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A review of electric vehicle wireless charging technology research

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Abstract. With an increasing focus on environmental protection and sustainability, electric vehicles have become the mainstream trend for future automotive development. However, the development of electric vehicles has been limited by the bottleneck of charging technology. As a result, wireless charging technology for electric vehicles is viewed as an important solution, featuring high efficiency, high power density, and low cost. Specifically, three-phase wireless charging technology offers superior advantages such as high power density, low magnetic field leakage, and high coupling tolerance, making it the major trend for future development. This paper provides an overview of wireless charging technology for electric vehicles, while highlighting the benefits of three-phase technology over single-phase alternatives.

Keywords: electric vehicle, wireless charging, three-phase system.

1. Introduction

In the context of today's global economic transformation, renewable energy and electric vehicles have gradually become important strategies and means for countries to promote sustainable development and environmental protection and energy conservation. However, with the popularity of electric vehicles, their charging technology also faces various challenges. Although the traditional wired charging method is stable and reliable, it has problems such as taking up space when the vehicle is parked, the cable is easily damaged, and the installation and maintenance costs are high. The advantage of wireless charging technology for electric vehicles is that it can be charged by electromagnetic field without physical contact, which is convenient and efficient and avoids the inconvenience of using cables and plugs, the tripping hazard that may be caused by charging cables, and the risk of corrosion of charger cables over time [1]. However, there are still some technical difficulties in the development and application of wireless charging technology for electric vehicles, such as charging efficiency and cost, which need further research and solution. Nowadays, the mainstream wireless charging system for electric vehicles mainly adopts single-phase system, and one of the major problems that limit the development of electric vehicles is the leakage magnetic problem, because once the high power electric energy is transmitted on the wire, the strong electromagnetic field will be inevitably generated around the wireless charging system, which will affect the human body. Therefore, the leakage field of the wireless charging system should be minimized so that the system can meet the magnetic field regulations of each country. Compared with single-phase system, three-phase wireless charging system has more uniform magnetic

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field distribution, and high power density, low magnetic field leakage and high coupling tolerance, which is a great prospect for future development.

This paper firstly introduces the current research status of wireless charging technology, then compares the advantages of three-phase system compared with single-phase system, and finally discusses the current shortcomings and analyzes the future research directions.

2. Current status of domestic and international research

2.1. Status of foreign research

The foreign research originated from the theory of wireless transmission of electric energy proposed by Tesla in the 1880s, which opened the research of wireless energy transmission abroad [2]. In 2013, the Korea Advanced Institute of Science and Technology (KAIST) built a 24 km long dynamic wireless charging road for electric vehicles based on electromagnetic induction wireless charging technology, which greatly improved charging efficiency up to 85% and power up to 100 kW. In March 2014, the Oak Ridge National Laboratory of the United States used magnetic resonance technology to transmit energy, focusing on the improvement and optimization of resonant coils, and conducted numerous experiments to improve the performance of coils. In 2018, Oak Ridge National Laboratory's latest achievement can fully charge an average electric car in one hour using wireless charging technology, which is six times more than conventional wireless charging systems.

2.2. Current status of domestic research

Wireless charging technology for electric vehicles has attracted widespread attention in China Chongqing University has been studying the wireless transmission of electric energy in space since 2002, and has developed a wireless charging system for electric vehicles based on this. Professor Xueliang Huang of Southeast University and his team developed the first electric vehicle with wireless energy transmission in China in 2013, which adopts electromagnetic resonance power technology and the charging power can reach 3 kilowatts, and it takes 7-8 hours to be fully charged at slow speed and can travel 180 kilometers. There are also many domestic enterprises such as ZTE New Energy Vehicle, which carried out research on wireless charging technology for electric vehicles and achieved a power of 60kw in 2014. 3.3kW wireless charging system was launched by Tsinghua University in 2015 and applied in BEIQI EV150. 11 kW wireless charging will be available in 2022 for SAIC Motor's brand ZHIJI L7. As you can see, the research and application of wireless charging technology in China has also achieved some milestones.

3. Wireless energy transmission method

3.1. Inductive power transmission

In applications that require high power wireless energy transmission, magnetic fields are often used with inductive power transfer systems. This involves energizing a coil to convert electrical energy into magnetic field energy, which is then transformed back into electrical energy through magnetic induction. This process requires at least one fixed primary coil device to generate alternating magnetic fields. The compensation circuit topologies and corresponding power electronics vary based on load characteristics, power range, and application requirements.

When a portion of the magnetic field passes through the secondary coil, an induced voltage is generated. However, the low permeability of air and increased edge and leakage effects can reduce the magnetic coupling coefficient k, lowering efficiency and transferable power when the air gap in the magnetic circuit is increased. These issues can be addressed by using higher frequencies and larger magnetic fluxes increase active power [3].

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3.2. Capacitive radio energy transmission

Capacitive wireless power transfer is a cost-effective and simple wireless charging method. Unlike traditional inductive wireless power transfer, this technology uses a coupled capacitor instead of a coil or magnet. It is suitable for high voltage and low current applications. To reduce the impedance between the transformer and the receiver in the resonant device, additional inductance is integrated into the circuit in series with the coupled capacitor. This arrangement also facilitates soft switching of the circuit. Rectification and filtering circuits convert the received AC voltage to DC voltage for the battery pack or load. The power transfer level of the system is influenced by the size of the coupled capacitor and the distance between the two poles. Capacitive wireless power transfer works effectively in small air gap environments. However, due to high power requirements and large air gaps, this technology is not widely used in electric vehicles [4].

3.3. Magnetic gear wireless power transfer

Unlike other wireless energy transmission methods implemented on the basis of coaxial cables, this method places two synchronous permanent magnets side-by-side and uses the magnetic gear as the hub for wireless energy transmission. The main power supply to the transmitter winding becomes current[5] and generates a mechanical torque on the primary synchronous permanent magnets. Under the action of the mechanical torque, the primary permanent magnet is rotated and through mechanical interaction, torque is also generated on the secondary permanent magnet. Similar to the energy conversion and interaction present in induction computer transmission, in this way, the primary permanent magnet functions as a generator, while the secondary permanent magnet receives the generated power and transfers it to the battery via the power converter and battery management system [4].

4. Advantages of three-phase wireless charging system

4.1. Higher system efficiency

Compared to single-phase systems, three-phase systems allow for a greater number of possible combinations. For the sake of achieving a symmetrical and balanced system, it is reasonable to use the same type of connections in all three phases on each side. One of the advantages of three-phase systems over single-phase systems is the ability to achieve higher output power. The system efficiency of three-phase systems based on overlapping windings is 94.93%, which is 2.93% higher than the efficiency of single-phase systems [6]. Furthermore, three-phase systems require less conductor material to achieve the same power at the same voltage level[3].

4.2. Magnetic leakage reduction

However, when the phase difference of the receiving coil exceeds 120 degrees, three-phase AC can be used to reduce the leakage magnetic flux. In 2015, a novel magnetic design was proposed that uses six overlapping transmission lines. This power line is centrally symmetrical through magnetic field cancellation. The current distribution entering the wire on each phase causes the sides and center of the power line to cancel each other out, the proposed magnetic design can significantly improve the performance of the motor and reduce the leakage field, similar to the leakage field of conventional three-phase transmission lines. The proposed magnetic field design was validated through measurement modeling, and the results showed that the proposed magnetic field design can reduce the magnetic field of the expected three-phase power line by 96%, which is far less than the leakage field of other power lines [7].

4.3. Improving coupling tolerance

The charging performance of inductive wireless charging systems depends heavily on the precise alignment between the charging pads or coils, and misalignment at the time of docking can lead to a significant degradation of power transfer and also to a reduction in system efficiency. Researchers at the University of Auckland have proposed a three-phase BD-IPT system with combined LCL and CL compensation at different phases to improve the overall coupling tolerance and power transfer performance in a multi-phase IPT charging system under large pad misalignment. This three-phase model can effectively avoid the coupling degradation and power degradation that arise when the charging pads are misaligned for wireless charging, and it is demonstrated that the combined compensation can be used to achieve high tolerance for pad misalignment [8].

5. Conclusion

Wireless charging technology is a great prospect for the future development of electric vehicles. In this paper, three methods of wireless energy transmission are introduced, and the advantages of three-phase system compared with single-phase system are introduced, and the three-phase system has the advantages of high power and low magnetic leakage under the existing technology, which is the future development direction of wireless charging system. Research results at home and abroad show that the transmission efficiency of wireless charging technology has been gradually improved, and the safety and reliability have also been continuously enhanced. Although the technology and business model still have some challenges and problems, but with the continuous progress of technology and application scenarios continue to expand, wireless charging technology is expected to become an important way for the electric vehicle charging field.

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