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Wireless Charging System for Electric Vehicles

Zheng Yan *

Department of Electrical & Electronic Engineering, Textile University, Wuhan, China
* Corresponding author email: 1257500916@qq.com

ABSTRACT

With the popularization of electric vehicles, wireless charging technology has shown significant advantages in charging convenience, security and other aspects, and has become a research hotspot in the field of new energy vehicles. The purpose of this paper is to discuss the principle, architecture, standards, protocols and development trend of the wireless charging system for electric vehicles. This paper expounds the basic concepts and main technical types of wireless charging, and reveals the application of electromagnetic induction and magnetic resonance in wireless charging; The composition and function of the wireless charging system, as well as the key technical challenges in practical application, are analyzed; The mainstream wireless charging standards and the importance of standardization are sorted out; The development direction, external influencing factors and future application scenarios of wireless charging technology are prospected, which provides theoretical basis and practical guidance for further research on wireless charging technology of electric vehicles.

KEYWORDS

Electric Vehicle; Wireless Charging Technology; Electromagnetic Induction.

1. INTRODUCTION

Under the background of energy crisis and environmental pollution, the development of electric vehicles, as a representative of clean energy transportation, has received extensive attention worldwide. The convenience and safety of charging facilities is one of the key factors to promote the popularization of electric vehicles. The emergence of wireless charging technology provides a new solution for electric vehicle charging, which not only improves the convenience of charging, but also helps to enhance the safety of the charging process. In this paper, we will focus on the wireless charging system for electric vehicles and discuss its technical principles, system architecture, standards and protocols, and future development trends, aiming to provide reference for the in-depth research and application of wireless charging technology for electric vehicles.

2. CURRENT STATUS OF DOMESTIC AND INTERNATIONAL RESEARCH

The development of wireless charging technology in China is mainly studied by universities. Tian Yong of Shenzhen University, taking the LCC-S compensation structure system as an example, proposed the combined method of Kalman filter and dynamic prediction model to improve the constant current control speed of the system by about 10%; He Xinyue of Zhejiang University has designed an interoperable system for different ground clearance and power to meet the needs of coil charging with different power; Zhuang Huimin of Chengdu University of Information Technology

used the information gap decision theory to enhance the system stability of the dual LCC compensation structure. When the coupling coefficient was reduced to 0.19, the transmission efficiency was still 96.4%; Xu Shihui of Shanghai Jiaotong University proposed the precise positioning method during static wireless charging to reduce the loss caused by lateral deviation, with the error not exceeding 0.003mm; Zhang Xian of Tianjin University of Technology proposed a current closed-loop self-tuning system with double LCC compensation structure, which improved the dynamic response capability of the system by 60%; Yang Jinming of South China University of Technology has achieved passive rectification effect by improving the charging structure. Under 20V transmission voltage, the voltage fluctuation does not exceed 1.6V A; Sun Yue of Hefei University of Technology proposed a new space magnetic coupling mechanism, which can ensure the stability of charging voltage when the charging angle deflection is not more than 60 degrees. Liu Tingzhang of Shanghai University calculated the equivalent inductance of the circuit of the wireless charging system based on Deng Xiao's resonant circuit model using the cyclic iterative particle swarm optimization algorithm. The accuracy of the equivalent inductance of the transmitter can reach 99.56%; Lu Zhe of Qingdao University proposed a composite shielding layer material composed of iron based nanocrystalline materials, ferrite and aluminum foil to simplify the composition of the magnetic coupler, reducing the total volume by 13.1% and the total weight by 4.44%; Shi Rui of Southwest Jiaotong University also chose the coupling structure of double transmitting coils, limiting the system power fluctuation to 2.6%.

Fig 1. Wireless charging sightseeing car developed by Chongqing University

In the practical application of wireless charging vehicles, universities and automobile companies have also entered the experimental stage. The Korean Academy of Advanced Science and Technology has run a wireless charging bus in Guiwei City, South Korea. The transmission power of the dynamic charging system can reach 100kW. In the latest generation of products, a kind of coreless guide rail is used. Compared with the traditional magnetic core structure, this coreless guide rail structure reflects a stronger ability in anti offset characteristics. In 2019, BMW Anonymous developed a hybrid electric vehicle with wireless charging technology. The battery can be fully charged in 210 minutes, and the charging efficiency can reach more than 90%. Sweden eRoadArlanda Company tested a two kilometer long charging road in the suburb of Stockholm, Sweden. This road is composed of several 50 meter long power supply rails, which can be used by charging trucks. There are still problems such as longitudinal deviation, weather impact and foreign matter detection, as shown in Figure 2.

Fig 2. Wireless charging road developed by eRoadArlanda

3. PRINCIPLES OF WIRELESS CHARGING TECHNOLOGY

3.1. Basic Concepts of Wireless Charging

Wireless charging, also known as non-contact charging or inductive charging, is a technology that utilizes electromagnetic fields to transmit power from the power source to the device without physical contact. The core of this technology lies in electromagnetic induction and magnetic field resonance, by generating an alternating magnetic field between two coupled coils to realize the wireless transmission of energy. The popularization of wireless charging technology greatly enhances the convenience of electronic devices, reduces the dependence on traditional wired charging, and also promotes the development of smart home and the Internet of Things.

3.2. The Main Technology Types for Wireless Charging

Electromagnetic induction charging. This is the most common type of wireless charging and is based on Faraday's law of electromagnetic induction. It involves a transmitting coil and a receiving coil. When an alternating current passes through the transmitting coil, an alternating magnetic field is generated, which induces an electric potential in the receiving coil, generating an electric current that charges the battery. Electromagnetic induction charging technology has high efficiency and stability, but the charging distance is shorter and usually requires the device to be in close contact or close to the charging plate.

Magnetic Resonance Charging. Magnetic resonance charging utilizes the magnetic resonance effect, which means that when two objects have the same natural frequency, the transfer of energy between them is much more efficient. In a wireless charging scenario, the coils of the transmitter and receiver are designed to have the same resonance frequency so that energy can be transferred efficiently even when they are not in direct contact. Magnetic resonance charging provides a longer charging distance than electromagnetic induction, making it suitable for charging environments that require greater degrees of freedom.

Radio wave charging. Energy is transmitted by transmitting high-frequency radio waves (e.g., microwaves), and the receiving end captures these electromagnetic waves through an antenna and converts them into electricity. This method can theoretically realize long-distance charging, but due to the low energy conversion efficiency, safety and health risks and other issues, is currently mainly used in specific professional fields, such as military and aerospace.

Capacitive coupling charging. Based on the principle of capacitive coupling, energy is transferred through the change of electric field between two parallel-placed electrode plates. The advantage of this technology is that it does not require magnetic materials and can realize energy transmission in non-metallic materials, but its transmission efficiency and distance are relatively limited.

4. WIRELESS CHARGING SYSTEM ARCHITECTURE

4.1. System Components and Functions

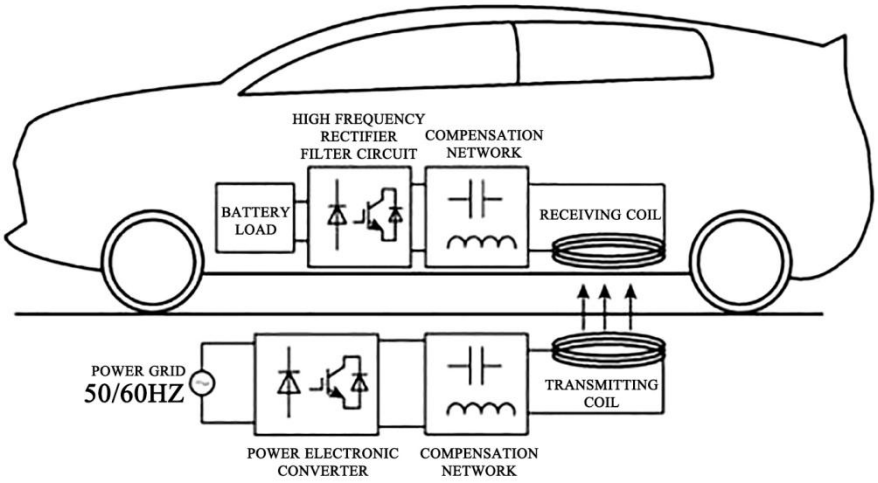

Fig 3. Structure of wireless charging system for electric vehicles

Ground power supply unit (GPU). The GPU is the heart of the wireless charging system, which is usually installed on the ground of the parking lot or charging station. It is responsible for converting the AC power of the power grid into high-frequency AC power, and generating an alternating magnetic field through the transmission coil embedded in the ground. The performance of GPU directly affects the efficiency and range of wireless charging.

On board receiving unit (ORU). The ORU is located at the bottom of the electric vehicle, including the receiving coil and the energy conversion circuit. When the vehicle stops at the designated position, the receiving coil is aligned with the transmitting coil of the GPU, receives energy through electromagnetic induction or magnetic resonance, and then converts it into DC to charge the vehicle battery.

Control system. The control system is the "brain" connecting GPU and ORU, which is responsible for monitoring the whole charging process, including power regulation, communication protocol implementation, security protection, etc. It ensures that the charging process is efficient and safe, and realizes the communication between GPU and ORU to adjust charging parameters in real time.

Auxiliary positioning system. In order to improve the efficiency and reliability of wireless charging, an auxiliary positioning system is used to accurately position the vehicle relative to the charging pad,

ensuring precise alignment of the transmitter coil with the receiver coil. This typically involves technology such as sensors, cameras or guided lights to automate the alignment.

4.2. Key Technological Challenges

The energy conversion efficiency of wireless charging is lower than that of wired charging, especially in large charging distance and power, how to improve the energy transfer efficiency and reduce energy loss is the primary challenge. Fast charging is the core demand of electric vehicle users, wireless charging system needs to ensure the safety of the premise, improve the charging speed and power to meet the requirements of high-power charging. Currently, the high cost of wireless charging system limits its commercialization. Reducing the cost and improving the economic efficiency of the system is the key to promote the wide application of wireless charging technology. Different brands and models of electric vehicles need to be compatible with wireless charging systems, and standardization and interoperability have become important prerequisites for the popularization of wireless charging. Electromagnetic fields generated by wireless charging systems may have an impact on human health and the surrounding electronic equipment, so ensuring system safety and evaluating and controlling the level of electromagnetic radiation are challenges that cannot be ignored. The wireless charging system needs to operate stably under various weather conditions, including high temperature, low temperature, rain and snow and other extreme environments, which puts forward higher requirements for the durability and reliability of the system. Accurate vehicle positioning and automatic alignment technology is the key to improve the efficiency of wireless charging and user experience, which requires further optimization of positioning algorithms and technology.

Zhang Wenjie of Taiyuan University of Technology proposed a constant current and constant voltage wireless charging system with the transmitter mutual inductance identification function, built a test prototype with a constant current of 5A and a constant voltage of 200V for verification, and the coupling coefficient and transmission current can remain stable within the offset of 160mm [1] . In the exploration of the influence of the shape of the magnetic coupling coil on the characteristics, Shi Song of Tianjin University of Technology simulated and compared the circular, D-shaped The results show that when the lateral deviation is 250m, the coupling degree of circular and square coils tends to zero, while the lateral coupling range of DD coils can reach 600m. The addition of ferrite cores has greatly improved the coupling performance of the four coils, which is 30.4% higher than that of the coils without ferrite cores [2] . Sun Kaidong of Xi'an University of Technology, based on the DD coil, optimized the length, width and turns of the coil with ant colony algorithm, and increased the magnetic induction intensity of each grid in the coupling system by 4.16T [3] . In order to stabilize the receiving power in the dynamic charging process, Professor Li's team of the Chinese Academy of Sciences proposed a segmented dynamic wireless charging system based on double transmitting coils and T-shaped structure, and added switches at the transmitting coils to eliminate the impact of cross coupling. The simulation results show that the power fluctuation of the system is less than 6% of the average output power [4] during dynamic charging; The Shi Rui team of Southwest Jiaotong University also chose the coupling structure of double transmitting coils, limiting the system power fluctuation to 2.6% [5].

5. STANDARDS AND PROTOCOLS

5.1. Mainstream Wireless Charging Standards

The standardization of electric vehicle wireless charging technology is the key to promote its commercialization and popularization. At present, many important wireless charging standards are being formed worldwide to guide technology research and development, equipment production and market standardization. Among them, the most prominent standards include SAE J2954 standard, Magnetic Resonant Coupling (MRC) standard and ISO/IEC 19363 standard.

SAE J2954 standard. Published by Society of Automotive Engineers (SAE), it aims to define the electrical, mechanical and communication interfaces of the wireless charging system and ensure that products from different manufacturers are compatible with each other. J2954 standard covers the power range from 7.7kW to 22kW and is applicable to household and public charging occasions. It is the most recognized wireless charging standard for electric vehicles worldwide.

MRC standard. It focuses on the use of magnetic resonance coupling technology to achieve long-distance, efficient wireless energy transmission. The MRC standard emphasizes the realization of more flexible charging positions and larger charging ranges without sacrificing charging efficiency, which is an important direction for the development of wireless charging technology in the future.

ISO/IEC 19363. It is jointly developed by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) to provide a comprehensive standardization framework for wireless power transmission systems. The ISO/IEC 19363 standard covers all aspects from system design, safety requirements to test methods, aiming to ensure the global interoperability and safety of wireless charging systems.

5.2. The Importance of Standardization

Standardization ensures a seamless interface between wireless charging devices from different manufacturers and electric vehicles, reducing technical barriers and improving the overall efficiency of the market and the consumer experience. The development and implementation of standards helps ensure that wireless charging systems meet internationally recognized safety standards for electromagnetic radiation and electrical safety, protecting users from potential harm while safeguarding public health and environmental protection. Standardization provides a clear path for technology iteration and innovation, encourages companies to invest in R&D resources, pushes the entire wireless charging industry forward, and accelerates the maturation and commercialization of the technology. Unified standards reduce the technical difficulty and cost for new enterprises to enter the market, promote market competition, and facilitate consumers to obtain better quality and more diversified wireless charging products and services. Standardization helps to eliminate technical barriers in international trade, promotes worldwide technical exchanges and product circulation, and accelerates the popularization and application of wireless charging technology in the world. Standardization enhances consumers' confidence in wireless charging technology, improves market trust, and provides strong support for the sales and market acceptance of wireless charging products. Standardization is the cornerstone for electric vehicle wireless charging technology to realize large-scale application and promote the healthy development of the industry. Through continuous improvement and promotion of standards, wireless charging technology will be able to better serve the needs of modern society and promote the future development of green mobility and intelligent transportation.

6. DEVELOPMENT TRENDS AND PERSPECTIVES

6.1. The Direction of Technological Progress

Looking to the future, wireless charging technology for electric vehicles is undergoing a profound transformation, the core of which lies in breaking through the technical bottlenecks of efficiency, range, cost and interoperability. In terms of energy efficiency improvement, researchers are committed to optimizing the coil design and energy conversion mechanism, and strive to reduce the loss in the energy transmission process, to achieve a more efficient and environmentally friendly wireless power transmission. Technological advances focus on expanding the effective range of wireless charging, explore the more relaxed space layout to achieve accurate charging methods, including dynamic wireless charging, that is, in the vehicle on the move to complete the charging, which will greatly improve the convenience and flexibility of charging. Intelligent and automated

charging is another major direction of development, through the integration of advanced sensing and positioning technology, to realize the charging process of automatic alignment and intelligent management, reduce human intervention, and enhance the user experience. Standardization and interoperability are also key to technological progress, and the establishment of globally harmonized standards will facilitate seamless charging between different brands and models of electric vehicles, accelerating the popularization of wireless charging technology. Cost control is the cornerstone to promote the widespread application of the technology, through technological innovation and large-scale production, reduce system costs and improve the economic viability of the technology.

6.2. External Influences

The development of wireless charging technology for electric vehicles does not proceed in isolation, but is profoundly influenced by a variety of external factors. The policy and regulatory environment plays a decisive role, the government's support policy, charging standards and incentives for new energy vehicles to pave the way for the commercialization of wireless charging technology. Market demand is another important driving force. With the proliferation of electric vehicles, consumers are increasingly demanding convenient and efficient charging, prompting wireless charging technology to evolve to meet market expectations. Technological innovation and integration of wireless charging for the injection of vitality, interdisciplinary research cooperation, especially materials science, power electronics, information technology cross-fertilization, giving rise to a series of technological breakthroughs to enhance the performance and reliability of wireless charging. Improvement of infrastructure is also an indispensable condition, the layout of wireless charging facilities in urban planning, as well as the upgrading of the power grid, to provide a material basis for the technology to land. The improvement of public awareness and acceptance is an important catalyst for the popularization of the technology. Through education and publicity, the public's understanding of and support for wireless charging technology will be enhanced, which will help it to be integrated into daily life more quickly.

6.3. Future Application Scenarios

Looking into the future, the application scenario of electric vehicle wireless charging technology will show unprecedented breadth and depth. In home and office environments, wireless charging parking spaces will become the standard configuration, providing all-weather, automated charging services for electric vehicles, significantly improving the convenience of charging. In public places, such as shopping centers, hotels, office buildings, etc., the popularity of wireless charging facilities will greatly facilitate the travel of electric vehicle users and alleviate charging anxiety. The public transport sector will also usher in a revolution. Buses, taxis and other vehicles will benefit from wireless charging technology to achieve rapid energy supplement and improve operational efficiency. The concept of dynamic wireless charging will change the rules of the game, enable electric vehicles to automatically charge while driving, completely subvert the traditional charging mode, and open up a new path for intelligent transportation and green travel. The wireless charging technology will also be deeply integrated with the smart city and Internet of Things technology to build an intelligent charging network, realize the intelligent interaction between vehicles and infrastructure, and promote the development of the future transportation system to a more efficient and low-carbon direction.

7. CONCLUSION

Wireless charging technology for electric vehicles is standing at a turning point in history, and its future development will profoundly affect the way of human travel, promote the transformation of energy structure, accelerate the popularization of green transportation, and contribute to the construction of a sustainable future society. With the continuous maturity of the technology and the optimization of external conditions, wireless charging will gradually become the mainstream of

electric vehicle charging, leading us to a new era of smarter and more environmentally friendly transportation.

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