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Summary of Wireless Charging Technology for Electric Vehicles

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Abstract: The rapid popularity of electric vehicles has promoted the rapid development of wireless charging technology. This paper reviews the current research progress and application status of wireless charging technology for electric vehicles. Inductive coupling, magnetic resonance coupling and non-directional radiofrequency radiation, three main wireless power transmission methods, including their principles and advantages, are introduced. In addition, the practical application of the technique, such as near field application and far field application, is also discussed. Finally, the development direction of wireless charging technology for electric vehicles in the future is looked forward, including the key technical paths of optimizing system design, improving energy transmission efficiency and reducing system cost. In summary, this paper aims to provide comprehensive theoretical support and practical guidance for the research and practice of wireless charging technology for electric vehicles.

Keywords: Wireless charging, electric vehicle, new energy.

1. Introduction

At present, the power supply of electric vehicles mainly includes traditional power supply, battery power supply and wireless power supply [1]. The traditional conduction charging method relies on cable connection for power transmission, while the battery power supply realizes the charge by replacing the battery pack. Wireless charging technology realizes non-contact power supply through electromagnetic field energy coupling, completely eliminating cable connection.

Although the traditional power supply method dominates the EV charging market due to its technical simplicity, there are still some significant drawbacks. First, the interface of charging facilities is not standardized enough, making it difficult for different brands of electric vehicles to be compatible with the same charging device, limiting the popularity and convenience of charging facilities. Second, long-term use can lead to aging and damage of cables, increasing maintenance costs and frequent repair needs. In addition, the traditional conductive charging method is often connected to the high-voltage power supply, and there are safety hazards, such as the possibility of sparks or leakage in bad weather conditions [2], which jointly limit its further development and wide application.

To address these challenges, researchers and manufacturers are actively exploring new charging technologies and solutions. The development of wireless charging technology represents one possibility for the future, which not only improves charging efficiency, but also significantly improves user experience and safety. Current mainstream wireless charging systems use electromagnetic field energy coupling to transfer electrical energy, so no direct electrical contact is required [3].

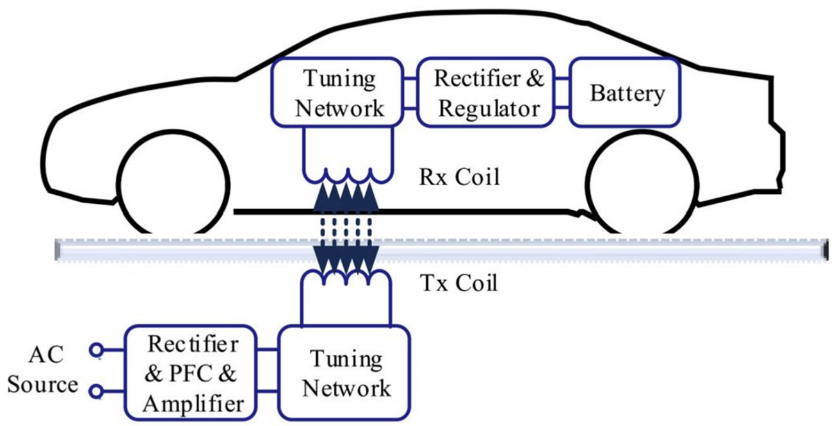

Figure 1. Wireless charging device of EV

For example, Figure 1 shows a wireless charging device for electric vehicles, with the transmitter partially buried underground and the receiver mounted on the electric vehicle, which improves the efficiency of power transmission by optimizing the magnetic coupling system.

Although wireless charging technology has made important progress in addressing the limitations of many traditional charging methods, the maximum range of a single charge is still limited due to the current battery technology and energy density limitations of electric vehicles. However, wireless charging technology has reduced the manufacturing and maintenance costs of electric vehicles and charging equipment, driving the popularization of electric vehicles. At the same time, its use of clean electricity reduces the dependence on traditional fossil fuels, which is in line with China's and the world's sustainable development policies and concepts.

Therefore, further research and promotion of wireless charging technology is of great significance for promoting the sustainable development of the electric vehicle industry.

2. Research Status of EV-WPT System

For the wireless power supply of electric vehicles, the foreign research on it is relatively early, so in theory and practice achieved more results.

Table 1 below investigates and describes the laboratory-level projects developed, the current status of publications, and the notable achievements made in the commercial development of products.

Table 1. WPT System in Laboratory Level

Name	Power	Distance	Frequency	Efficiency	Reference
ORNL	20KW	25.4cm			[4]
KAIST	15KW	15cm	29kHZ	80%	[5]
KRRI	818KW	5cm	60kHZ	82.7%	[6]
INTIS	30KW	15cm	35kHZ	90%	[7]
ETH-Zurich	50KW	20cm	85kHZ	95.8%	[8]
PATH	60KW	7.5cm	20kHZ	60%	[9]
Conductix Wampfler	120KW	4cm	20kHZ	90%	[10]
Fraunhofer	22KW	13.5cm	100kHZ	97%	[11]
University of Auckland	50KW	16cm	85kHZ	90%	[12]
Delft University of Technology	7.2KW	10cm	86.5kHZ	97.1%	[13]

It is clear from Table 1 that efficient power transmission can be achieved through technical means such as compensation topology, operating frequency, and optimization of air gap distance. However, all wireless Power transmission (WPT) systems face the challenge that misalignment can lead to reduced transmission efficiency (PTE).

Evatran, a Virginia-based company, has been working to bring wireless inductive charging technology to the global electric vehicle market since its inception in 2009. By 2014, the electric vehicle wireless charging system it developed was successfully certified by the ETL third-party safety agency in the United States. By 2019, Evatran announced that its plug-free products had successfully provided a total of 1 million hours of charging service for electric vehicles. The wireless charging technology used by the company is based on the principle of electromagnetic induction, and when a receiver in the chassis of the electric vehicle is aligned with the charging platform on the ground, the system is activated to transmit energy through the air gap.

In terms of EV-WPT in China, it is mainly concentrated in domestic universities, some related enterprises and scientific research institutions. Compared with foreign research, the research started relatively late. Although there is a gap, some important results have still been achieved.

Professor Yang Qingxin of Tianjin University of Technology and his research team have deeply explored the core mechanism of wireless power transmission under magnetic coupling. The team focused on analyzing the key factors that affect the transmission distance of the system, and studying how the system impedance affects the transmission efficiency and power. By carefully optimizing the resonant coils, they aim to greatly improve the efficiency of the wireless power system. In addition, in view of the wear, energy consumption and safety risks of high-speed rail when using the traditional sliding contact mode, Professor Yang put forward the innovative concept of applying wireless power transmission technology to the high-speed rail power system in 2013, and successfully built the relevant sandtable demonstration model, demonstrating the potential application prospect of this technology.

3. Wireless Charging technology (WPT) Overview

As an advanced technology, wireless power transmission (WPT) is getting more and more attention in different industries. Its main advantages include eliminating conductive components, reducing cable load, and improving the flexibility and convenience of the system. Depending on the needs of a particular application, different types of WPT technology can be selected. The following key parameters need to be considered when selecting the appropriate technology:

Operating power range: Covers different power needs from small consumer electronics devices to large electric vehicles.

Operating frequency range: From low frequency to high frequency, different frequencies have a significant impact on power transmission efficiency and device size.

Working distance: determines the maximum distance between the charging device and the receiving device, covering both near field and far field application scenarios.

Efficiency: Evaluate the degree of loss in the energy transmission process, which directly affects the energy efficiency of the system.

Electromagnetic Interference (EMI) : The potential impact of electromagnetic radiation that a WPT system may produce while operating on surrounding electronics and the human body.

Size of the device: Miniaturization and integration are critical for applications in confined Spaces such as electric vehicles.

Safety issues: including control of electromagnetic radiation, waterproof and dust-proof design of charging equipment and receiving equipment, and prevention of safety hazards caused by operational errors.

System complexity: includes the complexity of hardware design, the difficulty of system integration, and the cost of maintenance and management.

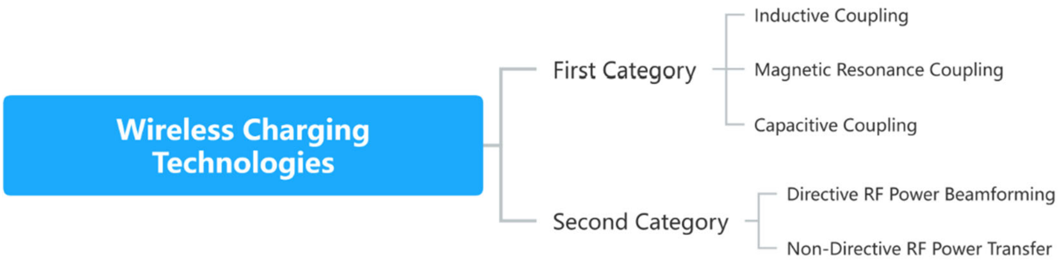

Figure 2. Classification of wireless charging technologies.

As shown in the Figure 2, WPT technology classification and its application scenarios Wireless charging technology is mainly divided into two categories based on non-radiative coupling and radiation-based RF. Non-radiation-coupled charging technologies include inductive coupling, magnetic resonance coupling and capacitive coupling, which transmit energy by utilizing the near-field characteristics of electromagnetic fields. In contrast, radiation-based RF charging technologies include directed RF power beamforming and non-directed RF power transmission, which relies on far-field radiation to transmit energy.

In capacitive coupling technology, the coupling capacity that can be achieved is limited by the surface area of the device. For smaller portable electronic devices, this approach faces the challenge of generating sufficient power density for charging, resulting in design limitations. One limitation of directional RF power beamforming is that the charging device requires precise knowledge of the location of the energy receiver, which may not be convenient in practical applications.

Considering the limitations of the above technologies, wireless charging usually prefers three technologies: inductive coupling, magnetic resonance coupling and non-directional RF radiation. Each of these methods has its advantages, such as inductive coupling is widely used in small devices such as smart phones and electric brushes, and magnetic resonance coupling has attracted attention due to its long effective distance and high efficiency.

3.1. Inductive coupling

Inductive coupling is a wireless energy transmission technology based on magnetic field induction, the principle of which involves the transfer of electrical energy between two coils. The primary coil of an energy emitter achieves inductive power transfer (IPT) by generating a magnetic field change on the secondary coil, which usually occurs within a near-field region less than one wavelength away. In this region, the near-field magnetic power induces a voltage or current in the secondary coil to charge a wireless device or an energy storage system. Inductive coupling typically operates in the kilohertz frequency band.

To improve charging efficiency, the secondary coil is tuned to a specific operating frequency. The quality factor of this technology is generally designed to be low to avoid rapid power attenuation at high quality factors. Despite its high efficiency, the effective charging distance is usually no more than 20 cm, limiting its range of applications. Inductive coupling technology is used in the field of inductively coupled radio frequency identification (RFID). Charging distances of tens of centimeters can be achieved, but the efficiency is relatively low (about 1-2%), and the received power is at the microwatt level. However, under certain conditions, such as electric vehicle charging, its transmission power can reach the kilowatt level, showing its powerful energy transmission capability.

The advantages of magnetic coupling include simplicity, ease of operation, high efficiency at close range and high security, especially for charging mobile devices. The recently developed MagMIMO technology at MIT further expands the potential of inductive coupling to charge wireless devices at distances of up to 30 cm, effectively receiving energy even when the device is placed in a pocket. This technology uses an energy cone to precisely project energy to a target device, demonstrating the potential for further development of inductive coupling in future wireless charging technologies.

3.2. Magnetic resonance coupling

The magnetic resonance coupling technique uses the principle of oscillating magnetic fields and evanescent wave coupling to transfer electrical energy between two coils tuned to the same resonant frequency. This approach not only achieves efficient energy transfer, but also minimizes energy leakage from external non-resonant properties. A recent experimental prototype successfully demonstrated a maximum power transfer efficiency of 92.6% over a distance of 0.3 cm. A significant advantage of magnetic resonance coupling is its high resistance to environmental interference and the ability to not need to look directly at the path.

Laboratory tests have shown that magnetic resonance coupling, [14] can transmit electrical energy over longer distances and more efficiently than traditional radiofrequency radiation methods compared to inductive coupling techniques. In addition, the technique supports the simultaneous transfer of power from a single transmitter to multiple receivers, which enables it to charge multiple devices simultaneously [14].

Magnetic resonance coupling technology typically operates in the megahertz frequency range and has a high quality factor, which helps mitigate the decrease in charging efficiency caused by a decrease in the coupling factor as the distance increases. This allows effective power transmission distances to be extended to several meters. In 2007, MIT researchers developed Witricity technology, based on strongly coupled magnetic resonance, which can light a 60W bulb at a distance of more than two meters with an efficiency of about 40%, and at a distance of one meter with an efficiency of 90%. However, reducing the size of the Witricity receiver is difficult because it requires coils of distributed capacitors to function properly, which poses a challenge for the application of the technology in portable devices. By tuning a coupled resonator between multiple receiving coils, Mr Coupling can also enable simultaneous charging of multiple devices, improving overall efficiency. However, the mutual coupling between the receiving coils can cause interference, so precise tuning is needed to avoid this problem.

4. Future and Prospects

At present, the bottleneck restricting the development of wireless charging technology for electric vehicles mainly lies in the low efficiency of wireless charging, the inability to adapt to the stable wireless charging of fast-moving vehicles, and the electromagnetic leakage caused by open energy transmission space

At present, the research of static EV-WPT system has been relatively mature, and related products have been put into the market. Future research directions may pay more attention to the design of dynamic EV-WPT systems to realize wireless charging of vehicles during driving and create a more convenient charging experience for users. Considering the limitations of current technology, even if static wireless power supply systems perform well in development, achieving the goal of "5 minutes of charging, 48 hours of driving" is still challenging, and dynamic wireless power supply systems may be able to effectively solve this pain point.

To sum up, in order to achieve automotive intelligence and automation, as well as provide users with a more convenient experience, EV-WPT technology will still have important research and application value in the future. In addition to the progress of the technology itself, it is also necessary to combine autonomous driving technology and Internet of Things (IoT) technology to form a closed loop and jointly promote the progress of the automotive and transportation fields.

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