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Research review on wireless charging technology of new energy electric vehicles

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Abstract:

With the advancement of science and technology, electric vehicles have become increasingly prevalent as a mode of transportation. The vehicle is equipped with both wired and wireless charging capabilities. However, the latter requires a larger area, which restricts the number of charging opportunities and is incompatible with the growing demand for charging. Consequently, wireless charging will become the dominant method of charging electric vehicles in the future. This study will provide a comprehensive comparison of five main radio power transmission methods, with a particular focus on the in-depth analysis of ICPT and MCRPT systems. It will also discuss strategies to improve the efficiency of the magnetic coupling mechanism and cope with power fluctuations in dynamic charging. Additionally, different power supply modes will be evaluated, with particular emphasis on the efficiency, stability, and cost-effectiveness of the compensated rail supply mode. Finally, this study sought to identify the key research areas for the advancement of wireless charging technology for new energy electric vehicles. It also highlighted the areas that require particular attention in future research.

Keywords: New energy electric vehicles, Magnetic coupling mechanism, Wireless charging technology, Power supply mode

1. Introduction

The costs associated with the manufacturing of electric vehicles are on the decline, and the price of each electric vehicle is falling. On February 19, 2024, BYD launched the Qin PLUS Glory Edition model with a starting price of only 79,800, prompting significant price reductions from other automotive manufacturers. In conjunction with the prevailing perception that electricity is a more cost-effective alternative to oil, an increasing number of individuals are opting for new energy-electric vehicles. However, the installation and layout of charging piles necessitate the utilization of a specific quantity of space, which may result in the inefficient utilization of resources in locations where parking spaces are limited. Furthermore, wired charging must be conducted in close proximity to the charging pile, which may restrict the mobility of electric vehicles to some extent. In contrast, wireless charging enables vehicles to be charged in a variety of locations, including while waiting at traffic lights and while driving on highways. This study will first introduce five basic radio energy transmission methods and then select the most suitable wireless charging method for new energy electric vehicles. In light of the aforementioned two common wireless charging scenarios, this study examines the influence factors and optimization methods of the magnetic coupling mechanism in static wireless charging from the perspective of static-dynamic wireless charging. One challenge in dynamic wireless charging is the fluctuation in charging power. This study identifies the limitations of current wireless charging technology and offers insights to facilitate further research in this field.

2. Principles of radio energy transmission

The fundamental principle of the WPT system is the utilization of electromagnetic induction to facilitate the transmission of electrical energy from one location to another, circumventing the necessity for a direct wire connection. Figure2.1 depicts the fundamental schematic diagram of the electric vehicle WPT system (EV-WPT):

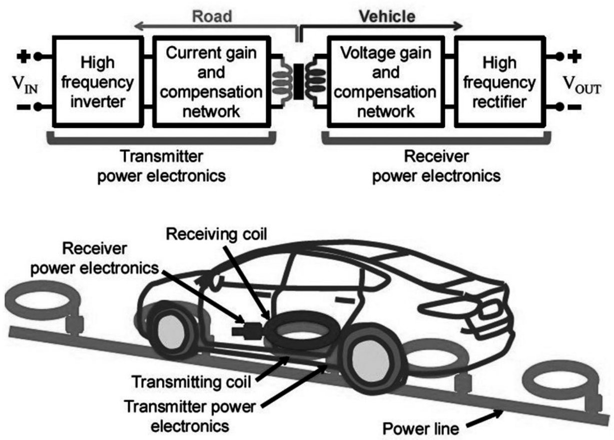

Figure 1 EV-WPT system schematic diagram

The EV-WPT system is comprised of two primary components: the ground transmitter and the vehicle chassis receiving end. The ground transmitting end comprises a high-frequency inverter, a current amplifying and compensating network, and a transmitting coil. The direct current (DC) power is converted into high-frequency alternating current (AC) through the high-frequency inverter and then flows into the transmitting coil through the amplification and compensation network. This conversion process results in the generation of high-frequency AC signals and an alternating magnetic field. The receiving end of the vehicle chassis comprises a receiving coil, a voltage amplification and compensation network, and a high-frequency rectifier. Upon reception of the magnetic field at the ground-transmitting end, the receiving coil employs the principle of electromagnetic induction to transform the voltage through the voltage amplification and compensation network into the high-frequency rectifier, subsequently into the DC current, which is then directed to the electric vehicle energy storage device.

3. The fundamental mode of radio energy transmission

At present, there are five basic WPT methods, including (1) Inductively Coupled Power Transmission (ICP), (2) Magnetic Coupling Resonant Power Transmission (MCRPT), (3) Captive Power Transfer (CPT), (4) Microwave Power Transmission (MPT), and (5) Laser Power Transmission (LPT). Table 3.1 below presents a comparative analysis of the various transmission modes:

Table 1 Comparison table of 5 WPT modes

Mode	ICPT	MCRPT	CPT	MPT	LPT
Principle of operation	Transmit energy through a magnetic field	Energy is transmitted using magnetic coupling resonance	Transfer energy through an electric field	Energy is transmitted by microwave radiation	Emitting laser light transfers energy
Transmission distance	Short distance	Middle distance	Short distance	Long distance	Long distance
Advantages	High security, simple equipment, short-distance transmission efficiency	High efficiency, high security, high anti-interference ability	The equipment is simple and not affected by metal occlusion	High security, good orientation	High energy density
Disadvantages	Low efficiency and short transmission distance	The equipment is complex and requires high accuracy of resonant frequency	Low efficiency, affected by electromagnetic interference	The equipment is complex and the coil is demanding	High energy loss and high equipment accuracy requirements

In light of the necessity for a stable power transmission mode for the wireless charging of electric vehicles, the majority of electric vehicles employ the ICPT system and the MCRPT system, which are radio energy transmission modes. This study will examine and evaluate the fundamental principles of these two systems.

3.1 *Inductively Coupled Power Transmission System*

The fundamental principle of the ICPT system is the utilization of the principle of electromagnetic induction. The transmission coil and the receiving coil are constructed in a manner analogous to that of a loose coupling transformer, with the objective of transmitting electric energy. Figure 2.1 depicts the fundamental configuration of this technology:

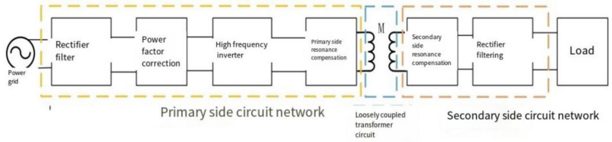

Figure 2 ICPT system basic structure diagram

The ICPT system has been lauded for its low cost, reliability, harmlessness, and straightforward control of electric vehicles utilized in the material handling industry[1]. It has also been extensively employed in the wireless charging of electric vehicles. Furthermore, the system's significant advantages in high-power transmission and reasonable electrical isolation have attracted the attention of numerous automobile manufacturers and researchers, indicating the potential for it to replace the traditional wired charging method.

3.2 *Magnetic Coupling Resonant Power Transmission System*

The MCRPT system is analogous to the ICPT system in its general structure, with the exception that the electrical energy is transmitted through the resonance of the primary and secondary side resonant coils. It should be noted that for optimal transmission efficiency, the operating frequency should align with that of the primary and secondary resonant coils, which correspond to their respective resonant frequencies. Figure 2.2 illustrates the fundamental structure of the technology:

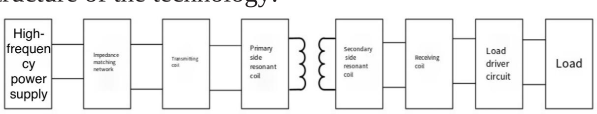

Figure3. 2 MCRPT system basic structure diagram

The high safety and transmission efficiency of the system renders it resistant to interference, making it a valuable component in the wireless charging technology of new energy electric vehicles.

In order to optimize the transmission efficiency of the system, literature[2] analyzed the influence of variable parameters on the output of the electric-field coupled energy transfer system through system modeling. This analysis led to the deduction of a relationship between system efficiency and important parameters. It was found that adjusting the capacitance value of the coupling mechanism and system frequency can avoid frequency splitting and improve system efficiency. It is of paramount importance for the MCRPT system to maintain consistency between its operating frequency and its resonant frequency.

3.3 *Captive Power Transfer System*

Captive Power Transfer (CPT) systems are similar to the architecture of MCRPT and ICPT systems, but differ in that electrical energy is transferred by electric field coupling rather than magnetic field coupling. The CPT system consists of an electric field resonance circuit of primary and secondary sides, the operating frequency must match the resonance frequency of both to obtain the best transmission efficiency. The following diagram shows the basic structure of the system:

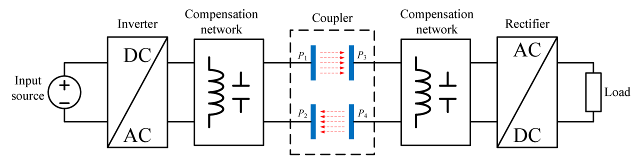

Figure3. 3 CPT system basic structure diagram

Although CPT systems have advantages in theory, they are rare in practical applications, mainly due to the limitations of short transmission distances, easy interference, high system complexity, and high cost.

For the optimization of the CPT system, literature[3] emphasizes the key role of system modeling and efficiency optimization in the research of CPT technology, pointing out that careful modeling can better understand and predict the behavior of the CPT system, while efficiency optimization ensures the maximum utilization of energy in the transmission process, which is crucial for the practical application and future development of CPT technology.

3.4 *Microwave Power Transmission System*

Microwave Power Transmission (MPT) is a technology that uses microwave energy for wireless transmission, typically used to transfer energy from a transmitter to a receiver. Although MPT has the advantages of long-range and efficient energy transfer, it is not widely used in wireless charging systems. This is mainly because the potential health risks of microwave radiation to the human body and the environment, as well as the interference of radiation leakage to electronic devices and other wireless communication systems, limit its widespread use in practical applications. In addition, the construction and maintenance costs of MPT systems are relatively high, which limits their use in wireless charging systems.

In order to optimize the efficiency of MPT systems, literature[4] points out that the main challenges in designing the system are to improve the overall efficiency of the system, ensure the robustness of the transmission, achieve accurate directional radiation (DR), and solve the complexity of the system design.

3.5 *Laser Power Transmission System*

Laser Power Transmission (LPT) is an efficient wireless power transfer method that uses a laser beam to transmit energy. This is despite the many advantages of LPT, such as high transmission efficiency, long-distance energy transfer capacity, and good directivity. According to the literature[5], LPT systems can be divided into space-based, terrestrial, and underwater types, depending on their intended use. However, all systems share some common subsystems, such as the laser emission subsystem, the laser transmission control subsystem, and the laser reception subsystem. The laser emission subsystem consists of the laser source, the aiming turntable, and the necessary safety measures that work together to safely fire the required laser.

However, this system is not common in wireless charging applications. This is mainly because lasers can pose risks to the human visual system and skin, so additional safety mechanisms are needed to protect users from harm. At the same time, the propagation efficiency of the laser in the atmosphere is affected by atmospheric absorption and scattering phenomena, which limits its practicality in wireless charging systems. Therefore, considering the limitations of safety and transmission distance, LPT technology is not widely used in the field of wireless charging.

4. Power supply mode

Normally, there are four kinds of power supply modes: single power supply, multiple power supply only, multiple power supply combination, and multiple power supply alternating. On this basis, the compensating guide rail power supply mode has been proposed in the literature[6]. Table 4. 1 shows the comparison table of the characteristics of the five power supply modes.

Table 4. 1 Comparison table of the characteristics of the five power supply modes

Power supply mode	Principle	Advantages	Disadvantages
Single power supply	The single power supply supplies power to the segmented guide rail in parallel, which is selected by switching the power supply guide rail	Simple structure, easy installation; Individual models are less expensive	The increase in cable length leads to a increase in the internal resistance of the line, which may cause a thermal effect. The switch is easy to burn; Two coils may be powered at the same time, requiring a large power output of the power supply
Multiple power supply only	Each guideway adopts an independent power supply and an independent cable power supply	Stable structure, easy installation; Switch parts that do not require cable switching	The large number of power supplies increases the cost of system configuration and equipment maintenance
Multiple power supply combination	The guides are grouped and equipped with a single power supply for segmented power supply, such as one power supply for two adjacent guides	Simple structure, easy installation; The cost is relatively low	Failure to fundamentally solve the situation of two coils powering at the same time, causing a certain pressure on the power supply
Multiple power supply alternating	Different power sources supply power to non-adjacent guideways to ensure that the same power supply guideways are not close to each other.	Reduce the number of power supplies, ensure system stability and timeliness; Reduce operation and maintenance costs; Avoid one power supply to two adjacent tracks at the same time to ensure the stability of the power supply	There is a trade-off between cost and complexity
The compensating guide rail power supply mode	The compensation coil and multiple power supply are used to ensure the smooth switching of the guide rail and the stability of the power supply	Ensure smooth switching of coil and high stability of power supply; Multi-source alternating power supply scheme is adopted to avoid one power supply for two adjacent tracks at the same time	The system complexity increases and more complex control strategies and more maintenance efforts may be required

According to the above table, the compensating guide rail power supply mode is the optimal choice. In this method, a combination of compensation coil and multiple power supply is used in alternation, effectively solving problems of energy loss and power stability. At the same time, this method not only reduces the energy loss of the system during rail switching, but also improves the reliability of the power supply and the flexibility of the system, so as to ensure efficient operation, but also takes into account the cost efficiency and convenience of maintenance.

5. Summary and Suggestions

5.1 *Summary of Research*

Wireless charging technology is considered to be the main way to charge electric vehicles in the future due to its convenience and reduction of charging station constraints. In this study, five basic wireless power transmission methods are compared, and the principles and optimization methods of ICPT and MCRPT systems are analyzed in detail. The importance of improving the efficiency of the magnetic coupling mechanism and solving the power fluctuation problem in dynamic wireless charging is emphasized. In addition, different power supply modes are also explored, and it is pointed out that the compensated rail power supply mode is the ideal choice for current wireless charging technology due to its efficient energy transfer, power stability, balancing cost, and ease of maintenance. Overall, this study aims to provide directions for the research of wireless charging technologies for NEVs, while pointing out key areas that future research should focus on and improve.

5.2 *Research Recommendations*

With the rapid development of the electric vehicle industry, research on wireless charging technology will continue to deepen, especially in improving the transmission efficiency of magnetic coupling mechanisms, optimizing power fluctuations during dynamic charging, and developing safer and more efficient power supply modes. Future research will focus on innovative wireless charging technologies, such as further exploring the potential of compensated rail power supply modes. Therefore, for future research of wireless charging technology for new energy electric vehicles, it is suggested to focus on the following aspects: (1) improve the transmission efficiency and system safety, explore more cost-effective solutions; (2) realize intelligent and automated charging process, improve the environmental adaptability of the system; (3) develop unified industry standards to enhance technical compatibility; (4) promote interdisciplinary cooperation to achieve technology innovation and broad application, and support the sustainable development of the electric vehicle industry.

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