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A Review of Research Related to Wireless Charging Technology for Electric Vehicles

Yuhao Wu

School of Electronic and Information Engineering, Chongqing Three Gorges University, 404020, China
Email: 814609731@qq.com

Abstract:

With the popularization of electric vehicles, wireless charging technology has received widespread attention from all walks of life due to its advantages of safety, convenience and low cost, and has become the key development direction of electric vehicle charging technology. This study mainly focuses on inductively coupled power transmission, microwave power transmission, magnetic coupling resonant power transmission and electric field coupling power transmission four wireless charging technology on the current research status as well as the advantages and disadvantages of the technology between the overview, analyze the current urgent problems and the future development trend.

Keyword: Electric vehicles, wireless charging technology, inductively coupled power transmission, microwave power transmission, magnetically coupled resonant power transmission, electric field coupled power transmission

1. Introductory

With the world's increasing attention to environmental protection and the government's strong support for the new energy industry in terms of policy and economy. Electric vehicles in today's era of rapid development, occupy a place in the automobile market, more and more users choose electric vehicles, so that it has a gradual trend to replace fuel vehicles. According to statistics as of the end of 2023, China's new energy vehicle ownership exceeded 20 million, and the newly registered new energy vehicles in 2023 increased by 38.76% year-on-year. Therefore, the problem of electric vehicle charging has become a problem that people need to solve. Due to the current electric vehicle lithium battery technology bottleneck, the range is short, which is not conducive to the development and application of electric vehicles. Currently there are three kinds of charging programs on the market: battery replacement type charging, traditional wired charging and wireless charging. Replacement battery charging: has the advantage of short replacement time, but at present the country is not popular, and only some car companies have used this way to provide range, such as Azalea car part of the model support battery operation. It can be seen that this technology has more limitations, such as the battery specifications are not uniform, the high cost of setting up the power exchange station, and safety hazards and other shortcomings.

Currently the more widely used solution is charging pile wired charging, but there are still shortcomings such as poor safety, poor convenience and high cost.

In comparison, wireless charging technology avoids a physical connection, making it possible to solve the problems of safety, convenience and cost. To a certain extent, it provides a solution to the range problem.

Therefore, this study will focus on the wireless charging technology of four types of electric vehicles, which is intended to provide reference for the current society, trolleybus enterprises and the government, and to promote the development of the electric vehicle industry as well as the protection of the environment.

2. Literature review

2.1 Current status of foreign research

The University of Auckland in New Zealand has partnered with Germany's ComStability to develop the world's first wireless charging bus.

Oak Ridge National Laboratory of the United States for the dynamic wireless charging of electric vehicles coupling mechanism, transmission characteristics, dielectric loss, electromagnetic radiation to carry out research, and its ground and the transmitter using a full-bridge inverter and series connection of the two primary windings, the experimental results show that the transmission power and efficiency by the position of the electric vehicle has a greater impact.

The University of Tokyo, Japan, proposes a DC/DC converter-based vice-side maximum efficiency control method, in which the coupling coefficients are estimated online in real time by the original-side equivalent impedance,

and the feed-forward controller is utilized to change the input duty cycle of the DC/DC converter to realize the maximum efficiency control.

2.2 Status of domestic research

Southeast University has conducted an in-depth study on the effect of primary and secondary coil dimensions on transmission efficiency and side shift based on dynamic wireless energy transfer, and concluded that the frequency control-based method achieves the optimal energy transfer efficiency of the system.

Chongqing University proposed a parameter identification theory to improve the problem that the parameter of the secondary side is difficult to be adjusted when the primary side is controlled, based on which the energy flow model of the system is established.

2.3 Feasibility Analysis and Selection of Wireless Power Transfer (WPT) Technologies

Today, the main modes of transmission of wireless energy are inductively coupled electrical energy transmission, microwave electrical energy transmission, magnetically coupled electrical energy transmission, and electric field coupled electrical energy transmission.

2.3.1 Inductively Coupled Power Transfer (ICPT)

The technology transmits electrical energy from one side of the system to the other through a loosely coupled magnetic induction link. Two coils are typically used, one as the sending end and the other as the receiving end. The coil on the sending end is usually fed current through a power supply, which produces a varying magnetic field. The coil on the receiving end, on the other hand, utilizes the phenomenon of magnetic induction to convert the magnetic field into electrical energy, which is supplied to the receiving device.

2.3.2 Microwave Power Transfer (MPT)

The electrical energy (direct current or alternating current) is first converted into microwaves by a microwave converter, and then the microwaves are sent into space by a microwave transmitting antenna at the transmitting station. The microwaves are transmitted in space to a ground receiving station. The received microwaves are converted to industrial frequency alternating current (AC) by a converter. It is available for use by the user.

2.3.3 Magnetically Coupled Resonant Power Transfer (MCR-WPT)

The basic principle of magnetic coupling resonant wireless energy transmission is to use two objects with the same resonant frequency to realize wireless energy transmission through magnetic coupling.

2.3.4 Electric field coupled power transfer (ECPT)

This technology is a way to realize wireless transmission of energy based on coupling between distributed capacitors. There are many common application areas with electromagnetic inductive power transmission, such as the biomedical field and the electronics field.

2.4 Summary and analysis

The following conclusions are drawn from the reading of the research literature related to these four types of wireless charging technologies and through comparison and analysis:

For wireless charging of electric vehicles, inductively coupled power transmission and magnetically coupled resonant power transmission are the current cost-effective technologies.

3. Research processes

3.1 Principles of wireless charging technology and its applications

3.1.1 Inductively coupled power transmission technology principles and application scenarios

Inductively coupled power transmission technology is based on the principle of electromagnetic induction to transmit energy and relies on two main components: a transmitter (primary coil) and a receiver (secondary coil) to realize wireless transmission of power. The primary coil is connected to an AC power source, and when AC current flows through the primary coil, a changing magnetic field is generated on the primary side. When the secondary coil is in the varying magnetic field generated on the primary side, according to the law of electromagnetic induction, the varying magnetic field induces an induced electromotive force through the secondary coil. This AC electric potential is usually converted to DC power by a rectifier to supply the lithium battery of the electric vehicle for charging.

The technology is widely used in medical instruments, wearable devices, and electric vehicles. Especially in smart roads, the transmitting coil can be bought into the road to provide dynamic charging for moving electric vehicles.

3.1.2 Microwave power transmission principles and application scenarios

Microwave power transmission technology is a technology that utilizes microwave radiation to transfer energy, which is converted into microwave energy and then transmitted through space to a distant receiving station, which then converts it from microwave energy to electrical energy.

Microwave transmitters, such as magnetrons or solid-state transmitters, are used to convert the ethical direct or alternating current received from a power source into high-frequency electromagnetic waves. The high-frequency electromagnetic waves are then transmitted through an antenna array device that can efficiently and accurately transmit the microwave energy to the target receiver. Microwaves are usually transmitted at 2.45GHz or 5.8Ghz to ensure transmission efficiency and minimize environmental interference. Once the microwave energy is received by the receiving antenna (rectifier antenna or rectifier array), it is converted into DC power by rectifier diodes to charge the lithium battery of the electric vehicle.

The technology is mainly used in space stations, remote areas or disaster areas of the emergency power supply and wireless charging of mobile devices, Xiaomi cell phone had released a space charging device in 2021 is through the 144 antennas will be the energy through the millimeter wave transmission to the cell phone for charging, charging power is only 5w, but the product is not actually on sale.

3.1.3 Magnetic coupling resonant power transmission principle and application scenarios

Magnetically coupled resonant power transmission is a technology that transfers energy through the phenomenon of resonance in a magnetic field. This technology is able to realize the wireless energy transmission between two objects over a long distance, and compared with the inductive coupling type power transmission, the magnetic coupling resonance type power transmission can still maintain a high power transmission efficiency under the circumstance that there is a larger air gap between the transmitting end and the receiving end.

Magnetically coupled resonant power transmission systems are similar to inductively coupled power transmission in that they rely on a transmitting coil and a receiving coil. However, both coils are connected to a capacitor, forming an LC (inductance-capacitance) resonant loop to ensure that each coil is maintained at a similar resonant frequency.

When working, the resonant coil of the transmitter is connected to the AC power supply, and the AC current generates an alternating magnetic field in the primary side coil after energization. The magnetic field frequency matches the resonant frequency of the coil and capacitor. In addition to frequency matching, efficient energy transfer is also achieved by matching the impedance of the drug to minimize the loss of power during transmission. The similarity of the resonant frequencies of the two coils results in the resonance of the two coils through the magnetic field. As a result, the power can be transferred from the transmitting coil to the receiving coil with very high efficiency. After the receiving coil receives the energy from the transmitting coil, it is converted from an alternating current (AC) form to a direct current (DC) form by a rectifier, which is supplied to the lithium battery of the electric vehicle for charging.

The application areas of this technology are similar to those cited for inductively coupled power transmission, but are not as widely used as inductively coupled power transmission due to the lack of maturity of the current technology and cost factors.

3.1.4 Principle and application scenarios of electric field coupled power transmission

Electric field coupled electric energy transmission technology, alias: capacitive coupling electric energy transmission. It is a wireless charging method that utilizes coupling capacitance to transmit power, and the larger the capacitance, the higher the energy transmission efficiency. The technology mainly uses the two pole plates of the capacitor to carry out the transmission of electric energy, one of the pole plates as a transmitter, the other pole plate as a receiver.

When a high-frequency AC power source is connected to the transmitting end, an alternating electric field will be generated at that pole plate. This electric field passes through the medium between the two polar plates and affects the polar plate at the receiving end. When the pole plate at the receiving end receives the effect of the alternating electric field generated at the transmitting end, it causes a change in the electric field that will cause a potential difference to be induced in the pole plate at the receiving end. This potential difference will drive a current in the circuit at the receiving end to charge the lithium battery in the electric vehicle.

The technology is primarily used in charging small electronic devices, charging medical implants, wireless sensor networks, and in specific industries or research where simultaneous transmission of data and energy is required.

3.1.5 A simple comparison of the four transmission methods

Inductively coupled power transmission is more cost-effective than magnetically coupled resonant power transmission, microwave power transmission, and electric field coupled power transmission for wireless charging of electric vehicles, and a comparison of the four different transmission methods is shown in Table 1.

Table 1 Comparison of the 4 transmission methods

Charging method	Transmission distance	Transmission efficiency	Safety	Costs (manufacturing, production etc)
Inductively coupled power transmission	Near (a few centimeters to a dozen centimeters)	Medium (50-75%)	Radiation is less of a problem, but need to protect against metal foreign body heating	Low
Microwave power transmission	Far (up to several kilometers)	relatively low	Need to protect against microwave radiation	High
Magnetic coupling resonant power transmission	Medium (a few centimeters to a few meters)	High (up to 90% or more)	Similar to Inductively coupled power transmission	Moderate
Electric field coupled power transmission	Near (within a few centimeters)	Low (usually less than 50%)	Low impact on non-conductive obstacles	Relatively low

3.2 The future of wireless charging and its outlook

With the emphasis on the development of new energy vehicles in China and the continuous iteration of technology, wireless charging technology will continue to improve and innovate.

With the expansion of the electric vehicle market and the increase in the number of trolleys on the road, dynamic wireless charging technology is expected to be implemented as a solution to the range woes of trolley owners.

At the same time, more investment is made in the research and development of new materials as well as the optimization of system design in order to improve the transmission efficiency, increase the transmission distance, and improve the safety of electric energy.

Considering the popularization of domestic intelligence, based on the gradual maturity of automatic driving technology, the future wireless charging system will be more intelligent and automated, can be combined with various types of sensors and intelligent algorithms for wireless charging position of automatic calibration and automatic adjustment of charging power.

The wireless charging mode of electric vehicles for distributed microgrid applications is also one of the future research hotspots, which will be more promising to realize the popularization of vehicle-to-grid (V2G) function with low energy loss.

4. Concluding remarks

Wireless charging technology for electric vehicles is more convenient and safer than wired charging, and is more in line with the future development trend of electric vehicles to solve the range anxiety problem. This study analyzes four different wireless charging technologies and compares their respective advantages and disadvantages as well as suitable application scenarios. The future development of wireless charging technology and the outlook is elaborated.

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