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Comparative Analysis of Wireless Charging Systems

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Abstract:

With the accelerated progress of global modernization, electric energy, as one of the most important basic energy sources in human society, has deeply penetrated all areas of production and life. From industrial production to smart homes, from transportation to information communication, the stable supply and efficient transmission of electric energy are always the key elements to support the operation of modern society. In this context, although the traditional wire transmission method is technologically mature, its inherent limitations such as complex wiring, high maintenance costs, safety hazards, and other issues are becoming increasingly prominent, especially in special environments (e.g., the ocean, high altitude, mobile equipment, etc.) in the application of serious constraints. As a breakthrough energy transmission method, wireless energy transmission technology is gradually becoming a research hotspot in the field of energy transmission by virtue of its non-contact, flexible, convenient, safe, and reliable advantages. This paper summarizes the comparative analysis of various wireless transmission methods. Firstly, it introduces the development history and basic principles of different wireless transmission methods. Secondly, it compares the performance of different wireless transmission methods, their construction costs, and transmission efficiency, and finally discusses the application scenarios of different wireless transmission methods, and analyzes the advantages and disadvantages, so that they can be better applied in different fields and reduce the resource application of the mismatch.

Keywords: wireless charging transmission; smart grid; comparative analysis; electromagnetic induction; applicable scenarios.

1. Introduction

In today's society, electric energy has become an indispensable energy source in our daily life, and all the electronic products we use need electric energy as the source of power, therefore, the power grid system has deeply affected our daily life, and the transmission line is an important component of the power grid system as well as the basic structure of it, which is vulnerable to the threat of natural disasters, such as strong winds, ice, snow, lightning and other force majeure, bringing great potential danger to the operation safety of transmission lines [1]. The threat of natural disasters, such as strong winds, ice and snow, lightning strikes, and other force majeure, to the transmission line operation safety has brought great potential danger. Therefore, in order to give feedback on the status information of transmission lines in time and prevent the occurrence of catastrophic accidents, online monitoring equipment has been applied to transmission line status monitoring and fault diagnosis [2]. At the same time, the power supply of monitoring equipment also exists in extreme weather instability, making it impossible to detect the power transmission accurately, so the study of resonance transmission mode, the wireless power supply, so that it can keep the power smooth in extreme environments [3]. However, the existing research is more for a single transmission method research, and not a variety of wireless transmission modes for comparison and discussion, so a variety of transmission modes together with research and discussion, can better reflect its advantages and shortcomings, so that can be more scientific in different areas of the use of different wireless transmission methods, reduce the waste of resources, and better improve efficiency. The purpose of this study is to compare and discuss the three transmission methods, analyze their advantages and disadvantages as well as the suitable areas of use, avoid the waste of resources, and improve the transmission efficiency.

2. Theoretical Basis Analysis

2.1 Development History of Wireless Charging Points

The theoretical basis of wireless charging from the 1830s, Michael Faraday discovered the phenomenon of electromagnetic induction. In 1978, the American George Bogle opened the electric car wireless charging precedent; in 1994, the Japanese Murata Manufacturing Company announced the realization of the "magnetic coupling resonance" of the application test. Into the 21st century, wireless charging technology out of the laboratory formally stepped into the industrialization of the development period. This period can be roughly divided into the following three stages:

Stage I: 2007-2013, the earliest wireless charging devices mainly appeared on the back of the cell phone and other accessories in the consumer electronics market. In 2012 before the consumer electronics wireless charging equipment power was mostly in the 5W below, electric vehicle charging power did not exceed 10KW.

Stage 2: 2014 officially entered the era of the receiving end, during this period, wireless charging receiver modules will be built into a large number of smartphones and other mobile devices, or applied in some industrial applications.

Stage 3: In 2017, the infrastructure era officially opened, charging transmitters will be built in cars, homes, offices, public facilities, and industrial equipment, and the future of wireless charging applications will be integrated into people's daily lives.

2.2 Wireless Charging Transmission Principle

2.2.1 Electromagnetic transmission principle

Based on Faraday's Law of Electromagnetic Induction, an alternating current is passed through the transmitting coil, causing it to generate an alternating magnetic field, and when the receiving coil is located in this magnetic field, the magnetic flux will change, generating an induced electromotive force in the receiving coil, which in turn generates an induced current for wireless transmission.

2.2.2 Coupled transmission principle

Based on electromagnetic transmission, coupled transmission causes the transmitting and receiving coils to be mutually inductively coupled to each other, and the strength of the coupling effect is related to the number of turns of the two coils, the geometry of the coils, their relative positions, and the magnetic medium between them. Hence, the design for the above factors can increase the degree of coupling.

A typical pole plate structure of an electric field coupled wireless energy transfer system is shown in Fig. 1, where the voltage across the coupling capacitors is increased by resonance between the inductor Ls and the coupling capacitors Cs1 and Cs2, thereby generating a large displacement current across the smaller coupling capacitors and realizing the transfer of energy. The resonance between inductor Ls and capacitors Cs1 and Cs2 also compensates for the reactive power of the power electronic converter and improves the efficiency of the converter [4].

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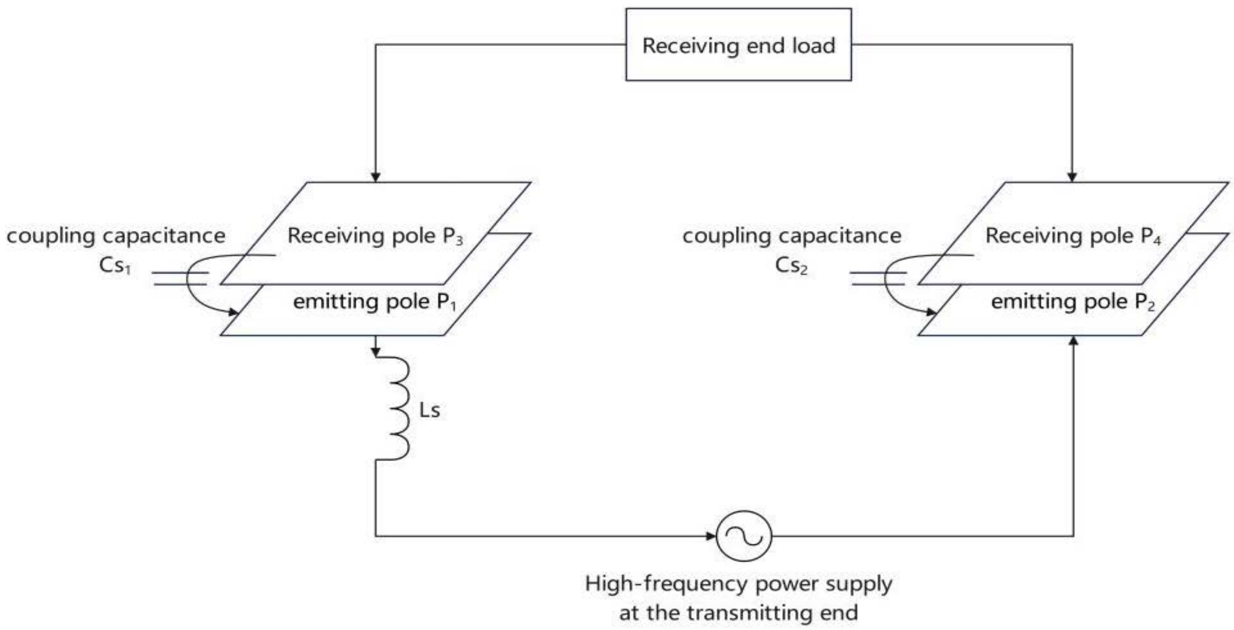

Fig. 1 Typical electric field coupled wireless energy transfer system

2.2.3 Resonant transmission principle

At the transmitting end, the electrical energy provided by the power supply is converted to high-frequency alternating current by an inverter and fed into the transmitting resonant circuit. The inductors and capacitors in this circuit have a fixed resonant frequency, and the circuit resonates when the frequency of the incoming high-frequency alternating current is the same as the intrinsic frequency of the transmitter resonant circuit.

At the receiving end, there is likewise a receiving resonant circuit with the same resonant frequency as that of the transmitting end. The receiving coil and capacitor form a resonant circuit whose intrinsic frequency is also precisely tuned to match that of the transmitting end.

When the transmitter is in resonance, a high-frequency resonant magnetic field is generated. According to the principle of electromagnetic resonance, the resonant circuit at the receiving end responds strongly to the alternating magnetic field generated at the transmitter, i.e., the receiving resonant circuit also enters resonance. This type of transmission is able to go from the transmitting end to the receiving end with minimum loss.

The basic structure of the MCR-WPT system is shown in Fig. 2, which mainly consists of a transmitting end consisting of a high-frequency power supply, an impedance matching network and a transmitting coil, and a receiving end consisting of a load and a receiving coil [5].

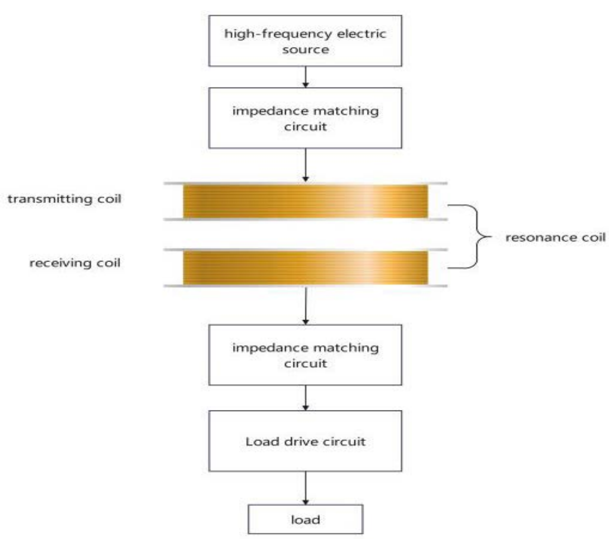

Fig. 2 Basic structure of MCR-WPT system

2.3 Summary

These three transmission methods are based on Faraday's principle of electromagnetic induction, which generates an alternating magnetic field at the transmitting end so that the electric energy reaches the receiving end, improves the efficiency of electric energy transmission, and reduces losses by changing the structure of the transmitting end and the receiving end.

3. Comparative Performance Analysis

3.1 Construction Costs

Electromagnetic induction technology development time is longer, the technology is more mature, and widely used, such as cell phone charging, electric toothbrush charging, etc., the relevant industry chain is more complete, so the hardware cost is relatively low, to cell phone wireless charging, for example, an ordinary electromagnetic induction wireless charging base, the material cost may be a few dollars to more than a dozen yuan, plus the chip and other control circuits, the cost is also relatively controllable.

Resonant wireless charging technology needs to accurately match the resonance frequency of the transmitter and receiver, so the hardware precision needs to be higher, in order to realize the resonance, the transmitter and receiver need to use special resonance devices, as well as circuit modules capable of generating alternating currents of specific frequencies. The cost of development and production increases accordingly.

Coupled wireless charging technology is relatively new, and is still in the stage of development and improvement, so the research and development costs are high, need to invest a lot of money to improve the technology, the charging efficiency, stability, etc., and the hardware production scale is small, fewer products, making the cost much higher.

3.2 Transmission Efficiency Comparison

Electromagnetic induction type wireless energy transmission research time is earlier, is the current through the coil, the coil produces a magnetic field, the induction of electric potential on the nearby coil, thus generating current. Therefore, the power is small, at about 5W, and the transmission distance is also shorter, but the efficiency is higher, at about 80%. However, this method needs to be placed in a specific location, there are limitations and higher heat.

There are many factors affecting the transmission efficiency in resonant wireless power transmission, such as the operating frequency of the system, which is higher at about 100Hz, and the mutual inductance coefficient, which is the highest at 28.1μH. In the case of ensuring that the first two coefficients remain unchanged, the load resistance will likewise have an impact on the transmission efficiency, after the control, change these three influencing factors to arrive at the transmission efficiency of the resonant electrical energy transmission between 66% and 82%, this parameter is affected by several aspects of the impact [6]. The specific experimental parameters can be reflected in Table 1.

Table 1. Transmission efficiency for different values of parameter variables

control subjects	Operating frequency f (SEM)	Mutual inductance coefficient M (μH)	Load Resistance R_p (Ω)	Transmission efficiency (η)
1	100.127	27.9	96.4	0.8212
2	104.52	40.1	77	0.8094
3	90.53	18.6	96.4	0.7605
4	98.52	18.6	90	0.8012
5	93.59	34	105	0.7616
6	87.26	11.6	78	0.6620
7	90.52	47.5	80	0.7183
8	76.25	12.7	74	0.6880
9	106.67	11.2	83	0.7207
10	113.72	13.6	113	0.7253
11	107.79	54.9	74	0.7021
12	101.63	12.6	102	0.6940
13	103.79	14.4	71	0.7619

To verify the validity of the efficiency product index, take the SS topology ICPT system as an example, set the output power of the system as 100W, and the transmission efficiency of the coupled wireless energy transmission system is around 50% after the efficiency product experiment testifies that the theoretical value is correct [7]. Table 2 shows the conclusions of the efficiency product experiment.

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Table 2. Conclusion of the efficiency product experiment

norm	U p - v / VUp-v/V	theoretical value	experimental value	theoretical value	experimental value	theoretical value
Maximum power transfer	8.9	9.1	50	48.9	11.3	12.1
Maximum performance product	9.5	10.2	66.7	65.4	15.9	16.1

3.3 Applicable Scenarios

3.3.1 Electromagnetic induction

It is currently the most widely used wireless charging method, commonly applied to cell phones, tablet computers, smartwatches, and other small electronic devices. Although its charging power is low, it features high charging efficiency and stability. For example, the research on the design and realization of a wireless charger based on electromagnetic induction technology has realized the design of a close-range, miniaturized, low-power cell phone charger, which firstly compares the advantages and disadvantages of different wireless transmission technologies, and proves the advantages and applicability of the electromagnetic induction technology in cell phone charging [8]. At the same time, electromagnetic induction wireless charging can also be optimized for the smart grid. For example, grid inspection robots using contact charging will have a lot of shortcomings, while the use of wireless charging technology will be more suitable for its complex working environment, after comparing and discussing the advantages and shortcomings of electromagnetic induction wireless charging transmission is more suitable for the charging of grid inspection robots [9].

3.3.2 Resonant

It is suitable for devices that need a certain distance for wireless charging, such as smart home devices such as smart speakers, smart cameras, and wireless charging of electric vehicles, etc., which can realize free charging in a specific range by setting up a resonant wireless charging base station. For example, the research of magnetic coupling resonant wireless charging for electric vehicles can realize wireless charging without plugging and unplugging, and the transmission efficiency can reach 90% [10]. At the same time, magnetic coupling resonance wireless charging can also be applied to the power supply of online monitoring equipment for high-voltage transmission lines in the smart grid [11].

3.3.3 Coupled

Since this charging mode is not affected by the position, it can be applied to some special scenarios, such as underwater robots, underwater sensors, etc., or it can be applied to cardiac pacemakers, etc., in medical treatment, providing a safe and reliable charging method. For example, through the design of an underwater wireless energy transmission system by the magnetic induction coupling principle, we finally get the system of synchronous transmission of electric energy and information [12].

4. Conclusion

After comparison, with the continuous development and optimization of wireless charging transmission technology, more wireless charging modes have been developed, which can better match the application of wireless charging transmission technology in different situations. These three wireless charging transmission modes have their advantages and shortcomings, but they can provide a more diversified application and are suitable for the demand for wireless charging technology in more scenarios.

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