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Optimization of New Energy Vehicle Battery Charging Schemes via Integration of Artificial Intelligence and Real-World Scenarios

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Abstract: With the increasing global adoption of New Energy Vehicles (NEVs), battery charging efficiency, lifespan, and safety have emerged as critical constraints on industry development. Addressing the shortcomings of traditional charging strategies, this research proposes a multi-objective charging optimization framework for NEV batteries, based on the deep integration of Artificial Intelligence (AI) and real-world scenarios. By leveraging deep learning and reinforcement learning technologies, this framework enables real-time perception of battery states and dynamic adjustment of charging parameters, effectively reducing charging duration, mitigating battery capacity degradation, and balancing grid load. The results demonstrate that AI technology significantly enhances charging efficiency and user experience, promotes the intelligent upgrade of charging infrastructure, facilitates the transformation of the energy structure towards sustainability, addresses the challenge of imbalanced charging facility distribution, and fosters a secure and reliable charging ecosystem. This study provides a significant reference for the intelligent development of the NEV industry.

Keywords: New Energy Vehicle; Charging; Artificial Intelligence; Scheme Optimization.

1. Introduction

The continuous global rise in the ownership and production of New Energy Vehicles (NEVs) has increasingly highlighted the conflicts between battery charging efficiency, lifespan, and safety, forming a critical bottleneck for the industry. Traditional charging strategies often rely on single-objective optimization, struggling to simultaneously address multi-dimensional constraints such as charging speed, battery state of health (SOH), and grid load. This leads to issues like over-charging/discharging, thermal runaway risks, and energy waste in practical applications. In recent years, artificial intelligence technology, with its powerful data processing and multi-objective decision-making capabilities, has provided novel theoretical tools and practical pathways for optimizing battery charging schemes. By integrating AI methods such as deep learning and reinforcement learning, real-time perception of battery states, dynamic adjustment of charging parameters, and multi-objective collaborative optimization can be achieved, thereby enhancing charging efficiency and extending battery life while ensuring safety. This paper focuses on the multi-objective charging optimization for NEV batteries through the deep integration of AI and real-world scenarios, proposing a hybrid optimization framework based on the synergy of data-driven approaches and physical constraints. This framework aims to resolve the inadequate adaptability of traditional methods in dynamic environments, demonstrating the comprehensive advantages of the proposed concept in reducing charging time, minimizing capacity fade, and balancing grid load. The findings can provide theoretical support and technical references for the intelligent upgrade of NEV charging infrastructure, promoting the transition of AI technology from laboratory research to practical engineering applications.

2. Current Status of New Energy Vehicles

Data from the European Automobile Manufacturers' Association indicates that over the past five years, the number of charging points in Germany has increased significantly each year compared to the previous year. Similarly, in China, public charging piles are continuously being deployed in locations such as highways, urban streets, and shopping mall parking lots. The most common types are AC Type 2 socket charging piles and DC charging piles. Comparatively, DC charging piles, which do not require AC-DC conversion and can charge vehicles directly, offer higher charging efficiency and speed, substantially reducing required charging time. Concurrently, Germany is enhancing NEV fast-charging technology through a combination of approaches, including material innovation and technical optimization. Furthermore, bidirectional charging technology (Vehicle-to-Grid, V2G) is gradually transitioning from laboratory research to increased application scale. Building on this, Germany is also exploring the use of AI prediction algorithms to optimize the dynamic scheduling of charging piles, utilizing recorded data and real-time information for comprehensive planning.[1]

3. Research Objectives

3.1. Charging Pile Optimization

Most domestic charging piles currently possess only basic charging and discharging functionalities. To achieve more efficient energy utilization and reduced charging times, AI technology can be integrated with the internal charging strategy selection of charging piles. By reading vehicle information through the charging interface – including short-term battery usage data, battery health information, and user preferences – and combining it with external data such as real-time electricity prices and weather conditions, AI algorithms

can simulate the most efficient charging strategies. Multiple charging options can then be presented to the user for selection at the charging pile.

3.2. Vehicle Battery Optimization

The battery is one of the most critical components of a New Energy Vehicle. To improve battery utilization efficiency and prolong its service life, beyond the optimizations in materials and structure mentioned earlier, AI technology can be incorporated into the interaction between the battery and the vehicle's system. By analyzing historical driving data, user driving habits can be profiled, allowing for the adjustment of battery output modes tailored to the user's current usage scenario. This includes providing different strategies based on varying climate conditions, road types, and traffic flow data. Optimization is not limited to pre-drive adjustments; during driving, real-time data can be continuously utilized to refine the battery management scheme, including discharge patterns for vehicle functions and regenerative braking charging strategies.[2]

3.3. Network Distribution Composed of Vehicles and Charging Piles

The growing number of NEVs has led to frequent supply shortages at charging piles in certain locations, causing users to experience long waiting times for both charger availability and the charging process itself. To address this, the positional distribution of vehicles and charging piles can be leveraged. By uploading data from both vehicles and charging piles, a network model can be constructed. This model would display real-time usage status of charging piles at various locations within the vehicle and show nearby traffic conditions at the charging pile interface. Utilizing this data, AI can analyze travel and charging options.[3]For instance, by analyzing data from nearby vehicles and charging piles, multiple options can be suggested to the user for planning subsequent travel and vehicle usage, including deciding which charging pile to use for recharging. Similarly, users at charging stations can utilize AI-derived strategies based on real-time traffic data to decide when to conclude charging and continue their journey.

3.4. AI-Real-World Optimization for User-Vehicle-Charging Pile Systems

Solutions provided by AI are derived solely from data and algorithms and may not necessarily align with real-world user needs or personal preferences. Therefore, the simple application of data-driven AI solutions is insufficient for achieving user satisfaction. Consequently, both in vehicles and at charging piles, users should be able to further refine the AI-proposed solutions based on their specific usage requirements and preferences. Furthermore, subsequent adjustments to the usage strategy can be made based on user feedback after implementation. Simultaneously, user-selected preferred strategies can be uploaded via charging piles, vehicles, or smartphone apps. These strategies can be stored for personal future use or shared to a public platform. This allows users to offer their charging strategies to others and, conversely, to reference strategies from others, using AI to adapt them according to their own vehicle's information and personal preferences.

4. Research Significance

4.1. Enhancing Charging Efficiency and User Experience

AI technology significantly improves the charging efficiency of NEVs through the deep integration of real-time battery state perception and dynamic optimization algorithms. This technology not only enables precise adjustment of charging current and voltage based on key parameters such as State of Charge (SOC), State of Health (SOH), and ambient temperature, achieving fine-grained control over the charging process – thereby substantially reducing charging time and minimizing battery degradation to extend service life – but also predicts user charging behavior. Combined with grid load data and real-time electricity pricing information, AI can recommend optimal charging periods and strategies, effectively helping users avoid peak tariffs and reduce charging costs.[4]This user-centric, precise charging management not only enhances the convenience and economic benefits of the charging process but also significantly improves the user experience by reducing waiting times and charging anxiety, laying a solid foundation for the widespread adoption and user acceptance of NEVs.

4.2. Promoting the Intelligent Upgrade of Charging Infrastructure

AI technology endows charging infrastructure with unprecedented intelligent capabilities, enabling full-chain optimization from equipment monitoring and fault (early warning) to resource scheduling. By integrating advanced AI algorithms, charging facilities can automatically identify vehicle types, match optimal charging power, and guide vehicles to the most suitable parking spots, greatly simplifying user operations and improving charging efficiency. Simultaneously, AI-driven fault prediction systems can preemptively identify equipment anomalies, accurately pinpoint problem sources through data analysis, significantly reducing operation and maintenance costs while enhancing facility reliability and operational efficiency. Furthermore, AI technology supports real-time monitoring and dynamic scheduling of charging loads, intelligently adjusting charging strategies based on grid load conditions, effectively alleviating grid stress, and promoting the transition of charging infrastructure from a traditional "passive response" mode to an "active optimization" mode. This provides robust support for the intelligent and efficient operation of charging networks.

4.3. Facilitating Energy Structure Transformation and Sustainable Development

Through Vehicle-to-Grid (V2G) and virtual power plant technologies, AI transforms charging piles into key nodes of the energy internet, providing a crucial technical pathway for the large-scale integration of renewable energy and the transformation of the energy structure. This technology can guide vehicle owners to charge during off-peak grid hours and discharge during peak hours, achieving spatiotemporal shifting of electrical energy, optimizing energy usage efficiency, stabilizing grid load fluctuations, and enhancing grid stability and flexibility. Concurrently, energy trading systems built on AI combined with blockchain technology enable direct peer-to-peer electricity transactions between vehicles and market-oriented operations, reducing

intermediary costs and improving the efficiency and transparency of energy trading. These innovative models not only drive the green transformation of the energy structure but also provide practical technical solutions for achieving the "Dual Carbon" goals (carbon peak and carbon neutrality), promoting the sustainable development of the energy system.

4.4. Addressing the Challenge of Imbalanced Charging Facility Distribution

AI technology, through big data analysis and machine learning algorithms, can accurately predict charging demand across different regions and time periods, providing data-driven decision support for the scientific layout and optimal configuration of charging infrastructure. By integrating multi-dimensional data such as EV ownership, traffic flow, and user behavior, AI models can construct siting and capacity determination models for charging facilities, scientifically planning the quantity, type, and distribution of charging points. This effectively reduces the number of underutilized or "zombie" piles, enhances facility utilization rates and coverage. Additionally, AI-driven dynamic pricing strategies can adjust charging fees based on real-time data like occupancy rates and charging demand, guiding users to (distribute) to less busy stations, further balancing supply and demand, and solving the problem of supply-demand mismatch inherent in traditional layout approaches. These applications not only improve the operational efficiency of the charging network but also provide scientific basis and decision support for the efficient and balanced coverage of charging infrastructure.

4.5. Constructing a Secure and Reliable Charging Ecosystem

AI technology plays an indispensable role in the realm of charging safety, effectively mitigating safety risks during charging through real-time monitoring of battery states, identification of potential hazards, and early warning of risks. Integrating advanced sensor technology and data analysis algorithms, AI systems can monitor key battery parameters such as voltage, current, and temperature in real-time, promptly detecting and issuing alerts for potential hazards like battery overheating, overcharging, or short circuits, thereby preventing safety incidents.[5]Simultaneously, AI technology can incorporate intelligent means such as image recognition and voice alerts to prevent Internal Combustion Engine (ICE) vehicle parking in EV spots, maintain charging order, and improve the operational standardization and user experience of charging stations. Furthermore, AI-driven safety mechanisms can optimize charging strategies through data analysis, avoiding damage caused by over-charging or over-discharging, protecting user property, and establishing a solid foundation for the healthy development and safe, reliable operation of the charging industry.

5. Conclusion

This study focused on the multi-objective optimization of NEV battery charging via the deep integration of AI and real-world scenarios, specifically addressing the inadequate adaptability of traditional charging strategies in dynamic environments. A hybrid optimization framework based on the synergy of data-driven methods and physical constraints was proposed. By integrating AI technologies such as deep learning and reinforcement learning, the framework achieved real-time perception of battery states, dynamic adjustment of charging parameters, and multi-objective collaborative optimization. The results indicate that this framework can significantly reduce charging time, decrease battery capacity fade, and effectively balance grid load. Specifically, AI technology, through real-time battery state monitoring and optimized charging strategies, not only enhanced charging efficiency but also extended battery service life. Furthermore, the AI-driven intelligent upgrade of charging infrastructure enabled full-chain optimization from equipment monitoring to resource scheduling, reducing operational costs and alleviating grid pressure. Moreover, AI played a key role in promoting energy structure transformation, solving the problem of imbalanced charging facility distribution, and building a secure and reliable charging ecosystem. This study provides theoretical support and technical references for the intelligent upgrade of NEV charging infrastructure, promotes the transition of AI technology from laboratory settings to practical engineering applications, and holds significant importance for the sustainable development of the NEV industry.

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