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Comparative Analysis of Battery Performance for Electric Micromobility BLDC Motors

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Abstract

The rapid growth of electric micromobility (EMM) encompassing e-scooters, e-bikes, and other lightweight electrically powered vehicles has intensified the need for a rigorous, application-specific understanding of the energy-storage technologies that power them. This paper presents a comprehensive comparative analysis of four battery chemistries, namely Lead-Acid (Pb-Acid), Nickel-Cadmium (Ni-Cd), Nickel-Metal Hydride (NiMH), and Lithium-Ion (Li-ion), for driving Brushless DC (BLDC) motors in urban EMM applications. A MATLAB/Simulink model integrating a battery block, a three-phase inverter, a Pulse-Width-Modulation generator, and a Proportional-Integral speed controller was developed to reproduce realistic operating conditions at a reference speed of 50 km/h. Each chemistry was evaluated across three practical configurations High Capacity, Balanced Performance, and Light and Economical using a consistent set of dynamic and steady-state indicators: rise time, RMS voltage, peak-to-peak voltage, slew rate, discharge behaviour, and state-of-charge (SOC) retention. The results demonstrate that Lithium-Ion batteries consistently outperform the competing chemistries, delivering the highest RMS voltage (50.90 V), the smallest voltage fluctuation, a rapid rise time (2.577 s), and a high slew rate (15.510 V/s), together with the flattest discharge curve under high current. NiMH offers competitive dynamic behaviour but weaker charge retention, Ni-Cd exhibits the best SOC stability yet suffers from memory effects, and Lead-Acid remains the least suitable for dynamic urban duty. These findings provide clear, quantitative guidance for selecting batteries in the design of sustainable, high-performance micromobility systems.

Keywords: electric micromobility; battery storage system; lithium-ion batteries; battery performance; energy efficiency; bldc motor dynamics; urban sustainability

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1. Introduction

The rise of electric micromobility solutions, including e-scooters, e-bikes, and Segways, represents a significant shift towards sustainable urban transportation [1]. These compact and electrically powered vehicles offer new opportunities to reduce emissions and relieve traffic congestion, yet they also introduce unique challenges in terms of safety, reliability, and performance. Because these vehicles operate in dense urban environments characterized by frequent starts and stops, sharp accelerations, and short trip distances, their powertrains are subjected to highly dynamic load profiles that place stringent demands on the energy-storage subsystem. Consequently, the battery is not merely an ancillary component but a determining factor in the overall behaviour, efficiency, and user acceptance of the vehicle.

Battery performance plays a critical role in these vehicles, as highlighted in our previous study [3], which emphasized that the choice of battery technology directly impacts the efficiency, range, and environmental footprint of micromobility vehicles. Complementary work has shown that different micromobility vehicles exhibit distinct acceleration and braking behaviours, suggesting that both infrastructure and rider-behaviour adaptations are necessary to improve safety [2]. In parallel, Alcázar-García and Martínez [4] noted that optimizing battery technologies is essential for smart cities, where the integration of energy-efficient micromobility solutions can significantly enhance urban mobility. Other researchers have explored the environmental impact of lithium-ion batteries, particularly their carbon footprint, which remains a key concern despite their superior performance compared with older chemistries [5].

Despite these advancements, a critical gap remains in the existing literature: there is no comprehensive recommendation on which type of battery technology is most suitable for the specific micromobility vehicles dedicated to urban EMM. This absence of targeted guidance leaves engineers and designers without clear criteria for selecting the optimal battery for applications that demand a careful balance between cost, performance, environmental impact, and adaptability to the physical constraints of micromobility systems. In practice, designers frequently rely on generic datasheet figures that do not capture the transient electrical behaviour of a chemistry when it is coupled to a BLDC drive operating under closed-loop speed control.

To address this gap, the present study compares four popular battery technologies Lithium-Ion, Nickel-Metal Hydride, Nickel-Cadmium, and Lead-Acid for electric micromobility applications, analyzing their performance to determine the most suitable option for micromobility vehicles. Key performance indicators such as rise time, RMS voltage, peak-to-peak voltage, and slew rate are examined to evaluate the dynamic response, stability, and overall efficiency of each chemistry, and these are complemented by an analysis of discharge characteristics and state-of-charge retention. The study aims to guide battery selection by identifying the chemistries that best balance speed stability, response efficiency, and reliability, thereby supporting engineers and researchers in developing high-performing, sustainable micromobility solutions for urban transport. The remainder of this paper is organized as follows: Section 2 reviews related work on micromobility and battery technologies; Section 3 describes the simulation methodology and the battery configurations considered; Section 4 presents and analyzes the results; Section 5 discusses their implications; and Section 6 concludes the paper and outlines directions for future research.

2. Literature Review

Research on electric micromobility has expanded rapidly as cities seek low-emission alternatives to private cars for short journeys. A comprehensive review of charging infrastructure for micromobility vehicles identified the technologies and challenges associated with deploying such systems at scale, underlining that energy-storage and charging behaviour are central to the viability of these vehicles [1]. From a safety and dynamics perspective, field experiments have demonstrated that different micromobility vehicles affect longitudinal control in distinct ways, with measurable differences in acceleration and braking that are directly influenced by the responsiveness of the powertrain [2]. These findings motivate the study of how a given battery chemistry shapes the transient response of the drive.

The relationship between battery technology and urban performance has also been examined at the systems level. Studies on micromobility and smart cities have analyzed efficiency, energy consumption, and range for electric vehicles, concluding that battery optimization is a prerequisite for the successful integration of micromobility into intelligent transport networks [4]. At the same time, environmental assessments based on cradle-to-gate life-cycle analysis have quantified the carbon footprint of micromobility batteries, drawing attention to the trade-off between the strong operational performance of lithium-ion cells and the environmental burden associated with their production [5]. Our own earlier review of battery technologies for micromobility surveyed the strengths and limitations of the principal chemistries and established the comparative framework that the present work extends through detailed dynamic simulation [3].

With respect to the individual chemistries, the literature reports a wide range of nominal voltages, capacities, and cut-off characteristics that depend heavily on the target application. Lithium-ion cells designed for electric scooters have been modelled electrochemically and mechanically to capture their behaviour under realistic loads [6], while charging-profile and thermal-behaviour studies of lead-acid batteries used in electric scooters have characterized their slower response and pronounced voltage sag under high current [7,10]. Nickel-based chemistries have likewise been studied in the context of electric vehicles, with evaluations of nickel-cadmium cells for traction use [11] and conversions of scooters to nickel-metal-hydride hybrid configurations [12]. Broader surveys of electric-vehicle batteries have compared these options in terms of energy density, cycle life, and cost [8,9]. Taken together, this body of work provides the parameter ranges adopted in the present study, but it stops short of a unified, closed-loop comparison of the four chemistries driving the same BLDC motor under identical control, which is precisely the contribution of this paper.

3. Simulation Methodology

3.1 Model Overview

The simulation model was designed to evaluate the performance of a Brushless DC (BLDC) motor powered by different battery types in an electric micromobility application. The model comprises several key components, including the battery system, the BLDC motor, a Proportional-Integral (PI) controller, and the associated power electronics. The battery block provides the necessary power, while the system continuously tracks the battery's voltage, current, and state of charge. This arrangement makes it possible to observe not only the steady-state speed of the vehicle but also the transient electrical quantities that distinguish one chemistry from another.

The BLDC motor is driven by a three-phase inverter, which is controlled by a Pulse-Width-Modulation (PWM) generator that receives commands from the PI controller. The PI controller compares the reference speed, set at 50 km/h, with the actual speed of the motor and adjusts the duty cycle of the PWM signal to maintain the desired speed. Hall-effect sensors are used to detect the rotor position and to provide the feedback signals required by the motor's commutation logic. Because the same controller, inverter, and mechanical load are retained across all experiments, any difference in the observed response can be attributed to the battery chemistry rather than to the control strategy. The complete model is illustrated in Figure 1.

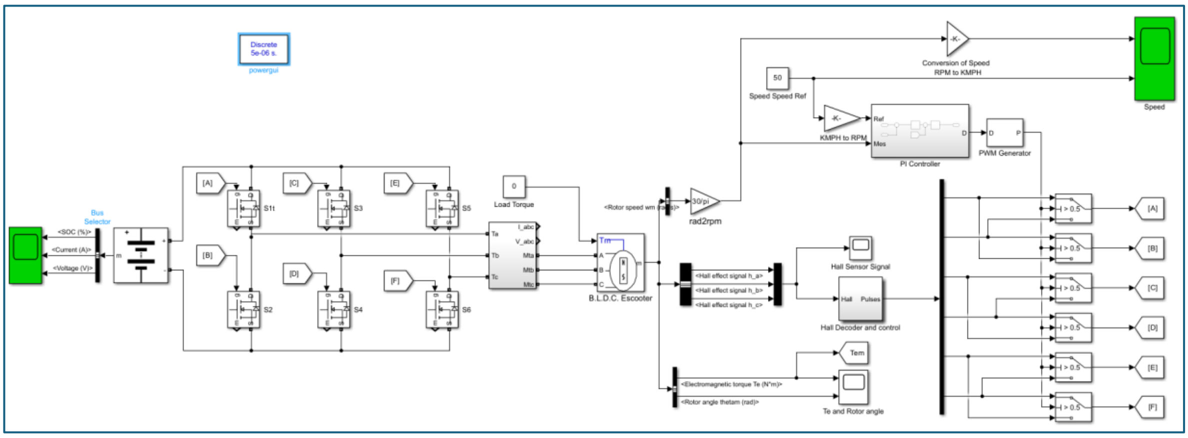

Fig. 1 Simulation model of the BLDC drive for electric micromobility.

The batteries were tested under three configurations in order to simulate different operational scenarios encountered in electric micromobility vehicles. The High Capacity configuration is designed to maximize battery autonomy, providing longer operational times and rapid response, and is therefore best suited to applications requiring extended range and frequent power demands. The Balanced Performance configuration offers a middle ground between capacity and weight, making it appropriate for general-purpose use where a compromise between efficiency and mobility is required. The Light and Economical configuration focuses on reducing overall weight and cost, catering to applications where a lower capacity is acceptable and cost-effectiveness is the priority. The nominal parameters adopted for each chemistry are summarized in Table 1.

Table 1 Battery parameters used for the Simulink comparison.

Parameter	Lithium-Ion	Lead-Acid	Nickel-Cadmium (NiCd)	Nickel-Metal Hydride (NiMH)
Nominal Voltage (V)	36 / 48 [6]	48 / 72 [7]	1.2 per cell / 48 pack [8]	1.2 per cell / 48 pack [9]
Rated Capacity (Ah)	≈25 [9]	12–30 (≈21) [10]	≈25 [11]	6–25 (≈15.5) [12]
Initial SOC (%)	100 [6]	100 [10]	100 [9]	100 [12]
Cut-off Voltage (V)	2.8–3.0 per cell [6]	42.5 pack [10]	1.0 per cell [7]	1.0 per cell [9]
Capacity Retention (%)	90–100 [9]	97.3 [10]	80–90 [8]	90 [12]

3.2 Performance Metrics

Four complementary metrics were selected to characterize the electrical behaviour of each battery under the dynamic conditions typical of urban micromobility. The rise time measures the time required for the battery voltage to stabilize after a load is applied and therefore reflects the responsiveness of the chemistry to sudden power demands, a quality that is essential during the frequent accelerations of city riding. The RMS voltage indicates the effective voltage delivered over the operating cycle and is crucial for maintaining consistent motor speed across varying load conditions. The peak-to-peak voltage quantifies the extent of voltage fluctuation under load; smaller fluctuations translate into more reliable and stable power delivery, which in turn produces smoother vehicle behaviour. Finally, the slew rate assesses how quickly the battery can adapt to rapid changes in load, an important factor in sustaining performance during the repeated starts and stops that characterize urban environments. Considered together, these four indicators provide a detailed picture of the strengths and limitations of each chemistry and form the basis of the comparison presented in the following section.

4. Results and Analysis

4.1 Dynamic Speed Performance

This section evaluates the performance of the four battery types Lead-Acid, Lithium-Ion, Nickel-Cadmium, and Nickel-Metal Hydride across the three configurations described above. The measured values of rise time, RMS voltage, peak-to-peak voltage, and slew rate are reported in Table 2, and the corresponding speed responses are shown in Figure 2.

Table 2 Performance metrics across battery types.

Battery Type	Rise Time (s)	RMS Voltage (V)	Peak-to-Peak Voltage (V)	Slew Rate (V/s)
Lead-Acid	2.602	50.60	71.42	15.370
Lithium-Ion	2.577	50.90	71.38	15.510
Nickel-Cadmium	2.606	50.60	71.37	15.338
Nickel-Metal Hydride	2.568	50.59	71.29	15.548

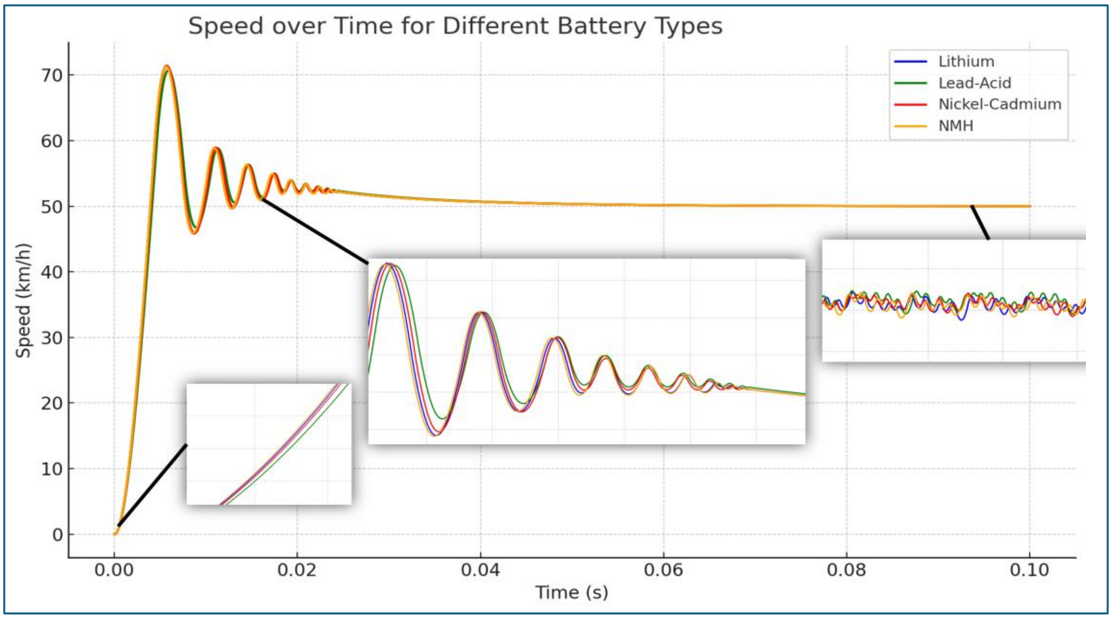

Fig. 2 Comparative speed performance of the four battery technologies.

The dynamic behaviour of each chemistry reveals clear, if closely spaced, differences. In terms of rise time, Lithium-Ion batteries achieved a near-optimal value of 2.577 s, only marginally longer than the 2.568 s recorded for NiMH, indicating rapid voltage stabilization after a load step. By contrast, Lead-Acid and Nickel-Cadmium exhibited longer rise times of 2.602 s and 2.606 s respectively, which could hinder vehicle performance in the frequent stop-and-go scenarios common to urban mobility [3]. With respect to RMS voltage, Lithium-Ion outperformed the other technologies with the highest value of 50.90 V, ensuring a consistent power output that is essential for maintaining stable motor speeds. The remaining chemistries clustered near 50.6 V, confirming that the advantage of Lithium-Ion, while modest in magnitude, is systematic across the operating cycle.

The peak-to-peak voltage further distinguishes the chemistries in terms of stability. The smallest fluctuations were observed for NiMH and Lithium-Ion, at 71.29 V and 71.38 V respectively, underscoring their ability to deliver steady performance, whereas Lead-Acid showed the largest fluctuation at 71.42 V and therefore the least stable power delivery. Finally, the slew-rate results show that NiMH and Lithium-Ion adapt most quickly to changing power demands, with values of 15.548 V/s and 15.510 V/s, enabling them to respond rapidly to the transients of urban traffic; Lead-Acid and Nickel-Cadmium trailed at 15.370 V/s and 15.338 V/s. Overall, the enlarged views in Figure 2 confirm that all four chemistries converge to the 50 km/h reference, but Lithium-Ion and NiMH track the reference with the smallest residual ripple.

4.2 Discharge Characteristics

Figure 3 presents the discharge characteristics of the four battery types, focusing on their voltage behaviour during the discharge process under varying current loads. The Nickel-Metal Hydride battery maintains a relatively steady voltage during most of the discharge process, followed by a sharp decline near the end; at the higher currents of 13 A and 32.5 A the voltage falls more quickly, indicating a reduced runtime under heavy loads. The Lead-Acid battery displays a rapid initial decline in voltage followed by a slower decrease as time progresses, and its voltage drops significantly under higher current loads, reflecting its lower efficiency in high-current applications.

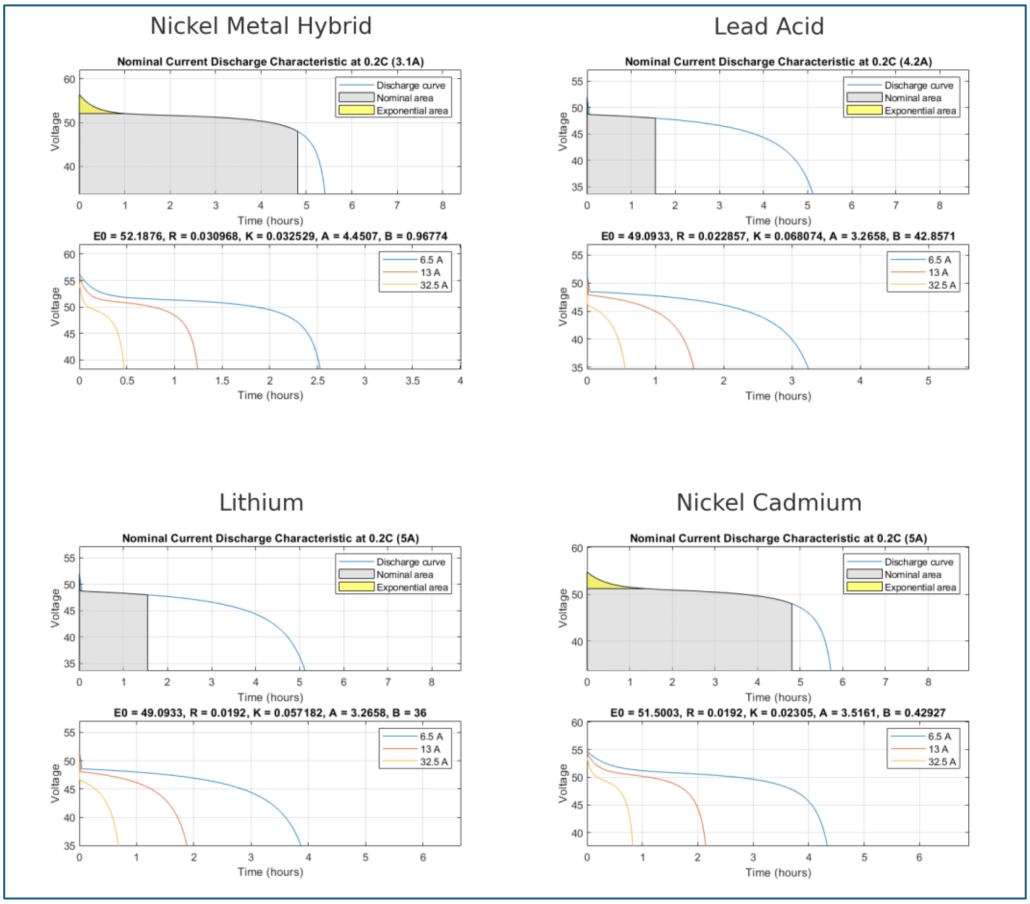

Fig. 3 Discharge characteristics of the four battery chemistries under varying current loads.

The Lithium battery, by contrast, maintains a markedly flatter discharge curve, sustaining a higher voltage throughout most of the discharge cycle before dropping steeply near the end. This behaviour allows Lithium-Ion cells to provide a longer runtime under high current loads than the other chemistries, making them particularly well suited to high-performance applications. The Nickel-Cadmium battery exhibits stable voltage during discharge more stable than Lead-Acid but less than Lithium and its voltage decreases only moderately as the current increases, indicating good performance under varying load conditions. These discharge profiles are consistent with the dynamic metrics of Section 4.1: the chemistries that hold their voltage most firmly under load are also those that exhibit the smallest fluctuations and the fastest response.

4.3 State-of-Charge Retention

Figure 4 compares the state-of-charge (SOC) retention of the four chemistries, revealing significant differences in how each maintains stored energy over time. The Lead-Acid battery, valued for its cost-effectiveness, showed a moderate SOC drop; although widely used in automotive applications, its comparatively high SOC decline suggests that it is not the best choice for long-term storage. The Lithium battery, favoured for its high energy density, exhibited a lower SOC drop than Lead-Acid, yet its drop rate remained higher than that of Nickel-Cadmium, indicating some room for improvement in long-term energy retention.

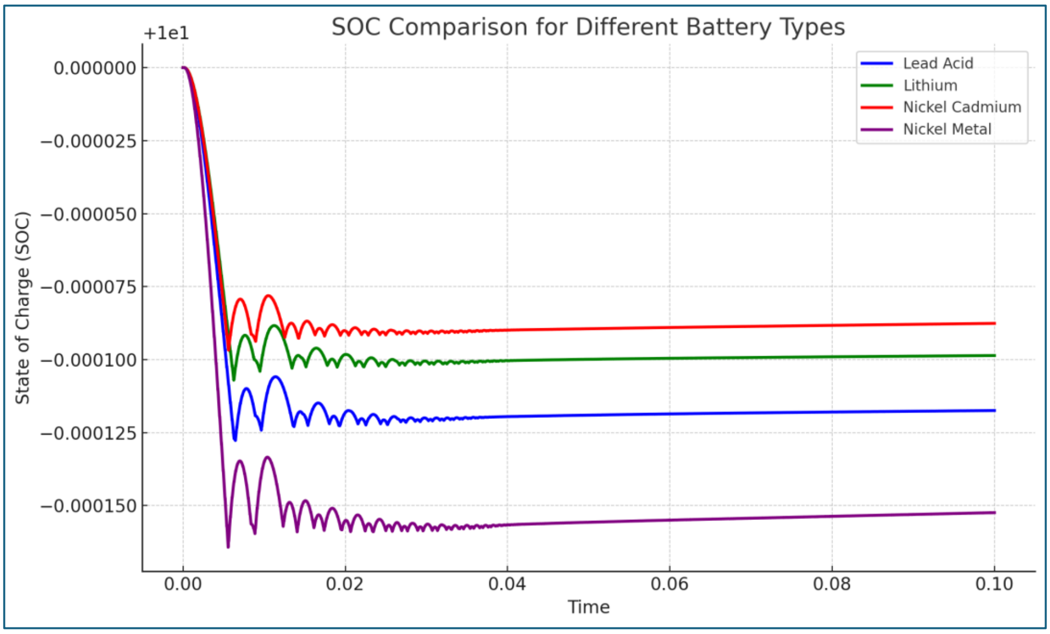

Fig. 4 State-of-charge comparison for the four battery types.

The Nickel-Cadmium battery outperformed the others in terms of SOC retention, its low SOC drop indicating a high suitability for applications that require stable energy storage over extended periods. The Nickel-Metal Hydride battery, although commonly used in hybrid vehicles, demonstrated a relatively high SOC drop and was therefore less efficient than both Nickel-Cadmium and Lithium for applications demanding prolonged charge retention. Taken as a whole, these results show that no single chemistry dominates every criterion: Lithium-Ion leads on dynamic response and discharge stability, whereas Nickel-Cadmium leads on static charge retention, a distinction that becomes important when matching a battery to a specific duty cycle.

5. Discussion

Lithium batteries deliver superior overall performance, maintaining higher voltages over extended periods, especially under high currents, and outperforming all other types across the key dynamic metrics. Despite their higher cost, their exceptional energy density, fast response times, and stable power output make them ideal for electric micromobility. Nickel-Metal Hydride batteries offer moderate performance, excelling under low current but falling behind Lithium-Ion in energy density and efficiency; although cost-effective, their high self-discharge rate and greater weight limit their suitability for modern applications. Nickel-Cadmium batteries, while durable and remarkable for their SOC stability, face environmental concerns and memory-effect issues that make them less practical for frequent short trips. Lead-Acid batteries, with their steep voltage drops under high current, suffer from slow response times and significant voltage fluctuations, which limit their efficiency in dynamic urban settings despite their low cost [3].

Through the comparative analysis conducted in this study, Lithium-Ion batteries consistently outperformed Lead-Acid, Nickel-Cadmium, and Nickel-Metal Hydride across all tested configurations. Their rapid rise times, high RMS voltage, minimal voltage fluctuations, and fast slew rates make them especially well suited to dynamic load conditions, ensuring immediate power delivery and stable performance. These attributes, combined with their superior energy density and their ability to adapt efficiently to variable urban driving conditions, reinforce Lithium-Ion technology as the most efficient and reliable solution for electric micromobility vehicles. By improving both the ecological footprint and the safety features of these vehicles, the continued adoption of Lithium-Ion batteries is expected to support the development of high-performance, sustainable urban transportation solutions. Nevertheless, the strong SOC retention of Nickel-Cadmium indicates that chemistry selection should ultimately be guided by the dominant demands of the target duty cycle rather than by a single figure of merit.

6. Conclusion

This study assessed the performance of Lead-Acid, Nickel-Cadmium, Nickel-Metal Hydride, and Lithium-Ion batteries in powering BLDC motors for electric micromobility, and identified Lithium-Ion as the superior choice owing to its rapid rise time, high energy efficiency, and stable voltage performance, all of which make it ideal for urban transportation. While Lead-Acid batteries are cost-effective, they suffer from slow response times and low energy density, and Nickel-Cadmium, despite its moderate dynamic performance and excellent charge retention, is hindered by environmental concerns and memory effects. Nickel-Metal Hydride offers a reasonable balance but falls short of Lithium-Ion on the most critical metrics. These findings underline the pivotal role of Lithium-Ion batteries in advancing reliable, efficient, and sustainable micromobility solutions. Future research could focus on quantifying the environmental impact of Lithium-Ion batteries across their full life cycle and on exploring emerging alternatives such as solid-state and sodium-ion technologies, which may further enhance the performance and sustainability of electric micromobility.

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References

[1] F. Corti, S. D. Iacono, D. Astolfi, M. Pasetti, A. Vasile, A. Reatti, and A. Flammini, "A comprehensive review of charging infrastructure for electric micromobility vehicles: Technologies and challenges," Energy Reports, vol. 12, pp. 545–567, 2024.

[2] M. Dozza, T. Li, L. Billstein, C. Svernlöv, and A. Rasch, "How do different micro-mobility vehicles affect longitudinal control? Results from a field experiment," Journal of Safety Research, vol. 84, pp. 24–32, 2023.

[3] M. Krichi, M. Fannakh, and T. Raffak, "Revolutionizing micromobility: A comprehensive review of battery technologies," in ASTFE Digital Library, Begell House Inc., 2024.

[4] D. Alcázar-García and L. R. Martínez, "Micromobility and smart cities: Efficiency, energy consumption and range analysis for electric vehicles," Renewable Energy and Environmental Sustainability, vol. 7, art. 14, 2022.

[5] H. K. Guney, C. S. Atılgan, Ö. Durmuş, M. Çelik, A. T. Gül, H. Y. C. Altıntaş, S. Erkin, and Y. Ay, "Micro mobility battery carbon footprint calculation with cradle-to-gate LCA approach."

[6] S. A. Khateeb, M. M. Farid, J. R. Selman, and S. Al-Hallaj, "Mechanical–electrochemical modeling of Li-ion battery designed for an electric scooter," Journal of Power Sources, vol. 158, no. 1, pp. 673–678, 2006.

[7] M. M. Ab Halim, K. Annuar, M. Harun, N. Anuar, M. A. M. Abid, and M. Zainuddin, "Evaluation of charging profile of lead acid battery used in electrical scooter," in Journal of Physics: Conference Series, IOP Publishing, vol. 1529, art. 032096, 2020.

[8] M. Indukala and M. Bincy, "A study on electric vehicle battery," International Research Journal of Engineering and Technology (IRJET), vol. 6, pp. 309–314, 2019.

[9] M. S. Khande, M. A. S. Patil, M. G. C. Andhale, and M. R. S. Shirsat, "Design and development of electric scooter," Energy, vol. 40, no. 60, art. 100, 2020.

[10] M. F. M. Ab Halim, K. A. M. Annuar, M. H. Harun, I. Sabirin, and M. F. A. Kamal, "Evaluation of charging profile and thermal behaviour of lead acid battery," Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, vol. 56, no. 1, pp. 124–132, 2019.

[11] W. A. Lynch, Nickel Cadmium Battery Evaluation, Modeling, and Application in an Electric Vehicle. University of Massachusetts Lowell, 1997.

[12] M. S. Alam, T. Moeller, and A. Maly, "Conversion of an Indian three-wheeler scooter into a hybrid fuel-cell Ni-MH battery vehicle and validation of the vehicle model for the Bajaj three-wheeler scooter," in 2006 IEEE Conference on Electric and Hybrid Vehicles, IEEE, pp. 1–6, 2006.