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Review of Fast Charging Techniques for Lithium-Ion Batteries in Electric Vehicles

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***Abstract*— The adoption of electric vehicles (EVs) is rapidly increasing worldwide, driven by the need to mitigate environmental concerns and reduce reliance on fossil fuels. One of the critical aspects influencing the widespread acceptance of EVs is the charging time and convenience. Fast charging techniques for lithium-ion batteries have garnered significant attention due to their potential to minimize charging durations and enhance the usability of EVs. This review comprehensively evaluates various fast charging techniques for lithium-ion batteries in electric vehicles, including their principles, advantages, limitations, and future prospects. Key factors such as battery chemistry, charging infrastructure, thermal management, and safety considerations are examined to provide a holistic understanding of the state-of-the-art in fast charging technologies. The review also discusses the challenges and opportunities associated with implementing fast charging techniques in EVs, with insights into potential strategies for overcoming existing limitations. By synthesizing existing research findings and identifying emerging trends, this review aims to guide future research directions and facilitate the development of efficient and reliable fast charging solutions for lithium-ion batteries in electric vehicles.**

Keywords*— Lithium-Ion, Batteries, Charging Techniques, Electric Vehicles.

I. INTRODUCTION

Electric vehicles (EVs) represent a promising solution to address pressing environmental concerns and reduce dependence on traditional internal combustion engine vehicles. With advancements in battery technology, particularly the widespread adoption of lithium-ion batteries, EVs have become increasingly competitive in terms of range, performance, and affordability. However, the acceptance and proliferation of EVs hinge significantly on the charging infrastructure and the time required to recharge the vehicle's batteries. Conventional charging methods often entail lengthy charging durations, posing challenges for EV users, particularly in scenarios where quick refueling is necessary.

Fast charging techniques have emerged as a viable solution to mitigate the long charging times associated with EVs, thereby enhancing their usability and attractiveness to consumers. By leveraging innovative charging strategies and advanced battery management systems, fast charging aims to significantly reduce the time required to replenish the energy stored in lithium-ion batteries, making EVs more convenient and practical for everyday use. However, the successful implementation of fast charging technologies necessitates a comprehensive understanding of the underlying principles, as well as careful consideration of various factors influencing battery performance, safety, and longevity.

This review provides a comprehensive examination of fast charging techniques tailored specifically for lithium-ion batteries in electric vehicles. It begins by outlining the fundamental principles underlying fast charging, including the impact of battery chemistry, electrode materials, and charging protocols on charging efficiency and battery health. Various fast charging approaches, such as high-power charging, pulse charging, and dynamic charging, are analyzed in detail, highlighting their advantages, limitations, and suitability for different EV applications.

Furthermore, the review delves into critical considerations associated with fast charging, including thermal management strategies to mitigate overheating risks, safety protocols to prevent battery degradation and potential safety hazards, and infrastructure requirements to support widespread adoption of fast charging technology. Additionally, emerging trends and future prospects in fast charging research and development are discussed, with a focus on addressing current challenges and unlocking new opportunities for enhancing the performance and reliability of fast charging systems for lithium-ion batteries in electric vehicles.

Through a comprehensive synthesis of existing literature and insights from industry experts, this review aims to provide a valuable resource for researchers, engineers, policymakers, and stakeholders involved in the advancement of electric vehicle technology. By identifying key challenges and opportunities, as well as outlining potential strategies for overcoming barriers to implementation, this review seeks to accelerate the development and deployment of efficient and sustainable fast charging solutions, ultimately facilitating the widespread adoption of electric vehicles and contributing to a cleaner, greener transportation ecosystem.

II. RELATED WORK

Y. Xie et al.,[1] presented a self-adaptive multistage constant current (SAMCC) fast-charging strategy for a battery at high ambient temperatures (40 °C). This strategy contains an electrothermal-degradation model for the battery and integrates a balanced cooling strategy. To realize the self-adaption of the algorithm, the genetic algorithm is used to determine the stage number of the charging strategy and the current in each stage. To balance the charging time and the capacity loss, the Pareto curve is adopted. Then, the SAMCC strategy is used for a 50-Ah prismatic battery.

Y. Li et al.,[2] presented a novel nonlinear control approach for fast charging of lithium-ion batteries, where health- and safety-related variables, or their time derivatives, are expressed in an input-polynomial form. By converting a constrained optimal control problem into an output tracking problem with multiple tracking references, the required control input, i.e., the charging current, is obtained by computing a series of candidate currents associated with different tracking references. Consequently, an optimization-free nonlinear model inversion-based control algorithm is derived for charging the batteries.

J. Tian, et al.,[3] Charging control is one of the essential functions of battery management systems. Battery charging involves behavioral changes such as electricity, heat, and aging. Balancing these factors is crucial for the safe and efficient operation of batteries. This work proposes an intelligent charging scheme for lithium-ion batteries that considers charging time, temperature rise, and health losses. First, charging aging experiments are conducted to investigate the effect of charging rate on battery aging. Specifically, half-cell experiments are carried out to construct an electrode open circuit voltage model to explore battery aging modes.

Y. Lu et al.,[4] Typical charging methods of lithium-ion batteries (LIBs) are challenged with the balance between charging speed and detrimental side reactions. In this work, a unique multi-objective optimized charging method based on model predictive control (MPC) and lithium plating detection is addressed to handle the above concerns. A new thermal-coupled decomposed electrode model (DEM) is constructed by introducing a reference electrode to precisely predict the cell anode potential.

R. S K et al.,[5] Battery is one of the major components of electric vehicles, which highly influences the performance of Electric Vehicles (EVs). However, enhancing the life of a Lithium-ion (Li-ion) battery is a challenging task because they have a high risk of fire hazards due to the electrochemical properties of Li-ion. Various key factors that have a significant influence on the health of the battery include a number of charge-discharge cycles, temperature, voltage, and current profiles. Hence, a highly efficient Battery Management System (BMS) with an optimal charging facility is needed. The main objective of the proposed work is to generate Multiple Hybrid Artificial Intelligence (MHAI)-based optimal charging current profiles for Li-ion batteries with minimum charging time and temperature rise in order to enhance the State Of Health (SOH).

A. A. Adejare et al.,[6] The growing acceptance of li-ion battery utilization in electric vehicles (EVs) has resulted in a

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greater contribution to greenhouse gas reduction. To maintain a healthy operational state, an EV goes through multiple charge and discharge cycles. EV owners switch between Fast and Normal charging modes according to their schedule, which has a significant impact on battery capacity degradation. The charging methodology utilized affects lithium-ion battery deterioration, which can range from loss of lithium inventory to loss of active material and the creation of a solid electrolyte interface. Using a charge profile-based degradation experiment, this study developed and tested four distinct charging protocols that potentially enhance battery life and decrease charging time.

M. Sarath et al.,[7] Electric vehicles (EVs) have gained increasing relevance as an environmentally friendly and energy-efficient alternative to traditional liquid or gas fuel vehicles. Lithium-ion battery packs are the primary source of power for EVs. To effectively estimate battery performance and comprehend the electrochemical behaviour of the cell, cell modelling is essential. It aids in boosting the battery's efficiency and design optimisation. This research work involves the cell modelling and parameter estimation of the lithium-ion battery using MATLAB, with input data obtained from pulse discharge tests. To address the energy and power needs of EVs, several lithium-ion cells are connected in series and parallel configurations.

P. P. Nikam et al.,[8] In 21th century the production and demand of EV is rising exponentially based on the development in the target towards Seventh Sustainable Development Goal (SDG7). Hence, charging time of electric vehicle (EVs) is one of the important factors. This paper investigates various charging algorithms such as Constant Current (CC), Constant Voltage (CV) and Hybrid Charging (HC) based on the buck converter closed loop control strategies in order to decrease the charging time. The simulation has been done in MATLAB for lithium-ion battery. This study carried out through MATLAB Simulation environment in order to reduce the charging time within 15 minutes. It includes the closed loop current and voltage control for this analysis.

A. Ramanan et al.,[9] imperative to have a robust ecosystem for repurposing of batteries. Government of India has laid special emphasis on the circular economy for Lithium-ion batteries and has set up a panel for framing standards under the Bureau of Indian Standards. Second-life batteries are expected to significantly reduce the life cycle emissions of EVs, reduce the need for mining new minerals, and expected to bring more financial viability for the purchase of EVs.

R. Zhang et al.,[10] presented a convolutional neural network (CNN) based SOH estimation method, which can extract health features from only 3-minute partial fast-charging segment and then accurately estimate the SOH of the batteries under fast-charging. The proposed method is validated by an open-source dataset, where the root mean square percentage error and mean absolute percentage error are less than 1% and the maximum percentage error is less than 2%. The proposed method may have a great potential in real application for the advantage of high accuracy and small amount of charging data needed.

III. CHALLENGES

The implementation of fast charging techniques for lithium-ion batteries in electric vehicles faces several significant challenges that must be addressed to realize their full potential. These challenges include:

1. **Battery Degradation**: Fast charging can accelerate battery degradation, reducing overall battery lifespan and performance over time. High charging currents and elevated temperatures during fast charging can lead to increased stress on battery materials, causing capacity fade, impedance growth, and reduced cycle life. Mitigating battery degradation while maintaining fast charging speeds is a critical challenge.
2. **Thermal Management**: Rapid charging generates significant heat within the battery cells, posing challenges for thermal management. Overheating can compromise battery safety and performance, leading to thermal runaway and potentially catastrophic failures. Effective thermal management systems are

essential to dissipate heat efficiently and maintain safe operating temperatures during fast charging.

3. **Infrastructure Requirements**: Implementing fast charging infrastructure at scale requires substantial investment in grid infrastructure, charging stations, and power distribution systems. Upgrading existing infrastructure to support high-power charging capabilities and deploying fast charging stations in strategic locations pose logistical and financial challenges. Coordinating efforts between utilities, governments, and private stakeholders is necessary to address infrastructure requirements effectively.

4. **Charging Standardization**: The absence of standardized fast charging protocols poses interoperability challenges and complicates the user experience. Different manufacturers employ proprietary charging technologies, leading to fragmentation in the fast charging ecosystem. Establishing universal standards for fast charging protocols, connectors, and communication interfaces is crucial to ensure compatibility and ease of use for EV drivers.

5. **Safety Concerns**: Fast charging introduces safety risks related to battery overheating, overcharging, and electrical faults. Ensuring the robustness of charging infrastructure and implementing comprehensive safety protocols is essential to minimize the risk of accidents and maintain consumer confidence in fast charging technology.

6. **Battery Material Constraints**: The adoption of fast charging may require the development of battery materials capable of withstanding higher charging currents and operating temperatures without sacrificing performance or durability. Research into advanced electrode materials, electrolytes, and battery architectures is necessary to overcome material limitations and optimize battery performance for fast charging applications.

7. **Grid Impact and Energy Management**: Fast charging stations impose significant demand on the electrical grid, particularly during peak charging periods. Managing grid impact and balancing energy demand effectively require intelligent energy management solutions, such as demand response programs, grid-connected energy storage, and smart charging algorithms. Coordinating charging schedules to leverage renewable energy sources and off-peak electricity rates can help alleviate grid strain and reduce environmental impact.

IV. CONCLUSION

The development and widespread adoption of fast charging techniques for lithium-ion batteries in electric vehicles (EVs) hold immense promise for revolutionizing the transportation sector by enhancing the usability, convenience, and environmental sustainability of EVs. Despite the numerous challenges outlined, significant progress has been made in advancing fast charging technology, driven by ongoing research, technological innovations, and collaborative efforts across industry sectors. Fast charging has the potential to address one of the primary barriers to EV adoption: long charging times. By significantly reducing the time required to recharge EV batteries, fast charging enhances the practicality and attractiveness of electric vehicles for consumers, making them a more viable alternative to conventional internal combustion engine vehicles.

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