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Research on the Development Status of Static Wireless Charging Technology for Electric Vehicles

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Abstract: With the greenhouse effect and massive energy exploitation, the energy crisis and environmental issues have attracted more and more attention. Electric vehicles have received widespread attention for their advantages of clean energy saving, low noise, environmental protection, zero emission, and smooth start. Wireless charging technology has advantages that contact charging cannot match, such as safety and convenience. Therefore, the adoption of static wireless charging technology for electric vehicles represents a prominent future development trend. This article commences by presenting the current research landscape of static wireless charging technology for electric vehicles globally, elucidates the principles behind three such technologies, conducts a comparative analysis of their merits and demerits, and ultimately outlines the future technological trends in static wireless charging for electric vehicles.

Keywords: Electric vehicles; Static wireless charging; Magnetic coupling resonant type; Development trend.

1. Introduction

With the rapid development of technology and economy, the number of automobiles continues to rise. However, while bringing convenience to people, traditional fuel vehicles produce a large amount of exhaust gas, which poses huge challenges to the earth's environment and also causes energy problems. Electric vehicles can effectively improve the above problems. Promoting the rapid growth of new energy electric vehicles plays a pivotal role in expediting the phase-out of conventional fuel-powered vehicles, thereby contributing significantly to reducing harmful vehicle exhaust emissions. This transition holds immense importance in ensuring long-term energy security, driving energy conservation and emission reduction efforts, and mitigating air pollution concerns. The electrification of the automotive industry represents an inevitable and forward-looking trend[1]. Reflecting on the historical trajectory of electric vehicle development, one can observe a consistent drive for innovation in charging technologies that has evolved in tandem with the growth of electric vehicles. Charging methods for electric vehicles can be broadly categorized into wired and wireless options. The former uses a combination of sockets and plug-in wires to charge the battery. However, sparks are easily generated during the power transmission process, which affects the life and safety of electrical equipment. At the same time, other Maintenance is difficult and the location of use is limited; the latter has higher flexibility and stability, which can reduce the impact on the power grid. At the same time, due to the current limited capacity of electric vehicle power batteries and insufficient endurance, wireless charging technology just solves this problem. A key technical issue [2]. The use of wireless charging technology can achieve flexibility and speed, and solve the safety and maintenance problems of wired charging [3].Simultaneously, the swift advancement of artificial intelligence technology is making electrified devices increasingly intelligent, leading to substantial reductions in labor costs. Hence, the adoption of wireless charging technology for electric vehicles aligns more closely with the future societal development trajectory.

This article conducts an in-depth analysis and examination of the state-of-the-art static wireless charging technology for electric vehicles, drawing upon existing research by both domestic and international scholars. Initially, the article provides an overview of the underlying transmission principles for three widely employed wireless power transmission technologies. Subsequently, a comparative analysis is performed to delineate the merits and demerits of these three technologies. Conclusively, building on this foundation and considering the evolving landscape of contemporary society, the article offers forward-looking insights into the development prospects and challenges inherent in static wireless charging technology.

2. Development Status of Wireless Charging Technology at Home and Abroad

2.1. Foreign development status

As early as the end of the 19th century, Nikola Tesla was constantly experimenting with wireless transmission of electrical energy. In 1889, he lit an incandescent lamp through the air based on the principle of electromagnetic induction, thus creating a new era of wireless energy transmission technology. First of all [2]. After years of research, foreign scientific research institutions and universities have carried out research on static wireless charging technology for electric vehicles in recent years. In the 1960s, the American defense company Raytheon conducted research on wireless power transmission and invented a new rectenna based on semiconductor diodes, achieving the key step from microwave to DC [2]; by the 1990s, The University of Oakland has done a lot of research on magnetic coupling mechanisms and designed a series of novel coil structures, which effectively improved the transmission performance of magnetic coupling mechanisms [1]; in the early 21st century, an experimental team from the Massachusetts Institute of Technology discovered magnetic field resonance. technology, realized the lighting of light bulbs in the air, and the emergence of magnetic field resonance technology opened a new chapter in wireless power transmission [2]; then in 2014, the Korea Advanced Institute of Science and Technology team achieved close-range high-power transmission and proposed large and small coils The coupling mechanism greatly improves the anti-offset ability of the system [1].

2.2. Domestic development status

Domestic research related to static wireless charging technology started relatively late and began to be studied at the beginning of the 21st century. The main universities and scientific research institutions include Chongqing University, Harbin Institute of Technology, Southeast University, and Tianjin University of Technology. Although my country has been engaged in research on wireless power transmission for only a dozen years, it has still made significant achievements in the optimization design of magnetic coupling mechanisms, electromagnetic compatibility and electromagnetic shielding, load identification and foreign object detection [1].

Since 2002, Chongqing University has been dedicated to the exploration of wireless power transmission technology, with a keen focus on both theoretical knowledge and practical engineering applications of this transmission method[2]. In 2013, a group of professors at Southeast University achieved a significant milestone by introducing the first domestically manufactured electric vehicle featuring wireless charging technology. This breakthrough was accompanied by corresponding research into electromagnetic leakage and electromagnetic shielding in the context of static wireless charging technology for electric vehicles[1]. Simultaneously, professors from Harbin Institute of Technology put forth a novel wireless charging system utilizing supercapacitors to advance this technology[1]. Further advancements were made by the experimental team at Tianjin University of Technology, which sought to optimize power transmission methods based on magnetic field resonance[2].

3. Basic Principles of Static Wireless Charging Technology

3.1. Electromagnetic radiation transmission

Another name for electromagnetic radiation power transmission is microwave transmission. The main working principle of this transmission method is to achieve effective conversion between current signals and microwave signals [2].

The primary energy conversion occurring during the transmission process involves the conversion of high-voltage alternating current sourced from the power grid. This AC current is first rectified to produce a DC signal and then further transformed into a microwave signal through a converter. The microwave signal is subsequently transmitted through free space as radiation and is ultimately received by the electric vehicle. The receiving device on the vehicle then absorbs, converts, and rectifies this energy to charge the vehicle's battery[2].

The main advantages of electromagnetic radiation power transmission technology are: the direction of microwave radiation is omnidirectional, directional and penetrating. It can be mainly used for long-distance or ultra-long-distance power transmission. However, the energy loss in the entire transmission process is large, resulting in Its transmission efficiency is low, and the current high-efficiency microwave rectification period lags behind in development. At the same time, radiation has a certain impact on biology and ecology [4]. Therefore, this technology is currently not suitable for static wireless charging technology of electric vehicles.

3.2. Electromagnetic induction transmission

For the field of static wireless charging of electric vehicles, electromagnetic induction is one of the main methods used [2].

The phenomenon of electromagnetic induction can be understood through a simple process: When a changing magnetic flux induces an electromotive force in a conductor, closing the conductor into a loop causes electrons to flow, creating an induced current[4]. The working principle of electromagnetic induction wireless charging technology is rooted in this electromagnetic induction concept. The power input end, co-located with the primary side of the induction coil placed underground, interacts with the secondary side of the induction coil inside the vehicle. During operation, the current received by the power input end is rectified and then directed into the primary side of the induction coil via a high-frequency inverter circuit. Leveraging electromagnetic induction principles, the secondary side of the coil generates a corresponding induced current. After rectification and filtering by the electric vehicle's internal control circuit, the power is adjusted to charge the battery[2].

The main advantages of electromagnetic induction wireless charging technology are reflected in its high energy conversion efficiency and wide transmission range. The minimum transmission power is as low as a few watts and the maximum transmission power can be as high as several kilowatts [2]. However, it can be seen from the above transmission principle that electromagnetic induction wireless charging technology needs to consider the distance between devices. Usually the distance between two induction coils needs to be controlled within 0.1m, and during the transmission process, electromagnetic radiation in the space It is non-directional [4].

3.3. Magnetic coupling resonant transmission

The research time on magnetic coupling resonant power transmission is still short, but after in-depth research by a large number of scholars, this transmission technology has become a key direction in the development of static wireless charging technology for electric vehicles.

The basis for the implementation of magnetic coupling resonance wireless charging technology is the principle of magnetic coupling resonance. Assuming there is an induction field, magnetic field energy will be transferred back and forth repeatedly inside the radiation source and its accessories. Using this characteristic, the radiation source is regarded as the emitter. At this time, the emitter maintains this characteristic, but when it has this In a changing magnetic field, the electric field generated is constrained by capacitance, and it cannot generate radio wave energy for external radiation. Therefore, in the transmission system realized by this coupled resonance wireless charging technology, the high-frequency flux linkage changes in the electromagnetic field do not affect the transmission system. The outside world radiates, this phenomenon is also called the principle of magnetic coupling resonance [4].

Magnetic coupling resonant wireless charging technology operates as follows: Initially, a high-voltage alternating current signal is sourced from the power grid. After rectification and filtering, it's transformed into direct current.

Next, a high-frequency inverter is employed to convert the DC signal into a high-frequency square wave signal. The interaction between the high-frequency square wave signal and two identical LC compensation circuits on both the primary and secondary sides of the induction coil results in resonance. This resonance, characterized by matching frequencies, enables energy transmission between the primary and secondary sides. The electric energy transmitted is subsequently directed through the vehicle's rectifier control circuit to charge the battery[2].

Comparing magnetic coupling resonant transmission and electromagnetic induction transmission, the advantage of the former is that the resonant frequency of the primary and secondary sides will not be easily interfered by the external magnetic field, and can improve the coupling coefficient and transmission efficiency [4], which is specifically reflected in: on both sides The coil's position changes have low sensitivity; it is more suitable for medium and long-distance power transmission, and the power transmission efficiency is very high when the distance is appropriate.

4. Future Development Trends of Static Wireless Charging Technology for Electric Vehicles

A comprehensive review of static wireless charging technology for electric vehicles, both domestically and internationally, as well as an analysis of the three common power transmission methods, reveals that substantial progress has been made in various facets of static wireless charging technology for electric vehicles. However, it is evident that several challenges and issues still require resolution. Mainly manifested in the following aspects:

(1) The system's anti-offset capability. In real-life applications, affected by the user's parking position, the relative position of the primary and secondary coil structures of the system will change within a certain range, causing changes in the coupling coefficient, which requires the system to have strong anti-offset capabilities. At present, the system's offset capability is mainly improved through the design of magnetic coupling mechanisms or system closed-loop control, but these technologies are still immature.

(2) The coil structure is a critical factor that directly impacts the efficiency of the entire charging system[2]. To enhance transmission efficiency, it is essential to determine the optimal distance between the two coils, as well as refine the winding method, shape, and arrangement of the coils.

(3) The environmental sensitivity of the system is a significant concern in the application of static wireless charging technology for electric vehicles. Given the complexity of usage scenarios, inherent system parameters like coil internal resistance and resonant frequency are susceptible to external environmental influences. Enhancing the system's capability to withstand fluctuations in these inherent parameters, such as resonant frequency, and reducing its sensitivity to environmental factors remains a paramount focus in the ongoing research of static wireless charging technology for electric vehicles.

(4) Orderly charging. In the case of disordered charging, the charging of a large number of electric vehicles will aggravate the power grid load fluctuations, causing grid capacity loss and worsening economic benefits [3]. Therefore, using a reasonable orderly charging control strategy can effectively improve the power grid's ability to handle large-scale charging loads. accommodation capacity.

(5) Energy transfer and human safety. Further study the amount of radiation produced by different charging methods and its impact on the human body, reduce the impact of electromagnetic radiation on the human body, and explore safer and more active radiation protection methods [2].

(6) Dynamic wireless charging technology involves the installation of a sequence of transmitting coils beneath roadways to charge electric vehicles in motion[2]. Implementing dynamic wireless charging represents a significant and forward-looking development trend in the electric vehicle charging landscape.

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