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Overview of new energy vehicle charging development

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Abstract:

The advancement of new energy vehicle charging technology is of great significance to increasing the cruising range of electric vehicles, shortening charging time, and enhancing user experience. Studying the development direction of new energy vehicle charging technology will help promote the improvement of charging infrastructure and promote the large-scale popularization of new energy vehicles. This article elaborates on the current status, development direction, and challenges of new energy vehicle charging technology, and on this basis puts forward corresponding conclusions and suggestions.

Keywords: New energy, Electric vehicle, Charging technology, Development direction, Challenge

1. Introduction

The burning of large amounts of fossil fuels emits large amounts of greenhouse gases, leading to global warming. As the world pays increasing attention to reducing greenhouse gas emissions and improving air quality, the promotion and popularization of new energy vehicles is considered one of the keys to achieving these goals[1]. Among them, the advancement of charging technology and the construction of charging infrastructure are important factors in promoting the popularity of new energy vehicles. As the number of new energy vehicles increases, the demand for charging piles is also rising rapidly. Many countries and regions have begun to increase investment in charging infrastructure to meet the growing charging demand. New energy vehicles are not only part of the modern transportation system, but also an important tool for achieving environmental sustainability and economic development.

Understanding different charging technologies and their pros and cons is critical to driving the adoption and use of electric vehicles. The basic principle of charging technology is mainly to transfer electric energy from the charging equipment to the battery of the electric vehicle to meet the energy needs of the electric vehicle. According to the method of power transmission, charging technology can be divided into the following categories: wired charging, wireless charging[2], and fast battery swap technology is also in a stage of rapid development.

Current wired charging technology is mainly divided into two modes: AC charging and DC charging. The charging method of AC charging can be subdivided into single-phase slow charging and three-phase fast charging. DC charging usually refers to DC charging with a power exceeding 22 kW [3].AC charging has low power and long charging time, but has relatively little impact on battery life; DC charging can significantly improve charging efficiency, greatly shorten charging time, and meet users' needs for fast charging, but has a certain impact on battery life and grid load. Moreover, the construction and operation costs are high, and both charging modes

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have limited distribution of charging stations, especially in remote areas and around cities. This inadequacy of the charging network has led to consumers' range anxiety, that is, they are worried that the electric vehicle will have insufficient power while driving and will not be able to find a charging station. The lack of sufficient charging infrastructure makes potential consumers have concerns about purchasing electric vehicles, thus affecting the market penetration rate of electric vehicles. Secondly, there are multiple charging standards and interfaces in the market, causing users to face confusion when choosing charging equipment. This incompatibility not only limits consumers' choices but may also lead to longer charging times and affect the convenience of electric vehicles[4].

Wireless charging technology is a major innovation in the field of charging, aiming to eliminate the trouble of traditional plug-in charging. This technology uses electromagnetic fields to transmit energy from the charging device to the receiving device of the electric vehicle. Users only need to park the vehicle in the charging area to start charging. As the technology matures, wireless charging is expected to become the mainstream method of charging electric vehicles in the future, reducing the need for physical connections and improving charging convenience. Wireless charging technology can be divided into near-field charging, mid-field charging, and far-field charging according to transmission distance[5]. According to usage scenarios, it can be divided into three methods: static wireless charging, dynamic wireless charging, and quasi-dynamic wireless charging. Among them, static wireless charging can be divided into inductive coupling power transmission[6], magnetic coupling resonant wireless power transmission, and microwave power transmission according to the transmission mechanism[7].

As an emerging energy vehicle solution, electric vehicle battery replacement technology is gradually becoming a hot topic in the market. Users only need to drive the vehicle into the battery swap station, and the battery replacement can be completed in a few minutes. Current battery swapping technology is mainly divided into two types: single battery swapping and quick battery swapping, among which quick battery swapping is the mainstream development direction. In China, NIO is one of the pioneers in battery-swapping technology, and its battery-swapping stations have been widely deployed across the country. As of 2024, the number of battery swap stations operated by NIO in China has reached 1,298 [8]. The rollout of battery-swapping technology has been relatively slow in the U.S., largely due to more widespread charging infrastructure. However, some startups such as Gogoro and Ample are exploring battery replacement solutions, especially in the field of electric motorcycles and light electric vehicles. The main purpose of battery replacement technology is to solve some key problems faced by electric vehicles during use, but it also faces multiple challenges such as infrastructure construction, user acceptance, battery management, and maintenance.

In short, the main issues facing the current development of electric vehicle charging technology involve many aspects, including infrastructure construction, compatibility, and charging efficiency.

2. Wired charging

In the context of new energy vehicle charging technology, fast charging technology has become an important part of electric vehicle infrastructure. Current fast charging stations can typically charge an electric vehicle to 80% capacity in 30 minutes or less [9], which is significantly faster than the several hours required by traditional charging methods. This is mainly due to high-power charging and the expansion of charging networks. High-power charging uses high-power charging equipment (such as DC fast charging) to speed up charging. Recent research shows that ultra-fast charging stations are becoming a new direction in technological development. These charging stations utilize advanced power electronic conversion technology to provide higher charging power, which can reach 350kW or higher, which greatly shortens the charging time [10].

Batteries play a crucial role in the realization of fast charging, which depends not only on the development of charging infrastructure but also on advancements in battery technology. Innovative battery materials and chemistries, such as solid-state batteries and lithium-sulfur batteries, are being researched to enhance charge rates and cycle life. These new battery types can theoretically endure higher charging currents, facilitating faster charging speeds. Regarding the impact of fast charging on battery life, research indicates that it has a relatively minor effect. Some studies suggest that fast charging does not significantly influence battery capacity, health, or long-term vehicle range [11]. However, it is worth noting that frequent high-voltage charging may accelerate battery degradation and reduce battery life in certain cases. Overall, the implementation of fast charging technology is not expected to cause substantial performance degradation. Long-term reliance on fast charging can harm the health of your battery. Developing new battery materials and charge management systems to reduce the loss of batteries caused by fast charging is the focus of current research.

Research on the standardization and compatibility of charging piles is critical to the advancement of the electric vehicle industry. By establishing unified technical

standards, leveraging international guidelines, and optimizing the layout and design of charging piles, we can significantly enhance their compatibility and user experience. Furthermore, the increasing market demand for charging piles has driven the continuous enhancement of their functionalities. The technical standards governing charging piles have a direct impact on construction costs and the compatibility of charging infrastructure. Variability in charging interfaces among different electric vehicle brands, stemming from their unique protection strategies, leads to suboptimal charging compatibility. Therefore, the establishment of unified technical standards is essential for ensuring the compatibility of charging piles. Since 2016, China has implemented a new national standard for electric vehicle charging piles[12]. This standard aims to standardize the design, installation, and operation of charging piles, thereby improving their safety and reliability. In addition to domestic standards, referencing international standards is also crucial for enhancing the compatibility of charging piles. For instance, the International Electrotechnical Commission (IEC) has conducted standardization efforts regarding electric vehicle charging interfaces, which serve as a valuable reference for the development of charging piles across various countries[13].

3. Wireless charging

Wireless charging technology is a non-contact charging method primarily based on the principle of electromagnetic induction, which facilitates the transmission of energy from the charging device to the battery of the electric vehicle via an electromagnetic field. The fundamental process involves a transmitter and a receiver: the charging system comprises both components. The transmitter generates a high-frequency electromagnetic field, while the receiver converts the electrical energy into direct current through induction, thereby supplying power to the battery. During wireless charging, the alignment between the transmitter and receiver is crucial. Modern wireless charging systems are frequently equipped with automatic alignment technology to ensure efficient charging when the vehicle is parked [14].

Wireless charging technology offers several advantages over traditional wired charging methods. Users no longer need to plug or unplug cables; instead, they simply park their electric vehicles in the designated charging area to initiate the charging process, significantly enhancing convenience. Additionally, wireless charging eliminates the risks associated with physical connections and reduces the likelihood of cable damage or leakage, thereby improving charging safety. Many wireless charging systems also feature intelligent charging management functions that can automatically adjust the charging power based on battery status, optimizing overall charging efficiency.

The application of wireless charging technology in new energy vehicles is progressively advancing, as evidenced by several key developments. First, certain cities have initiated the deployment of public wireless charging stations, enabling users to conveniently charge their vehicles while parked, thereby alleviating the inconvenience of charging queues. Second, future electric vehicles are expected to be increasingly equipped with wireless charging receivers, which will further enhance the intelligence and convenience of these vehicles. Finally, wireless charging systems not only facilitate charging but also can feed power back into the power grid, thereby enabling two-way energy flow and improving overall energy utilization efficiency.

Despite the many advantages of wireless charging technology, there are still some challenges in practical applications. At present, the efficiency of wireless charging is generally lower than that of wired charging, and although the technology is improving, it still needs to be improved. The high cost of construction and maintenance of wireless charging systems may lead to hesitation in the initial investment [15]. At present, the standards of wireless charging technology in the market are not uniform, and products from different manufacturers may have compatibility issues, which affects the user experience[16].

With the advancement of science and technology and the demand of the market, wireless charging technology is expected to make breakthroughs in the following aspects. Researchers are working to improve the energy transfer efficiency of wireless charging to shorten charging time and enhance the user experience. The industry is promoting the standardization of wireless charging, and making different brands and types of wireless charging devices compatible, making it more convenient for users to use [17]. The wireless charging system of the future will be even more intelligent, able to monitor battery status in real-time, optimize charging strategies, and even seamlessly connect with smart home systems.

Wireless charging technology has revolutionized the way new energy vehicles are charged. Its convenience and safety have greatly improved the user's charging experience, and have become an important direction for electric vehicle charging in the future. Although the technology still faces some challenges, as the industry continues to develop and innovate, wireless charging technology is expected to play a greater role in the future, helping the popularization and development of new energy vehicles.

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4. Battery swapping technology

Electric vehicle battery-swapping technology has gradually attracted attention in recent years, especially in the context of the rapid development of new energy vehicles. As the core component of this technology, the basic functions and composition of the battery swapping station are an important basis for understanding the battery swapping system. The primary function of a battery swapping station is to quickly and efficiently replace the battery of an electric vehicle. With specially designed robots, the site can quickly remove depleted batteries from the vehicle and install a fully charged battery onto the vehicle. The entire process is usually completed within five minutes, which saves a lot of charging time for vehicle users.

Battery swapping stations need to have an advanced battery management system to monitor and manage the status of the battery. This includes things like the battery's state of charge, health, and lifespan. Through data analysis, the management system can optimize the use and replacement of batteries, improving overall efficiency. For efficient battery management, battery swapping stations need to be equipped with data storage and cloud services. These systems are capable of recording and analyzing the usage, charge cycle, and performance data of each battery in real-time for subsequent maintenance and scheduling[18]. The battery swapping station also needs to be equipped with a communication interface to communicate with the vehicle and the user's mobile device in real time. Users can use the mobile app to find out the status of the battery, schedule a replacement time, and view nearby replacement sites. During the battery replacement process, depleted batteries need to be transported to the charging area for charging and maintenance. This feature ensures that the battery can be recharged and put back into service in a short period, maintaining the operational efficiency of the replacement station.

The replacement platform is the core part of the battery swapping station and is usually equipped with a robotic arm and a robotic system. They are responsible for removing the battery from the vehicle and installing a new one. In terms of design, the platform needs to consider the compatibility of different models of vehicles to meet the diverse market needs. The battery storage area is used to store the charged batteries and the batteries to be charged. This area needs to have good ventilation and temperature control systems to ensure the safety and performance of the battery. Through scientific storage management, the service life and performance of the battery will be effectively guaranteed[19]. Charging facilities are another important component of battery swapping stations. They are responsible for charging a depleted battery and often include fast-charging devices that can fully charge the battery in a short period. The efficiency of the charging infrastructure has a direct impact on the operational efficiency of the battery swapping station. Battery swapping stations need to be equipped with monitoring and management systems to ensure that all operations are safe and efficient. These systems include video surveillance, alarm systems, and data analysis tools that enable real-time monitoring of battery status and site operations [20]. The user interface provides a user-friendly platform for users to operate, often including kiosks and mobile apps. Users can use these interfaces to check the status of the battery, schedule a replacement, make a payment, and more.

Despite the many advantages of battery-swapping technology, its implementation and adoption also present several challenges. Building a battery-swapping station requires significant capital investment and resource allocation, which is a major challenge for many businesses and governments. Especially between urban and rural areas, the layout of battery-swapping stations needs to be properly planned to ensure coverage and convenience[21]. Despite the multiple advantages offered by battery swapping-technology, user acceptance of this new charging method is still an issue. Many consumers lack an understanding of how battery swapping works and how safe it is, which can hinder its widespread adoption. Battery swapping stations require effective management and maintenance of the battery to ensure the safety and performance of the battery. This requires specialized technicians and a sound management system, which adds to the complexity of the operation. With the rapid development of the electric vehicle market, the competition between traditional charging pile technology and battery-swapping technology has become increasingly fierce. While battery-swapping technology has advantages in some ways, efforts are still needed to prove its long-term viability and economics to gain a foothold in the market.

5. Conclusion

The importance of charging infrastructure: The construction of charging infrastructure is a key factor in increasing the adoption of electric vehicles. The global electric vehicle market continues to grow, and the layout and technological development of charging piles are constantly following to meet the growing demand for charging.

Diversification of charging technologies: Wired charging (AC charging and DC charging) and wireless charging technologies have their advantages and disadvantages. AC charging has less impact on battery life, but it takes a long time to charge; DC charging can significantly improve charging efficiency, but construction and operating

costs are high. Wireless charging technology improves the convenience and safety of charging, but it is currently less efficient and costly.

Development of fast charging technology: Fast charging technology has become an important part of the electric vehicle infrastructure, capable of charging electric vehicles to 80% in a short period. Although fast charging has a relatively small impact on battery life, frequent high-power charging cycles can lead to an accelerated decline in battery capacity.

The potential of battery swapping technology: Battery swapping technology enables the battery replacement of electric vehicles quickly and efficiently, saving a lot of charging time. However, the construction of battery swapping stations requires a lot of capital investment and resource allocation, and user acceptance is also an issue.

6. Suggestion

Strengthen the construction of charging infrastructure: Governments and enterprises should increase investment in charging infrastructure, especially in remote areas and around cities, to improve the convenience of charging and reduce consumers' "range anxiety".

Promote the standardization and compatibility of charging technology: formulate unified technical standards and charging interfaces, improve the compatibility and user experience of charging piles, and reduce the confusion of users when choosing charging equipment.

Optimize fast charging technology: Develop new battery materials and charge management systems to reduce the loss of batteries caused by fast charging, improve charging efficiency, and ensure battery safety.

Promote wireless charging technology: improve the energy transmission efficiency of wireless charging, reduce construction and maintenance costs, promote the standardization of wireless charging, and improve user experience and convenience.

Improve user acceptance: Through education and publicity activities, improve users' understanding and acceptance of battery swapping technology and wireless charging technology, and enhance users' trust and dependence on new charging methods.

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