vehicles

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Editorial

Advanced Storage Systems for Electric Mobility

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1. Introduction

Electrified vehicles (EVs) are increasingly integrated into modern air, road, and water transportation systems. This process was accelerated in the European Union by the preliminary decision to ban the commercialization of light- and medium-duty vehicles with non-zero carbon emissions beginning in 2035. However, market adoption of EVs faces challenges due to technical, environmental, and economic factors.

EVs typically use rechargeable batteries for energy storage, although hybrid electric storage systems (HESSs), which combine batteries with supercapacitors, are also explored in the literature. HESSs exploit the higher power density, the longer operative life, and the negligible aging effects of supercapacitors [1,2]. Today's batteries are characterized by unsatisfactory energy and power densities and charge current and are prone to degradation if not correctly controlled. This is particularly critical in aerospace applications because of its stringent weight and safety constraints.

The battery management system (BMS) has a critical role in terms of battery health and safety because it not only estimates the state of charge (SOC), state of health (SOH), and remaining useful life (RUL) but also performs charge balancing and temperature control. Rule-based controllers or look-up tables are proposed as short-term technologies to improve energy consumption and minimize battery aging. Recently, artificial intelligence (AI) has been introduced to optimize the operation of the BMS based on online measurements of sensors that monitor the electrical and physical state of the battery. AI algorithms have the advantage, over traditional physical-based methods, of not requiring a deep knowledge of the multi-domain processes that take place in battery packs. Moreover, they are computationally efficient but require a large amount of data for their development, training, and validation. However, the use of advanced controllers like model predictive control (MPC) is not a technology ready to be implemented because of the very high onboard computational load [3].

The need to reduce the environmental impact of battery production and disposal, for example, by encouraging recycling, finding new materials, and lessening battery aging (Contribution 2) can help to reach the break-even point in terms of distance traveled that makes electric vehicles less carbon-intensive than vehicles equipped with internal combustion engines [4–6]. The second life of the battery, i.e., the possibility to use batteries in less demanding applications like stationary energy storage services after they are no longer suitable for transportation, is another interesting way to reduce the environmental impact of battery production and disposal [7].

Another concern in the design of battery packs for automotive applications is the location of the battery, which has to take into account different aspects like the minimization of mass and occupied space, the effect on the vehicle's center gravity (and, consequently, drivability), the necessity of managing thermal control, and the need to ensure battery protection in case of impacts [8].

This Special Issue aimed to provide a platform for sharing knowledge on advanced storage systems by seeking review papers and original research highlighting improvements in range, cost, safety, and environmental impact across all transportation sectors.

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2. Overview of Published Articles

The response to the present call for papers was good in terms of the number of submissions (8) and publications (5). An overview of the contribution to this Special Issue is reported in Table 1. Despite the Special Issue being open to all means of transport, all contributions submitted to this Special Issue are related to the automotive industry. This can be explained easily since most of the research proposed in the scientific literature about the optimal management of batteries is in the automotive field, even if the need to develop advanced battery technologies also involves other means of transportation, particularly the aerospace industry. However, in this last field, the higher required level of confidentiality makes it difficult to publish information on new technologies and advanced solutions for electrified vehicles.

Table 1. Overview of the contributions to the Special Issue.

	Authors	First Affiliation	Country	Focus
1	Armenta-Déu, C.; Cortés, H.	Facultad de Ciencias Físicas, Universidad Complutense de Madrid	Spain	Potential energy recovery
2	Pipicelli, M.; Sessa, B.; De Nola, F.; Gimelli, A.; Di Blasio	Institute of Sciences and Technologies for Sustainable Energy and Mobility (STEMS)	Italy	Optimal management of hybrid energy storage systems (batteries and supercapacitors)
3	Belingardi, G.; Scattina, A.	DIMEAS Department of Mechanical and Aerospace Engineering, Politecnico di Torino	Italy	Integration of the battery pack in the vehicle structure
4	Lipu, M.; Miah, M.; Jamal, T.; Rahman, T.; Ansari, S.; Rahman, M.; Ashique, R.; Shihavuddin, A.; Shakib, M.	Department of Electrical and Electronic Engineering, Green University of Bangladesh	Bangladesh	Use of artificial intelligence for battery health diagnostics, fault analysis, and thermal management
5	Saiteja, P.; Ashok, B.; Upadhyay, D.	Vellore Institute of Technology	India	Advanced controllers for electric motors to optimize the utilization of batteries

The paper of Arment et al. (Contribution 1) addresses kinetic energy recovery in the case of descending routes and, therefore, accounts for the variation of potential energy in the energy analysis of the electric vehicle, which is an aspect that is usually neglected. The increase in battery charge during descent is calculated and converted into a driving range extension. In this scope, the paper proposes an equation to calculate the increase in the driving range as a function of characteristic parameters that include the specifications of the vehicle, the battery, and the driving conditions. Sensors are used in experimental tests to obtain information about the operating conditions of the battery and electric motor during braking and descent.

In Contribution 2 of the Special Issue, Pipicelli et al. 2023 propose several configurations of hybrid energy storage systems (HESSs) and compare them in terms of battery aging under real-world operating conditions. The aging of the battery is estimated with an empirical equation depending on the state of charge, cell temperature, and charge. Passive and semi-active topologies are considered for the HESS. The use of HESSs was found to reduce ohmic losses by up to 2.4%. The results show that the passive topology is more effective at reducing the peak of currents, while the semi-active topology can reduce the aging of the battery up to 10 times.

The investigation of Belingardi et al. (Contribution 3) deals with the protection of the battery pack in case of crashes, and particular side impacts, for battery packs integrated in the vehicle structure. The paper includes an interesting review of the location and design of battery packs in automotive vehicles on the market as a starting point to propose an interplay between the battery pack enclosure and the vehicle's underbody structure. A simplified model is used to evaluate the effectiveness of different configurations, and the results show that the proper selection of wall thickness in the interplay must be performed to ensure battery protection.

The paper of Lipu et al., Contribution 4, is a review of artificial intelligence approaches to enhance the battery management system (BMS) in electric vehicles. They found that several methodologies belonging to AI have been adopted in the scientific literature to accurately predict battery SOC, SOH, and RUL and avoid overheating, overcharging, and overdischarging. AI is often combined with optimization algorithms to improve the accuracy of the prediction, but this requires complex and long calculations. The prediction is based on the acquisition of information about voltage, current, temperature, etc. that is collected and preserved in a cloud-based database.

Saietja et al. (Contribution 5) propose a new supervisory controller for switched reluctance machines based on adaptive self-learning methods to manage fluctuations of battery SOC in real-time scenarios. The new controller achieves better battery utilization than traditional methods like PID and fuzzy logic.

3. Concluding Insight and Directions of Further Research

Despite the differences in the topics and the methodologies of the contributions, they share the same main goals, i.e., the need to reduce environmental impact by increasing battery life and the necessity of ensuring safety in BEV operation.

According to Contribution 2, a way to increase battery life is the adoption of hybrid energy storage systems. HESSs are also suitable to improve regenerative braking efficiency [9], and this could be an interesting bridge between the two studies proposed in contributions 1 and 2.

Another path to increase the battery life and, consequently, reduce its environmental impact is the adoption of advanced BMSs based on AI [10], as proposed also in contribution 4, while in contribution 5, intelligent controllers are considered to minimize the consumption of battery energy in an electric vehicle during traction and in regeneration. As pointed out in Contribution 5, such advanced techniques are required because of the nonlinear behavior of batteries, which introduces multiple uncertainties in the estimation of SOC.

The different focus of the submitted contributions proves the necessity of adopting, in the future, a holistic approach to the sustainability of electric vehicles that considers the entire life cycle of batteries, from manufacturing to disposal, through their optimal use under realistic driving conditions.

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List of Contributions:

1. Armenta-Déu, C.; Cortés, H. Analysis of Kinetic Energy Recovery Systems in Electric Vehicles. *Vehicles* **2023**, *5*, 387–403. https://doi.org/10.3390/vehicles5020022.
2. Pipicelli, M.; Sessa, B.; De Nola, F.; Gimelli, A.; Di Blasio, G. Assessment of Battery–Supercapacitor Topologies of an Electric Vehicle under Real Driving Conditions. *Vehicles* **2023**, *5*, 424–445. https://doi.org/10.3390/vehicles5020024.
3. Belingardi, G.; Scattina, A. Battery Pack and Underbody: Integration in the Structure Design for Battery Electric Vehicles—Challenges and Solutions. *Vehicles* **2023**, *5*, 498–514. https://doi.org/10.3390/vehicles5020028.
4. Lipu, M.; Miah, M.; Jamal, T.; Rahman, T.; Ansari, S.; Rahman, M.; Ashique, R.; Shihavuddin, A.; Shakib, M. Artificial Intelligence Approaches for Advanced Battery Management System in Electric Vehicle Applications: A Statistical Analysis towards Future Research Opportunities. *Vehicles* **2024**, *6*, 22–70. https://doi.org/10.3390/vehicles6010002.

5. Saiteja, P.; Ashok, B.; Upadhyay, D. Evaluation of Electric Vehicle Performance Characteristics for Adaptive Supervisory Self-Learning-Based SR Motor Energy Management Controller under Real-Time Driving Conditions. *Vehicles* **2024**, *6*, 509–538. https://doi.org/10.3390/vehicles6010023.

References

1. Dong, Z.; Zhang, Z.; Li, Z.; Li, X.; Qin, J.; Liang, C.; Han, M.; Yin, Y.; Bai, J.; Wang, C.; et al. A Survey of Battery–Supercapacitor Hybrid Energy Storage Systems: Concept, Topology, Control and Application. *Symmetry* **2022**, *14*, 1085. [CrossRef]
2. Shi, J.; Xu, B.; Shen, Y.; Wu, J. Energy Management Strategy for Battery/Supercapacitor Hybrid Electric City Bus Based on Driving Pattern Recognition. *Energy* **2022**, *243*, 122752. [CrossRef]
3. Bemporad, A.; Bernardini, D.; Long, R.; Verdejo, J. *Model Predictive Control of Turbocharged Gasoline Engines for Mass Production*; SAE International: Warrendale, PV, USA, 2018.
4. Shafique, M.; Azam, A.; Rafiq, M.; Luo, X. Life Cycle Assessment of Electric Vehicles and Internal Combustion Engine Vehicles: A Case Study of Hong Kong. *Res. Transp. Econ.* **2022**, *91*, 101112. [CrossRef]
5. Zheng, G.; Peng, Z. Life Cycle Assessment (LCA) of BEV's Environmental Benefits for Meeting the Challenge of ICExit (Internal Combustion Engine Exit). *Energy Rep.* **2021**, *7*, 1203–1216. [CrossRef]
6. Kawamoto, R.; Mochizuki, H.; Moriguchi, Y.; Nakano, T.; Motohashi, M.; Sakai, Y.; Inaba, A. Estimation of CO_2 Emissions of Internal Combustion Engine Vehicle and Battery Electric Vehicle Using LCA. *Sustainability* **2019**, *11*, 2690. [CrossRef]
7. Han, X.; Lu, L.; Zheng, Y.; Feng, X.; Li, Z.; Li, J.; Ouyang, M. A review on the key issues of the lithium ion battery degradation among the whole life cycle. *eTransportation* **2019**, *1*, 100005. [CrossRef]
8. Arora, S.; Shen, W.; Kapoor, A. Review of mechanical design and strategic placement technique of a robust battery pack for electric vehicles. *Renew. Sustain. Energy Rev.* **2016**, *60*, 1319–1331. [CrossRef]
9. Jin, L.; Zheng, Y.; Li, J.; Liu, Y. A Study of Novel Regenerative Braking System Based on Supercapacitor for Electric Vehicle Driven by In-Wheel Motors. *Adv. Mech. Eng.* **2015**, *7*, 1687814015573762. [CrossRef]
10. Hannan, M.A.; Lipu, M.S.H.; Hussain, A.; Saad, M.H.; Ayob, A. Neural network approach for estimating the state of charge of lithium-ion battery using backtracking search algorithm. *IEEE Access* **2018**, *6*, 10069–10079. [CrossRef]