Battery Management in Electric Vehicles - Current Status and Future Trends

Citation for published version:
Das, PK 2024, 'Battery Management in Electric Vehicles - Current Status and Future Trends', *Batteries*, vol. 10, no. 6, 174. https://doi.org/10.3390/batteries10060174

Digital Object Identifier (DOI):
10.3390/batteries10060174

Published In:
Batteries

batteries MDPI

Editorial

Battery Management in Electric Vehicles—Current Status and Future Trends

Prodip K. Das

School of Engineering, University of Edinburgh, Edinburgh EH9 3FB, UK; prodip.das@ed.ac.uk

Rechargeable batteries, particularly lithium-ion batteries (LiBs), have emerged as the cornerstone of modern energy storage technology, revolutionizing industries ranging from consumer electronics to transportation [1,2]. Their high energy density, long cycle life, and rapid charging capabilities make them indispensable for powering a wide array of applications, with electric vehicles (EVs) standing out as one of the most transformative domains. The rise of EVs represents a pivotal shift in the automotive industry, driven by the urgent need to mitigate climate change and reduce greenhouse gas emissions.

Conventional internal combustion engine vehicles are major contributors to air pollution and greenhouse gas emissions, exacerbating the global climate crisis. Conversely, EVs offer a cleaner and more sustainable alternative, leveraging LiBs to propel a greener transportation revolution [3]. EVs powered by LiBs offer a promising solution to decarbonize transportation, reducing reliance on fossil fuels and mitigating the adverse impacts of vehicle emissions on human health and the environment [4]. In this context, the intersection of lithium-ion batteries, electric vehicles, and greenhouse gas emissions embodies a transformative synergy with profound implications for global sustainability.

Despite significant growth in the usage of lithium-ion batteries in EVs worldwide, this expansion is not without its challenges. The continuous demand for LiBs is anticipated to precipitate global environmental and supply chain concerns regarding critical raw materials [2,5]. The critical materials essential for LiBs, including cobalt, lithium, nickel, graphite, and manganese, are finite resources primarily mined in limited regions worldwide. This reliance on scarce resources coupled with the inevitable proliferation of battery waste poses formidable challenges for the future of electric mobility. The increasing demand for LiBs highlights the urgent need for effective battery management strategies to mitigate environmental and supply chain concerns while optimizing battery performance and lifespan, and understanding their degradation [6,7]. Improved battery management not only enhances the efficiency and longevity of EV batteries, but also facilitates their safe integration into secondary applications and promotes recycling and reuse, thereby minimizing the environmental footprint of spent EV batteries [8–11].

In response to these challenges, we have undertaken an exploration of the recent advances and future trajectories of battery management in electric vehicles within this Special Issue. This issue was crafted to provide the scientific community with up-to-date insights into the latest advancements and prospects regarding various facets of lithium-ion batteries. Researchers were invited to contribute original research articles as well as review papers for inclusion in the Special Issue titled "Battery Management in Electric Vehicles: Current Status and Future Trends".

This Special Issue presents seven research papers [12–18] and three critical reviews [19–21], meticulously scrutinized through peer review processes. These publications span a spectrum of EV battery advancements, encompassing fundamental studies of batteries to the application of neural network modeling and machine learning to optimize battery performance. Ren et al. [12], for instance, proposed a deep learning neural network and

Citation: Das, P.K. Battery Management in Electric Vehicles—Current Status and Future Trends. *Batteries* **2024**, *10*, 174. https://doi.org/10.3390/batteries10060174

Received: 13 May 2024
Accepted: 23 May 2024
Published: 23 May 2024

fine-tuning-based transfer learning strategy to accurately estimate the state of health of batteries, thereby ensuring reliable and safe operating conditions for EVs. In another study, artificial neural network modeling was employed to forecast thermal and electrical performances using an innovative cooling method [13], suggesting that direct cooling surpasses conventional air cooling and indirect cooling methods for developing next-generation thermal management techniques for high-power density batteries [13,22]. Conversely, Juan et al. [14] employed a hybrid methodology, combining simulation and reinforcement learning, to address the orienteering problem and optimize battery management under dynamic routing conditions.

To address prolonged recharging times and the limited availability of recharging stations for electric vehicles, the practice of battery sharing or swapping was introduced [15]. This initiative has garnered support from key industrial players such as Eni in Italy and Shell in the UK. It was concluded that battery swapping holds promise in alleviating traffic congestion and mitigating environmental impact. Iterative nonlinear fuzzy modeling of lithium-ion batteries was also employed to enhance their efficiency and ensure proper management [16].

The imperative to explore potential strategies for reusing, remanufacturing, or recycling batteries at the end of their lifecycle prompted an investigation into the structural optimization of battery module cases [17]. This study presents an approach aimed at enhancing the design and construction of protective housing/cases for electric vehicles, ensuring compliance with safety and reliability standards throughout various stages, from initial design to impact. Furthermore, the parametric evaluation of thermal behavior for different lithium-ion battery chemistries was showcased [18], revealing the potential of NMC ($LiNi_xMn_yCo_{1-x-y}O_2$) chemistry in future applications for lower-cost and higher-specific-energy batteries for EVs.

Complementing the research papers, three review articles focusing on wireless charging, battery packing design, and battery management are featured in this Special Issue [19–21]. Ghazizadeh et al.'s [19] review offers a comprehensive analysis of the factors influencing the efficiency of wireless charging for EV batteries, including coil designs and compensation techniques. Likewise, the second review [20] delves into the core challenges confronting battery thermal management systems within EVs, proposing innovative design approaches for battery packing to enhance efficiency and longevity. Finally, the third review [21] serves as a comprehensive roadmap to the latest technological advancements propelling EVs into the future, providing a panoramic view of innovations in storage technology, battery management systems, and power electronics, with a particular emphasis on charging strategies, methods, algorithms, and optimizations. This review encapsulates the dynamic landscape of EV technology, offering insights into the advancements shaping the vehicles of tomorrow.

Funding: Financial support from the Faraday Institution as part of its ReLiB Project (grant numbers FIRG005 and FIRG027) is gratefully acknowledged.

Acknowledgments: As the editor of this Special Issue, I wish to extend my heartfelt gratitude to all the authors for their invaluable contributions, and to the reviewers for their diligent efforts in assessing the relevance and quality of the papers. Furthermore, I am deeply appreciative of the unwavering assistance and support provided by the editorial team of *Batteries*, including our assistant editor, Spring Deng, throughout the review process.

Conflicts of Interest: The author declares no conflicts of interest.

References

1. Li, M.; Lu, J.; Chen, Z.; Amine, K. 30 years of lithium-ion batteries. *Adv. Mater.* **2018**, *30*, 1800561.
2. Harper, G.D.; Kendrick, E.; Anderson, P.A.; Mrozik, W.; Christensen, P.; Lambert, S.; Greenwood, D.; Das, P.K.; Ahmeid, M.; Milojevic, Z. Roadmap for a sustainable circular economy in lithium-ion and future battery technologies. *J. Phys. Energy* **2023**, *5*, 021501. https://doi.org/10.1088/2515-7655/acaa57.

3. Alanazi, F. Electric Vehicles: Benefits, Challenges, and Potential Solutions for Widespread Adaptation. *Appl. Sci.* **2023**, *13*, 6016. https://doi.org/10.3390/app13106016.
4. Sanguesa, J.A.; Torres-Sanz, V.; Garrido, P.; Martinez, F.J.; Marquez-Barja, J.M. A Review on Electric Vehicles: Technologies and Challenges. *Smart Cities* **2021**, *4*, 372–404. https://doi.org/10.3390/smartcities4010022.
5. Dunn, J.; Slattery, M.; Kendall, A.; Ambrose, H.; Shen, S. Circularity of Lithium-Ion Battery Materials in Electric Vehicles. *Environ. Sci. Technol.* **2021**, *55*, 5189–5198. https://doi.org/10.1021/acs.est.0c07030.
6. Akbarzadeh, M.; Kalogiannis, T.; Jaguemont, J.; Jin, L.; Behi, H.; Karimi, D.; Beheshti, H.; Van Mierlo, J.; Berecibar, M. A comparative study between air cooling and liquid cooling thermal management systems for a high-energy lithium-ion battery module. *Appl. Therm. Eng.* **2021**, *198*, 117503. https://doi.org/10.1016/j.applthermaleng.2021.117503.
7. Andriunas, I.; Milojevic, Z.; Wade, N.; Das, P.K. Impact of solid-electrolyte interphase layer thickness on lithium-ion battery cell surface temperature. *J. Power Sources* **2022**, *525*, 231126. https://doi.org/10.1016/j.jpowsour.2022.231126.
8. Cusenza, M.A.; Guarino, F.; Longo, S.; Mistretta, M.; Cellura, M. Reuse of electric vehicle batteries in buildings: An integrated load match analysis and life cycle assessment approach. *Energy Build.* **2019**, *186*, 339–354. https://doi.org/10.1016/j.enbuild.2019.01.032.
9. Attidekou, P.S.; Milojevic, Z.; Muhammad, M.; Ahmeid, M.; Lambert, S.; Das, P.K. Methodologies for large-size pouch lithium-ion batteries end-of-life gateway detection in the second-life application. *J. Electrochem. Soc.* **2020**, *167*, 160534. https://doi.org/10.1149/1945-7111/abd1f1.
10. Christensen, P.A.; Wise, M.S.; Attidekou, P.S.; Dickmann, N.A.; Lambert, S.M.; Das, P.K. Thermal and mechanical abuse of electric vehicle pouch cell modules. *Appl. Therm. Eng.* **2021**, *189*, 116623. https://doi.org/10.1016/j.applthermaleng.2021.116623.
11. Fordham, A.; Milojevic, Z.; Giles, E.; Du, W.; Owen, R.E.; Michalik, S.; Chater, P.A.; Das, P.K.; Attidekou, P.S.; Lambert, S.M. Correlative non-destructive techniques to investigate aging and orientation effects in automotive Li-ion pouch cells. *Joule* **2023**, *7*, 2622–2652. https://doi.org/10.1016/j.joule.2023.10.011.
12. Ren, Z.; Du, C.; Zhao, Y. A Novel Method for State of Health Estimation of Lithium-Ion Batteries Based on Deep Learning Neural Network and Transfer Learning. *Batteries* **2023**, *9*, 585. https://doi.org/10.3390/batteries9120585.
13. Garud, K.S.; Han, J.-W.; Hwang, S.-G.; Lee, M.-Y. Artificial Neural Network Modeling to Predict Thermal and Electrical Performances of Batteries with Direct Oil Cooling. *Batteries* **2023**, *9*, 559. https://doi.org/10.3390/batteries9110559.
14. Juan, A.A.; Marugan, C.A.; Ahsini, Y.; Fornes, R.; Panadero, J.; Martin, X.A. Using Reinforcement Learning to Solve a Dynamic Orienteering Problem with Random Rewards Affected by the Battery Status. *Batteries* **2023**, *9*, 416. https://doi.org/10.3390/batteries9080416.
15. Neroni, M.; Herrera, E.M.; Juan, A.A.; Panadero, J.; Ammouriova, M. Battery Sharing: A Feasibility Analysis through Simulation. *Batteries* **2023**, *9*, 225. https://doi.org/10.3390/batteries9040225.
16. Andújar, J.M.; Barragán, A.J.; Vivas, F.J.; Enrique, J.M.; Segura, F. Iterative Nonlinear Fuzzy Modeling of Lithium-Ion Batteries. *Batteries* **2023**, *9*, 100. https://doi.org/10.3390/batteries9020100.
17. Szabo, I.; Scurtu, L.I.; Raboca, H.; Mariasiu, F. Topographical Optimization of a Battery Module Case That Equips an Electric Vehicle. *Batteries* **2023**, *9*, 77. https://doi.org/10.3390/batteries9020077.
18. Buidin, T.I.; Mariasiu, F. Parametric Evaluation of Thermal Behavior for Different Li-Ion Battery Chemistries. *Batteries* **2022**, *8*, 291. https://doi.org/10.3390/batteries8120291.
19. Ghazizadeh, S.; Ahmed, K.; Seyedmahmoudian, M.; Mekhilef, S.; Chandran, J.; Stojcevski, A. Critical Analysis of Simulation of Misalignment in Wireless Charging of Electric Vehicles Batteries. *Batteries* **2023**, *9*, 106. https://doi.org/10.3390/batteries9020106.
20. Widyantara, R.D.; Zulaikah, S.; Juangsa, F.B.; Budiman, B.A.; Aziz, M. Review on Battery Packing Design Strategies for Superior Thermal Management in Electric Vehicles. *Batteries* **2022**, *8*, 287. https://doi.org/10.3390/batteries8120287.
21. Lipu, M.S.; Mamun, A.A.; Ansari, S.; Miah, M.S.; Hasan, K.; Meraj, S.T.; Abdolrasol, M.G.M.; Rahman, T.; Maruf, M.H.; Sarker, M.R.; et al. Battery Management, Key Technologies, Methods, Issues, and Future Trends of Electric Vehicles: A Pathway toward Achieving Sustainable Development Goals. *Batteries* **2022**, *8*, 119. https://doi.org/10.3390/batteries8090119.
22. Tan, X.; Lyu, P.; Fan, Y.; Rao, J.; Ouyang, K. Numerical investigation of the direct liquid cooling of a fast-charging lithium-ion battery pack in hydrofluoroether. *Appl. Therm. Eng.* **2021**, *196*, 117279. https://doi.org/10.1016/j.applthermaleng.2021.117279.