The impact of fast charging technology on battery longevity in electric vehicles

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ABSTRACT

Fast charging technology has revolutionized the electric vehicle (EV) industry by addressing range anxiety and significantly reducing charging times. However, this convenience introduces challenges concerning battery longevity, as high charging currents and elevated temperatures accelerate battery degradation. This paper investigates the mechanisms through which fast charging impacts lithium-ion batteries, including thermal stress, lithium plating, and mechanical wear. It synthesizes findings from various studies, highlighting how fast charging can shorten battery lifespan by up to 20-30% compared to standard charging methods. Strategies to mitigate these effects, such as advanced materials, adaptive charging protocols, and efficient thermal management systems, are discussed. Furthermore, the paper emphasizes the importance of standards and policies to promote sustainable fast charging practices. By balancing charging speed with long-term battery health, the EV industry can achieve widespread adoption while ensuring sustainability. This work aims to provide a comprehensive understanding of the trade-offs associated with fast charging and offers actionable insights for improving EV battery durability.

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1. INTRODUCTION

Electric vehicles (EVs) have emerged as a cornerstone of global efforts to reduce greenhouse gas emissions and transition towards sustainable transportation. As the adoption of EVs continues to accelerate, the need for efficient and reliable charging infrastructure has become increasingly apparent. Among the available charging technologies, fast charging has garnered significant attention due to its ability to dramatically reduce charging times, thereby alleviating one of the primary barriers to widespread EV adoption-range anxiety. Fast charging technology enables drivers to replenish their EV batteries within minutes, providing a level of convenience that is comparable to refueling conventional internal combustion engine vehicles. This advancement is critical for facilitating the integration of EVs into everyday life, especially for long-distance travel and urban commutes. However, the benefits of fast charging come with a trade-off: its impact on the longevity and health of lithium-ion batteries [1]–[3].

Lithium-ion batteries, the dominant energy storage solution in EVs, are complex electrochemical systems that are highly sensitive to factors such as temperature, current density, and charging speed. Fast charging introduces unique stressors to these batteries, including elevated temperatures, lithium plating, and mechanical wear, all of which contribute to accelerated degradation. These effects not only shorten the battery's operational lifespan but also raise concerns about the overall cost of EV ownership and the sustainability of battery manufacturing and recycling processes [4]–[7].

The interplay between fast charging and battery longevity is a multifaceted challenge that demands a holistic approach. While advancements in battery chemistry, thermal management systems, and charging algorithms offer promising solutions, they must be complemented by robust industry standards and supportive policies to ensure their effectiveness. Moreover, understanding the mechanisms of battery degradation under fast charging conditions is essential for developing strategies to mitigate these effects and enhance the durability of EV batteries. This paper aims to provide a comprehensive analysis of the impact of fast charging technology on battery longevity. By examining the underlying mechanisms of degradation, quantifying its effects, and exploring potential mitigation strategies, this work seeks to inform the development of sustainable fast charging solutions that balance the need for convenience with the imperative of long-term battery health. The findings presented herein are intended to guide researchers, policymakers, and industry stakeholders in advancing the next generation of EV charging technologies while ensuring the durability and reliability of lithium-ion batteries [8]–[10].

2. THE MECHANISMS OF BATTERY DEGRADATION DURING FAST CHARGING

2.1. Elevated temperature

Figure 1 shows the lithium plating process. Fast charging introduces several stressors to lithium-ion batteries. High charging currents result in significant heat generation within the battery. This heat arises primarily due to resistive heating, also known as Joule heating, within the electrodes and electrolyte. Elevated temperatures accelerate side reactions, such as the decomposition of the electrolyte and the growth of the solid electrolyte interphase (SEI) layer. These reactions not only deplete active lithium and electrolyte materials but also increase the battery's internal resistance, further exacerbating heat generation during subsequent charging cycles. Persistent exposure to high temperatures can lead to thermal runaway, a catastrophic failure mode that poses safety risks. Effective thermal management systems are thus crucial to maintain battery temperatures within a safe operational range during fast charging [11], [12].

2.2. Lithium plating

Lithium plating occurs when the rate of lithium-ion intercalation into the anode exceeds the diffusion capability of lithium-ions within the electrode material. During fast charging, the high current densities drive lithium-ions to deposit as metallic lithium on the anode surface instead of being properly intercalated. Lithium plating not only reduces the active lithium available for energy storage but also increases the risk of dendrite formation. These dendrites can penetrate the separator, potentially causing internal short circuits and thermal runaway. Factors such as low temperatures, high state of charge (SOC), and rapid charging rates exacerbate lithium plating. Ran *et al.* [13] are exploring solutions such as pre-charging conditioning, advanced anode materials, and optimized charging protocols to mitigate this issue.

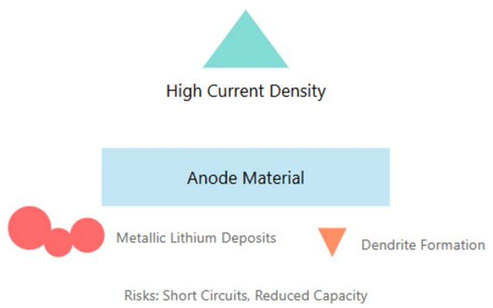

Figure 1. Lithium plating process

2.3. Mechanical stress

Figure 2 shows the mechanical stress in battery electrodes. Repeated cycles of fast charging and discharging induce significant mechanical stress within the battery's electrodes. During charging, lithium-ion intercalation causes the anode material to expand, while de-intercalation during discharging leads to contraction. This continuous expansion and contraction generate mechanical strain, leading to the formation of micro-cracks in the electrode material. Over time, these micro-cracks grow, reducing the structural integrity of the electrodes and causing the loss of electrical contact between active materials and the current collector. The accumulation of these effects degrades the battery's capacity and efficiency. Advanced electrode designs, such as flexible binders and nanostructured materials, are being investigated to address these challenges [14].

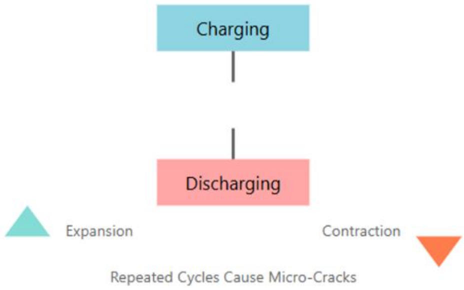

Figure 2. Mechanical stress in battery electrodes

2.4. Electrolyte decomposition

The electrolyte in lithium-ion batteries plays a critical role in facilitating ion transport between the anode and cathode. However, during fast charging, the high temperatures and voltages can accelerate the decomposition of the electrolyte. Decomposition products may form deposits on the electrode surfaces, further impeding ion transport and increasing resistance. Additionally, the breakdown of the electrolyte can release gases, leading to swelling, and potential leakage of the battery cell. Stabilizing additives in the electrolyte and advanced cooling strategies can help mitigate these issues [15].

2.5. Accelerated aging of the solid electrolyte interphase layer

The SEI layer is a passivation film that forms on the surface of the anode during the initial charge-discharge cycles. While the SEI layer is essential for stabilizing the battery, its growth is exacerbated under fast charging conditions. Repeated charging cycles at high currents cause continuous breaking and reformation of the SEI layer, consuming active lithium and electrolyte components. This process reduces the battery's capacity and increases its internal resistance. Developing stable SEI layers through electrolyte additives and surface coatings is a promising approach to address this issue [16]–[18].

3. QUANTIFYING THE IMPACT OF FAST CHARGING ON BATTERY LONGEVITY

3.1. Cycle life reduction

Figure 3 shows the battery cycle life reduction. Fast charging significantly reduces the number of charge-discharge cycles a battery can undergo before reaching its end-of-life criterion, typically defined as 80% of its original capacity. For instance, batteries subjected to frequent fast charging may see a reduction in cycle life by up to 500-1,000 cycles compared to those charged using slower, standard methods. The accelerated degradation is primarily driven by elevated temperatures, lithium plating, and increased stress on the battery materials during rapid ion transfer [19], [20].

Figure 3. Battery cycle life reduction

3.2. Capacity fade

Capacity fade refers to the gradual decline in the amount of charge a battery can hold over time. Fast charging exacerbates capacity fade due to mechanisms such as the growth of the SEI layer, lithium plating, and mechanical stress on the electrodes [21]. Studies have reported that batteries charged using high-power fast chargers experience a capacity loss rate that is 1.5-2 times higher than those charged with slower chargers. This accelerated capacity fade directly impacts the driving range of EVs, necessitating more frequent charging and reducing overall convenience for users.

3.3. Increased internal resistance

Fast charging contributes to a rise in the battery's internal resistance over time. This increase is caused by factors such as SEI layer thickening, electrolyte decomposition, and the loss of active materials within the electrodes [22]. Higher internal resistance not only reduces the efficiency of the battery but also leads to greater heat generation during operation, further compounding the issues associated with thermal degradation. A higher resistance also results in reduced power delivery, negatively affecting the performance of EVs.

3.4. Thermal degradation

Frequent exposure to high temperatures during fast charging accelerates the breakdown of critical battery components, including the electrolyte and electrode materials. Thermal degradation can result in the formation of gas pockets, swelling of the battery cell, and in extreme cases, thermal runaway. Studies indicate that batteries with inadequate thermal management systems are particularly vulnerable, with some experiencing up to a 30% reduction in lifespan under continuous fast charging conditions. Effective cooling strategies are therefore essential to mitigate the thermal impacts of fast charging [23].

3.5. Variability across chemistries

The impact of fast charging on battery longevity varies significantly across different lithium-ion chemistries. For example, lithium iron phosphate (LFP) batteries are generally more resistant to thermal and chemical degradation compared to nickel manganese cobalt (NMC) batteries. However, NMC batteries offer higher energy densities, making them more susceptible to the stresses imposed by fast charging. Understanding these trade-offs is crucial for selecting the optimal battery chemistry for applications requiring frequent fast charging [24]–[26].

3.6. User behavior and charging patterns

User behavior, such as the frequency of fast charging and the SOC range used, also plays a critical role in determining battery longevity. Batteries that are consistently charged from a low SOC to a high SOC using fast chargers experience greater degradation than those charged within a moderate SOC range. Educating users on best practices, such as limiting the use of fast charging to occasional or emergency scenarios, can significantly extend battery life [27].

4. MITIGATION STRATEGIES

4.1. Advanced battery materials

Developing advanced materials is a cornerstone for mitigating the impact of fast charging. Heat-resistant electrolytes can withstand high temperatures without degrading, reducing the likelihood of thermal runaway. Stable SEI layers can prevent lithium plating and improve the battery's cycling stability [28]. Additionally, robust electrode materials such as nickel-rich cathodes and silicon-doped anodes can endure the mechanical stress caused by rapid ion transfer during fast charging. Ongoing research into novel materials, including solid-state electrolytes and high-entropy alloys, holds promise for further advancements in this area.

4.2. Adaptive charging protocols

Smart charging algorithms play a critical role in reducing the stress placed on batteries during fast charging. These algorithms dynamically adjust the charging current and voltage based on real-time data about the battery's SOC, temperature, and health. For instance, charging can be slowed as the battery approaches full capacity, minimizing the risk of overcharging and thermal stress [29]. Machine learning models are increasingly being employed to predict optimal charging patterns, enabling a personalized approach to fast charging that maximizes longevity while maintaining speed.

4.3. Thermal management systems

Effective thermal management is essential to counteract the heat generated during fast charging. Advanced cooling technologies, such as liquid cooling systems and phase-change materials, can efficiently dissipate heat and maintain the battery within its optimal temperature range [30]–[33]. Emerging solutions, such as integrated thermal management using microchannel heat exchangers or passive cooling techniques, offer promising alternatives for enhancing thermal control without significantly increasing system complexity or cost. The integration of sensors to monitor temperature distribution within the battery pack further enhances the effectiveness of these systems.

4.4. Pre-charging conditioning

Pre-conditioning the battery before initiating fast charging can significantly mitigate degradation risks. For example, warming a battery to its optimal temperature range in cold environments or cooling it in hot climates can reduce stress during charging. Pre-conditioning technologies, often integrated with vehicle management systems, ensure that the battery's internal environment is primed for efficient and safe fast charging. Additionally, intelligent pre-conditioning strategies can adapt to the battery's age and health, offering tailored solutions to extend its lifespan.

4.5. Optimizing charging infrastructure

The design and deployment of fast charging stations can also influence battery longevity. Chargers equipped with advanced power control systems can deliver consistent and efficient energy transfer while minimizing fluctuations that contribute to battery wear. Grid-connected charging stations capable of distributing power intelligently can reduce peak loads and avoid excessive charging currents. Furthermore, integrating vehicle-to-grid (V2G) technology enables bidirectional energy flow, which can stabilize the grid while optimizing battery usage.

4.6. User education and behavioral interventions

Educating EV users on best charging practices is an often-overlooked but highly impactful strategy. For instance, users can be encouraged to use fast charging sparingly, reserving it for long trips or emergencies, while relying on standard charging for daily needs. Charging habits, such as avoiding charging to 100% or discharging under 20%, can significantly extend battery life. Vehicle manufacturers and policymakers can facilitate this education through in-app notifications, user manuals, and public awareness campaigns. Collaboration between automakers, battery manufacturers, and charging infrastructure providers is vital to developing holistic solutions. Standardizing fast charging protocols and power levels across the industry can reduce inconsistencies that contribute to battery degradation [34], [35].

5. THE ROLE OF STANDARDS AND POLICIES

Governments and industry stakeholders play a pivotal role in shaping the landscape of fast charging through standards and policies [36]–[40]. By establishing clear guidelines and regulatory frameworks, they can ensure that fast-changing technology evolves in a manner that prioritizes both performance and sustainability.

5.1. Establishing charging standards

Unified charging standards are essential to promote compatibility and efficiency across different EV models and charging networks. Standards such as the combined charging system (CCS) and charge de move (CHAdeMO) have streamlined fast charging, but further harmonization is required to minimize inconsistencies. Governments can mandate standardized charging protocols that define power levels, connector designs, and communication interfaces, enabling seamless integration across global markets.

5.2. Regulating charging rates

Fast charging subjects batteries to high currents and voltages, which accelerate degradation. Policymakers can impose limits on maximum allowable charging rates to balance charging speed with battery health. Dynamic regulations that consider advancements in battery technology can provide flexibility while safeguarding longevity. Additionally, tiered charging rates based on battery age or health can be explored to mitigate stress on older batteries.

5.3. Incentivizing research and development

Governments can foster innovation by funding research into advanced battery technologies, thermal management systems, and adaptive charging protocols. Public-private partnerships can accelerate the development of solutions that address the challenges of fast charging. Incentives for automakers and battery manufacturers to adopt these innovations can drive industry-wide adoption.

5.4. Environmental and safety regulations

Fast charging infrastructure must comply with environmental and safety standards to ensure sustainable and secure operations. Policies can mandate the use of renewable energy sources to power charging stations, reducing the carbon footprint of EVs. Safety regulations, including robust fire suppression systems and real-time monitoring, can mitigate risks associated with high-power charging.

5.5. Consumer protection policies

To enhance user confidence, governments can implement policies that protect consumers from potential drawbacks of fast charging. These may include warranties on battery life, transparency requirements for degradation rates, and standardized metrics for assessing battery health. Informing consumers about the trade-offs of fast charging and providing tools to monitor battery performance can empower them to make informed decisions.

6. CONCLUSION

Fast charging technology has undoubtedly been a game-changer for the EV industry, offering substantial benefits in terms of convenience and alleviating range anxiety. However, this technological advancement comes with trade-offs, particularly concerning the longevity of lithium-ion batteries. As highlighted throughout this paper, the elevated temperatures, mechanical stress, and phenomena like lithium plating introduced by fast charging accelerate battery degradation, reducing their lifespan by 20-30% compared to standard charging methods. The effects of fast charging are influenced by several factors, including battery chemistry, charging protocols, and user behavior. Mitigation strategies, such as the development of advanced materials, adaptive charging protocols, and effective thermal management systems, offer promising solutions to minimize these degradation effects.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest to disclose.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

[1] G. Arena, A. Chub, M. Lukianov, R. Strzelecki, D. Vinnikov, and G. D. Carne, "A comprehensive review on DC fast charging stations for electric vehicles: standards, power conversion technologies, architectures, energy management, and cybersecurity," *IEEE Open Journal of Power Electronics*, vol. 5, pp. 1573–1611, 2024, doi: 10.1109/OJPEL.2024.3466936.

[2] W. ur Rehman, J. W. Kimball, and R. Bo, "Multilayered energy management framework for extreme fast charging stations considering demand charges, battery degradation, and forecast uncertainties," *IEEE Transactions on Transportation Electrification*, vol. 10, no. 1, pp. 760–776, Mar. 2024, doi: 10.1109/TTE.2023.3275110.

[3] P. Fan, B. Sainbayar, and S. Ren, “Operation analysis of fast charging stations with energy demand control of electric vehicles,” *IEEE Transactions on Smart Grid*, vol. 6, no. 4, pp. 1819–1826, Jul. 2015, doi: 10.1109/TSG.2015.2397439.

[4] S. Negarestani, M. F.-Firuzabad, M. Rastegar, and A. R.-Ghahnavieh, “Optimal sizing of storage system in a fast charging station for plug-in hybrid electric vehicles,” *IEEE Transactions on Transportation Electrification*, vol. 2, no. 4, pp. 443–453, Dec. 2016, doi: 10.1109/TTE.2016.2559165.

[5] N. Naik, C. Vyjayanthi, and C. Modi, “Filter-based active damping of DAB converter to lower battery degradation in EV fast charging application,” *IEEE Access*, vol. 11, pp. 74277–74289, 2023, doi: 10.1109/ACCESS.2023.3295988.

[6] L. Wang, Z. Qin, T. Slangen, P. Bauer, and T. V. Wijk, “Grid impact of electric vehicle fast charging stations: trends, standards, issues and mitigation measures - an overview,” *IEEE Open Journal of Power Electronics*, vol. 2, pp. 56–74, 2021, doi: 10.1109/OJPEL.2021.3054601.

[7] W. Yang, W. Liu, C. Y. Chung, and F. Wen, “Joint planning of EV fast charging stations and power distribution systems with balanced traffic flow assignment,” *IEEE Transactions on Industrial Informatics*, vol. 17, no. 3, pp. 1795–1809, 2021, doi: 10.1109/TII.2020.2995742.

[8] J. S. Karunarathna, U. K. Madawala, M. Sandelic, F. Blaabjerg, and C. Baguley, “The impact of operational and environmental conditions on battery lifetime in fast electric vehicle charging systems,” *IEEE Transactions on Power Electronics*, vol. 39, no. 4, pp. 4645–4656, Apr. 2024, doi: 10.1109/TPEL.2023.3342121.

[9] M. H. Abbasi, Z. Arjmandzadeh, J. Zhang, V. Krovi, B. Xu, and D. K. Mishra, “A coupled game theory and Lyapunov optimization approach to electric vehicle charging at fast charging stations,” *IEEE Transactions on Vehicular Technology*, vol. 73, no. 10, pp. 14224–14235, Oct. 2024, doi: 10.1109/TVT.2024.3407068.

[10] S. Habib, M. M. Khan, F. Abbas, L. Sang, M. U. Shahid, and H. Tang, “A comprehensive study of implemented international standards, technical challenges, impacts and prospects for electric vehicles,” *IEEE Access*, vol. 6, pp. 13866–13890, 2018, doi: 10.1109/ACCESS.2018.2812303.

[11] Y. Liang, G. R. C. Mouli, and P. Bauer, “Charging technology for electric aircraft: state of the art, trends, and challenges,” *IEEE Transactions on Transportation Electrification*, vol. 10, no. 3, pp. 6761–6788, Sep. 2023, doi: 10.1109/TTE.2023.3333536.

[12] M. E. Kabir, C. Assi, H. Alameddine, J. Antoun, and J. Yan, “Demand-aware provisioning of electric vehicles fast charging infrastructure,” *IEEE Transactions on Vehicular Technology*, vol. 69, no. 7, pp. 6952–6963, Jul. 2020, doi: 10.1109/TVT.2020.2993509.

[13] L. Ran, J. Qin, Y. Wan, W. Fu, W. Yu, and F. Xiao, “Fast charging navigation strategy of EVs in power-transportation networks: a coupled network weighted pricing perspective,” *IEEE Transactions on Smart Grid*, vol. 15, no. 4, pp. 3864–3875, Jul. 2024, doi: 10.1109/TSG.2024.3354300.

[14] D. Mao, J. Tan, and J. Wang, “Location Planning of PEV fast charging station: an integrated approach under traffic and power grid requirements,” *IEEE Transactions on Intelligent Transportation Systems*, vol. 22, no. 1, pp. 483–492, Jan. 2021, doi: 10.1109/TITS.2020.3001086.

[15] X. Gan, H. Zhang, G. Hang, Z. Qin, and H. Jin, “Fast charging station deployment considering elastic demand,” *IEEE Transactions on Transportation Electrification*, vol. 6, no. 1, pp. 158–169, Mar. 2020, doi: 10.1109/TTE.2020.2964141.

[16] D. Bi, Y. Zhao, J. Chen, S. He, X. L. China, and Y. Cen, “A control strategy for electric vehicles participating in frequency regulation considering user demand and battery longevity,” in *2023 6th International Conference on Electronics and Electrical Engineering Technology (EEET)*, Dec. 2024, pp. 166–172. doi: 10.1109/eeet61723.2023.00029.

[17] S. W. Amarasinghe, W. M. S. L. Ariyasinghe, and A. M. H. S. Abeykoon, “Intelligent battery management algorithm for second-life battery systems using voltage based active cell balancing,” in *EECon 2024 - Proceedings of the 2024 4th International Conference on Electrical Engineering*, Dec. 2024, pp. 72–77. doi: 10.1109/EECon64470.2024.10841880.

[18] A. Sharma, R. Bhokare, and R. Warbhe, “IoT-based enhanced battery safety and management system in EV’s,” in *2024 International Conference on Intelligent Systems and Advanced Applications, ICISAA 2024*, Oct. 2024, pp. 1–6. doi: 10.1109/ICISAA62385.2024.10829104.

[19] T. T. Makuwatsine and M. Singh, “State of charge (SOC) and state of health (SOH) estimation for electric vehicle battery,” in *2024 International Conference on Computer, Electronics, Electrical Engineering and their Applications, IC2E3 2024*, Jun. 2024, pp. 1–6. doi: 10.1109/IC2E362166.2024.10827735.

[20] T. Shakir, H. Naz, M. Jamil, and S. Kirmani, “A comparative analysis of deep learning algorithms based SoH prediction of Li-Ion batteries,” in *2024 International Conference on Computer, Electronics, Electrical Engineering and their Applications, IC2E3 2024*, Jun. 2024, pp. 1–5. doi: 10.1109/IC2E362166.2024.10827462.

[21] M. P. Mohandass, T. R. Regan, A. Vignesh, and V. Sabari, “Battery thermal management system for electric vehicle using LABVIEW,” in *Proceedings of 5th International Conference on IoT Based Control Networks and Intelligent Systems, ICICNIS 2024*, Dec. 2024, pp. 586–592. doi: 10.1109/ICICNIS64247.2024.10823360.

[22] K. Ibrahim, S. Sabathiel, F. Farooq, G. Hofer, A. Bergmann, and R. Heer, “An empirical model for state of charge estimation based on electrochemical impedance spectroscopy,” in *2024 IEEE International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles and International Transportation Electrification Conference, ESARS-ITEC 2024*, Nov. 2024, pp. 1–6. doi: 10.1109/ESARS-ITEC60450.2024.10819895.

[23] G. S. Babu, K. P. Varma, K. Gorji, V. R. Kammampati, K. P. Rao, and E. P. Konakalla, “An efficient battery monitoring system for electrical vehicles based on Arduino,” in *Proceedings of the 5th International Conference on Data Intelligence and Cognitive Informatics, ICDICI 2024*, Nov. 2024, pp. 396–400. doi: 10.1109/ICDICI62993.2024.10810819.

[24] R. Baharom and M. H. Hayroman, “A comprehensive review on advancements in battery charger technologies for electric vehicles,” in *IEACon 2024 - 2024 IEEE Industrial Electronics and Applications Conference*, Nov. 2024, pp. 190–195. doi: 10.1109/IEACon61321.2024.10797305.

[25] S. Karna, P. R. Satpathy, and P. Bhowmik, “Enhanced state of charge estimation for lithiumion batteries using polynomial voltage approximation,” in *3rd Odisha International Conference on Electrical Power Engineering, Communication and Computing Technology, ODICON 2024*, Nov. 2024, pp. 1–4. doi: 10.1109/ODICON62106.2024.10797595.

[26] S. Sushma and M. P. R. Prasad, “Fuzzy logic control strategy to operate EDS,” in *2023 2nd IEEE International Conference on Measurement, Instrumentation, Control and Automation, ICMICA 2023*, May 2024, pp. 1–4. doi: 10.1109/ICMICA61068.2024.10732265.

[27] S. S. Sinha and P. Bharadwaj, “Hybrid energy storage system for the life extension of lithium-ion batteries in electric vehicles,” in *2024 IEEE 4th International Conference on Sustainable Energy and Future Electric Transportation, SEFET 2024*, Jul. 2024, pp. 1–6. doi: 10.1109/SEFET61574.2024.10718026.

[28] S. Mateen, A. Haque, S. Mehfuz, and Q. A. Khan, "Accelerating EV charging: ANFIS-controlled pulse charging strategy," in *2024 IEEE 4th International Conference on Sustainable Energy and Future Electric Transportation, SEFET 2024*, Jul. 2024, pp. 1–6. doi: 10.1109/SEFET61574.2024.10717952.

[29] V. Jayanth, P. Bhanu, K. Deekshitha, and V. Sandeep, "Study on computation of state-of-charge in electric vehicle batteries using various control methods," in *2024 IEEE 4th International Conference on Sustainable Energy and Future Electric Transportation, SEFET 2024*, Jul. 2024, pp. 1–6. doi: 10.1109/SEFET61574.2024.10717951.

[30] S. C. Mathi, P. N. Tammisetti, H. K. Gowra, and P. V. Manitha, "Wireless parameter monitoring of solar-powered electric vehicles," in *Proceedings of the 5th International Conference on Smart Electronics and Communication, ICOSEC 2024*, Sep. 2024, pp. 343–349. doi: 10.1109/ICOSEC61587.2024.10722461.

[31] C. R. A. Varshini, A. Jha, A. Tiwari, and K. Deepa, "Hybrid machine learning model for EV Battery SoC and SoH prediction," in *2024 3rd International Conference on Electrical, Electronics, Information and Communication Technologies, ICEEICT 2024*, Jul. 2024, pp. 1–8. doi: 10.1109/ICEEICT61591.2024.10718590.

[32] T. E.-Picken, C. M. D. Silva, and C. H. Amon, "Multi-objective design optimization of pin-fin cold plates for electric vehicle battery packs using convolutional neural networks and genetic algorithms," in *InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, ITHERM*, May 2024, pp. 1–10. doi: 10.1109/ITherm55375.2024.10709450.

[33] S. Yan, X. Cong, and L. Zhao, "Optimization design study of thermal management system for lithiumion batteries," in *2024 6th International Conference on Electronic Engineering and Informatics, EEI 2024*, Jun. 2024, pp. 1049–1053. doi: 10.1109/EEI63073.2024.10696393.

[34] F. Zahid, G. E. M. Abro, R. Boudville, N. Talpur, and S. Rajput, "Recent constraints and challenges in battery management system of EVs - a brief review," in *14th IEEE International Conference on Control System, Computing and Engineering, ICCSCE 2024 - Proceedings*, Aug. 2024, pp. 76–81. doi: 10.1109/ICCSCE61582.2024.10696083.

[35] B. Srujana and K. Chenchireddy, "Electric vehicle charging and temperature monitoring system," in *5th International Conference on Electronics and Sustainable Communication Systems, ICESC 2024 - Proceedings*, Aug. 2024, pp. 54–57. doi: 10.1109/ICESC60852.2024.10689817.

[36] K. I. Ibrahim, N. B. Ahmad, and M. A. Razali, "Fuzzy logic controller-based efficient Li-ion battery charging system for electrical vehicles," in *ICFTSS 2024 - International Conference on Future Technologies for Smart Society*, Aug. 2024, pp. 52–56. doi: 10.1109/ICFTSS61109.2024.10691357.

[37] D. Kumar and M. Das, "EV charging infrastructure: smooth power delivery using pulse charging methods for swappable charging station," in *INTELEC, International Telecommunications Energy Conference (Proceedings)*, Aug. 2024, pp. 1–6. doi: 10.1109/INTELEC60315.2024.10678988.

[38] B. F. Chademunhu, S. Gupta, and P. K. Mishra, "Enhancing cold-weather performance of electric vehicles through innovative thermal management strategies," in *Proceedings of CONECCT 2024 - 10th IEEE International Conference on Electronics, Computing and Communication Technologies*, Jul. 2024, pp. 1–6. doi: 10.1109/CONECCT62155.2024.10677109.

[39] D. Ebrahimi, S. Kashefi, T. E. A. D. Oliveira, and F. Alzhouri, "Efficient routing and charging strategy for electric vehicles considering battery life: a reinforcement learning approach," in *Canadian Conference on Electrical and Computer Engineering*, Aug. 2024, pp. 429–435. doi: 10.1109/CCECE59415.2024.10667251.

[40] K. Sevdari, M. Marinelli, and F. Pastorelli, "Overview of EV battery types and degradation measurement for Renault Zoe NMC batteries," in *2024 International Conference on Renewable Energies and Smart Technologies, REST 2024*, Jun. 2024, pp. 1–5. doi: 10.1109/REST59987.2024.10645453.

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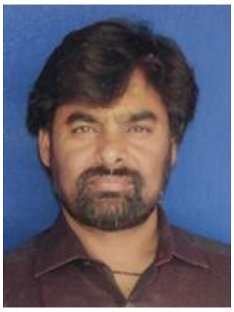

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