid electric ground vehicle driven by in-wheel motors," by Liu *et al.*, the authors present a hierarchical optimization control strategy for a four-axle hybrid electric ground vehicle driven by in-wheel motors (IWMs), in order to enhance its handling stability. The upper-layer controller regulates the vehicle motion states to track the references using a nonlinear sliding mode control method. In the lower-layer controller, a control allocation method is used to distribute the torque demand among motors. The simulation and hardware-in-the-loop verification results corroborate that the proposed control strategy shows better handling stability, compared to commonly used control strategies, with potential real-time implementation.

In ''Analysis of the characteristics of solar cell array based on MATLAB/simulink in solar unmanned aerial vehicle,'' by Wang *et al.*, to assess the solar cell power system of a solar unmanned aerial vehicle (UAV), the authors develop a simulation model of solar cells. The characteristic curves of solar cells are mimicked in MATLAB/Simulink via considering changing solar intensities and external temperatures. The simulation and testing results show that the solar cells have a certain maximum power point in any condition, which is beneficial to exploring the maximum power tracking of solar cells for solar UAVs.

In ''Modeling and integration of a lithium-ion battery energy storage system with the more electric aircraft 270 V DC power distribution architecture,'' by Tariq *et al.*, the evolution of a more electric aircraft (MEA) along with the load profile for the electrical load is investigated. A high-energy-density lithium-ion ''Li iron phosphate'' battery is picked, designed, and modeled. A modified Shepherd curve-fitting model is employed to model the battery, with the consideration of the voltage polarization. The battery charger uses the phase-shifted high power bidirectional dc–dc (PSHPBD) converter. The battery integration with a 270-Vdc MEA power distribution bus is examined by using the optimal number-based harmonic model of the PSHPBD converter and a predicted peak current-based fast response control technique. The results indicate that the proposed control method is able to prevent the transformer core from saturation, thereby prolonging the life of the battery charger.

Battery energy storage can significantly assist in the development of smart grids for promoting a sustainable energy future, via frequency regulation, peak shaving, valley filling, renewables storage, etc. Examining how to integrate battery energy storage systems with smart grids has been an active area of research, with an increasing number of studies carried out from technological and/or economic perspectives.

In ''Reliability oriented modeling and analysis of vehicular power line communication for vehicle to grid (V2G) information exchange system,'' by Zhang *et al.*, the authors construct a V2G information interaction system structure to develop a vehicle power line communication (VPLC) channel model for the vehicular data collection system. The model is built in Simulink and adopts different vehicular noise models and binary frequency shift keying (BFSK) modulation. Simulation results demonstrate the feasibility of the proposed VPLC.

In ''Energy management and optimization methods for grid energy storage systems,'' by Byrne *et al.*, the authors provide a comprehensive review of energy management systems (EMSs) and optimization tools for efficient operations of energy storage in the existing and future grid infrastructure. This article presents a brief history of the grid-scale energy storage, a review of EMS architectures, and a summary of representative storage applications. It also outlines potential research directions for catalyzing energy storage applications in smart grids.

In ''Battery storage for the utility-scale distributed photovoltaic generations,'' by Mohd Nor *et al.*, the authors deliver a mixed-integer optimization, by virtue of genetic algorithm, for optimally sizing and siting a battery-sourced distributed PV generation (B-SDPVG) in distribution networks. In the optimization, the total energy loss is specified as the objective function, and the bus voltage deviations and penetrations of the B-SDPVG are derived. The PV system is modeled using 15 years of weather data and a beta probability density function. The charging and discharging controls of batteries at each hour are determined by a charge–discharge control model. Considering different time-varying voltage-dependent load models, the authors validated the advantages of the proposed algorithm in the IEEE 33 bus and the IEEE 69 bus test distribution networks.

In ''Optimal operation of residential microgrids in the harbin area,'' by Wu *et al.*, the optimization of user costs for a residential building in Harbin is discussed. Based on local electricity prices and building characteristics, this article leverages linear programming to calculate the optimal power distributions. The results demonstrate that users, on average, save approximately 15.6% electricity cost annually and save up to 55.3% in the summer.

In ''Secondary frequency regulation strategy with fuzzy logic method and self-adaptive modification of state of charge,'' by Li *et al.*, a control strategy of battery storage involved in secondary frequency regulation for automatic generation control (AGC) is put forward. The investigation of the control mode based on area control error signal and the control mode based on area regulation requirement signal in AGC produces an integrated control strategy, with the definitions of the switch timing and the output depth of the battery storage. The simulation results show that the proposed strategy is able to ameliorate the frequency regulation performance, improve the battery SOC profile, and raise the utilization rate of the generator set.

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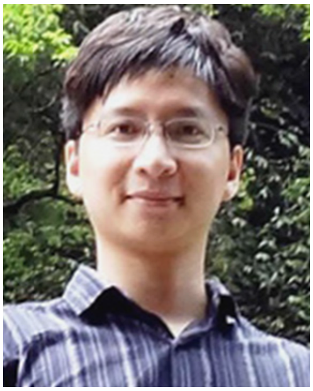

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