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Advances in Battery Manufacturing, Service, and Management Systems

Edited by
Jingshan Li • Shiyu Zhou • Yehui Han

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ADVANCES IN BATTERY MANUFACTURING, SERVICE, AND MANAGEMENT SYSTEMS

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PREFACE

Due to the fast development of mobile technology and renewable energy sources, battery, as a key energy storage device, has played an ever-growing important role in daily life and the world economy. Because of the unprecedent broad application of batteries, the commercial-scale manufacturing of batteries, as well as their service and management, are essential to ensure high quality, high reliability, and high performance of batteries. At present, major investment in battery-related research is on the new battery materials and design. However, the innovative system-level technologies on battery mass production, service, and management are also critical in order to materialize the impact of the emerging battery technology on the society and the economy at a large scale. Furthermore, the growing demands and rapid development in energy storages have introduced enormous challenges in battery manufacturing, service, and management. Therefore, there is a need to systematically address the methodology and theoretical foundation to study the issues and challenges in these areas.

This book volume is exclusively devoted to battery manufacturing, service, and management systems (BM^2S^2). It highlights the cutting edge research advances in BM^2S^2 and promotes an innovative integrated research framework responding to the challenges. There are three major parts included in this volume: manufacturing; service; and management.

The first part focuses on battery manufacturing systems, including modeling, analysis, design, and control, as well as economic and risk analyses.

Chapter 1 by Cai presents a comprehensive overview of lithium-ion battery and battery electric vehicle (BEV) manufacturing, with particular emphasis on the joining, assembly, and packaging of battery cells, modules, and packs. The reviews cover from different battery types, advantage and disadvantages of several battery-joining

technologies, to battery manufacturing process, as well as applications from battery suppliers and BEV manufacturers.

Chapter 2 by Ju, Li, Xiao, Huang, Arinez, Biller and Deng introduces an integrated model of productivity and quality in serial production lines with repair for battery manufacturing. An analytical method to evaluate line performance is developed and identification methods for downtime and quality bottlenecks are introduced. Such a work can lead to providing a quantitative tool for production engineers to analyze and improve system performance in battery manufacturing.

Chapter 3 by Chang, Li, Biller, and Xiao presents an event-based modeling (EBM) approach for the large-format power battery manufacturing systems. Through quantifying the impacts of disruption events using sensor data, and modeling market demand as an end-of-line virtual station, the whole battery production line is analyzed, and bottleneck-based improvement strategies are proposed. Finally, real-time costing method is established based on EBM.

Chapter 4 by Jin discusses the economic and ecological benefits, principles, operational strategy and processes of battery remanufacturing. In addition, three major challenges associated with batteries remanufacturing, as well as the modeling methods and analytical solutions to address these challenges are discussed, including remaining useful life estimation of end of life (EOL) batteries; decision making for EOL batteries with uncertainty; and remanufacturing operations considering balancing and compatibility issues.

Chapter 5 by Johnson, Biller, Wang, and Biller discusses a set of analytical methods with the capability of raising the economic return while reducing the financial and operational risks in the design and operations of manufacturing ecosystem, built on battery production example at General Electric. The market demand is endogenously incorporated into production design and operations optimization, leading to higher economic returns, robust order fulfillment, and derisked management of capital-intensive projects.

The second part emphasizes on information technology's impact on service system, such as data-driven reliability modeling, failure prognosis, and decision-making methodologies for battery services.

Chapter 6 by Son, Kontar, and Zhou discusses prognosis problem in battery health management in the form of classification problem. It is shown that the joint prognostic model (JPM) outperforms the conventional logistic regression. In addition, a brief discussion on the imbalanced data issue is presented, and a possible resolution for overcoming the issue is provided by oversampling the minority class (failed batteries) or to undersampling the majority class (censored batteries).

Chapter 7 by Saha reviews the conventional approaches used in estimating battery state of charge (SOC) and state of health (SOH), as well as a more advanced algorithmic approach based on Bayesian inference. Both data-driven and model-based approaches are discussed with suggestions on how to leverage the best features of both.

Chapter 8 by Xi, Jing, Lee, and Hayrapetyan investigates recent research on battery diagnostics, prognostics, and uncertainty management especially for lithium-ion (Li-ion) batteries, such as models and diagnosis algorithms for battery SOC and SOH

estimation, data-driven prognosis algorithms for predicting the remaining useful life (RUL) of battery SOC and SOH, and management of five important types of uncertainties, which play key roles for reliable battery diagnostics and prognostics.

Chapter 9 by Peng, Lu, Xie, Liu, and Liao compares several popular model aggregation techniques and presents a new alternative for lithium-ion battery prognostics. The method utilizes the mixture of probability distributions obtained from different RUL estimation models and updates the aggregation structure under a Bayesian framework. It is also extendable to more complex data-driven prognostic applications where heterogeneous models are developed.

Chapter 10 by Zhou, Man, and Son introduces a prognostic framework for estimating the RUL of batteries under hard failure. A joint modeling scheme is used to take into consideration both the degradation data and the time-to-failure data. The maximum power interval (MPI) is introduced to better assess the performance of the prognostic algorithm. Such an algorithm is suitable for applications where monitored degradation signal (e.g., internal resistance) does not have a clear preset failure threshold.

The third part addressing battery management system (BMS) intends to control and optimize battery cells, operations, and hybrid storage systems to ensure overall performance and safety, as well as EV management.

Chapter 11 by Li, Han, and Zhang reviews and compares the topologies, advantages, and disadvantages of different kinds of battery equalizers and introduces their broad applications. In addition, an integrated building block design of a distributed BMS is presented, which integrates the power electronics and the battery cell together in each building block to achieve easy reconfiguration and installation, high equalization efficiency and speed, and enhanced protection and reliability.

Since battery equalization is a critical part of the BMS, Chapter 12 by Han, Zhang, and Han presents an overview of the results to date on the issues of mathematical modeling, performance analysis, and control of battery equalization systems. In addition, the new developments in this area are discussed and the future topics are summarized.

As batteries have high energy density and relatively low cost, but low specific power and short cycle life, while supercapacitors preserve high peak power, long cycle life, but relatively low energy density and high cost, combining the two can potentially overcome the drawbacks of each single energy storage device. Chapter 13 by Ju, Zhang, Deng, and Li reviews the state of the art of battery, supercapacitor, and battery-supercapacitor hybrid energy storage system (HESS) for advanced electric vehicle applications, and discusses the optimal control methods for such HESS.

Following it, Chapter 14 by Zhang, Deng, Wu, Ju, and Li studies power management strategies for HESS in electric vehicles. The goal is to improve energy supply and power flow for better vehicle performance, energy efficiency, and extended battery life. The low-level hybrid topologies are reviewed, and high-level supervisory control methods are discussed. An integrated power management strategy to combine both time and frequency domain controls is presented.

Chapter 15 by Canis discusses the steps by which federal support for battery research has grown over the past 40 years and considers how successful the major

initiatives have been in promoting development and use of electric vehicles. It also reviews some of the major battery technologies in use and on the drawing board and the framework of international competition that is shaping this infant industry.

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PART III BATTERY MANAGEMENT SYSTEMS (BMS)