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An Examination of Wireless Charging Technologies for Electric Vehicles Powered by New Energy

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Abstract:

In recent years, the increasing prevalence of new energy electric vehicles in the automotive industry has led to a yearly growth in the number of electric vehicles. This trend highlights the increasing importance of wireless charging technology. This paper centers on the advancements in wireless charging technology for new energy-efficient vehicles. It assesses the current state of the technology, both domestically and internationally, and delves extensively into the operational principles of the pivotal wireless charging technology. The findings indicate that wireless charging, as a novel charging approach for electric vehicles, possesses considerable potential and warrants additional research and implementation. The objective of this paper is to provide a significant point of reference for the advancement of wireless charging technology.

Keywords: new energy electric vehicles, wireless charging technology, wireless electric power transmission, research review

1.Introduction

Individuals have long utilized automobiles as a mode of transportation. However, due to advancements in science and technology, heightened environmental consciousness, and the endorsement of national policies, new energy electric vehicles have emerged as the prevailing trend in the automobile sector. Currently, frequent plugging and unplugging compromises the predominant charging method for electric vehicles, wired charging, leading to electrical leakage, fire hazards, and additional safety risks. Wireless charging technology, on the other hand, is more convenient, eliminates several issues associated with connecting and unplugging, and demands no physical contact. This paper will examine the underlying principles of four distinct wireless charging methods utilized in electric vehicles: electromagnetic induction, magnetic coupling resonance, electric field coupling, and radio waves. We will present a comparative analysis of these four charging technologies, concluding that magnetic coupling resonance wireless charging holds the most promising prospects in the realm of new energy electric vehicles. Moreover, it can serve as the primary research technology in this area.

2.The research status of wireless charging technology is currently being conducted both domestically and internationally.

The implementation of wireless charging technology has garnered international attention and achieved noteworthy advancements. Wireless charging technology's origins can be traced back to the late nineteenth century in the United States. During that time, Nikola Tesla, an electrical engineer, conducted experiments on wireless energy transmission in order to fulfill the demands of his profession. Electromagnetic induction served as the foundation for these experiments. Two of the world's preeminent universities, the University of Auckland in New Zealand and the Massachusetts Institute of Technology, discovered the phenomenon of magnetic resonance and demonstrated its application through collaborative research at the end of the twentieth century. Using magnetic resonance technology, they illuminated a 2-meter electric bulb. As an emerging wireless energy transmission technology, magnetic coupling resonance enables the transmission of energy through obstacles and increases the distance of transmission to the meter range [1]. Consequently, the development of wireless charging technology relied on the theory of magnetic field resonance. With the rise in popularity of new energy-efficient vehicles in recent years, nations have devoted a substantial amount of manpower and resources to conducting in-depth research on wireless charging technology. Despite the diverse outcomes of this research, it's important to explore the unique research methods each country has implemented.

2.1 .A Review of International Research Re-

garding Wireless Charging Technology for Electric Vehicles Fueled on New Energy

In contrast to their domestic counterparts, foreign nations commenced the adoption of wireless charging technology for new electric vehicles earlier. Consequently, they have achieved notable advancements and experienced some practical implementation successes. Certain nations have conducted extensive research on wireless charging technology; when implemented in electric vehicles, it can guarantee a power transmission level exceeding 10 kW and a distance of approximately 20 cm between the receiving coil and the transmitting coil of the electric vehicle.

Researchers in South Korea have conducted extensive investigations into the field of electromagnetic induction wireless charging technology, resulting in specific findings. So far, numerous electric buses have been able to traverse the thirty-kilometer-long highway that South Korea has constructed in Gyeonggi-do to facilitate wireless charging of electric vehicles. These electric buses, with a capacity of 100 kW, can recharge en route using coils buried in the earth, achieving a charging efficiency exceeding 80%.

Prominent research institutions in the United States have undertaken substantial investigations into the magnetic coupling resonance charge technique in recent years. As a result, they have successfully developed magnetic coupling resonance coils, which enable the complete elucidation of power transmission characteristics. By integrating the coil design with the planar spiral winding technique, it is possible to enhance the efficiency of power transmission. For instance, the United States developed and utilized a “spider web coil” as the foundation for an electric vehicle motion charging platform. The University of Scandinavia laboratory has utilized the magnetic coupling resonance principle to develop a wireless charging system for new energy-efficient electric vehicles. In its operational state, the system boasts an impressive wireless charging efficiency exceeding 95%, a transmission power surpassing 3 kilowatts, and a system resonance frequency surpassing 3.8 MHz.

Furthermore, Japanese automobile manufacturers have a more extensive history of wireless charging research. As a result, Japan has attained a more prominent position in the global wireless charging technology market with regard to electric vehicle wireless charging technology. Showa, a Japanese company operating in Haneda airport and Nara city, has developed a wireless charging technology for electric vehicles based on electromagnetic induction. While in operation, the system operates at a frequency of 22 kHz and can achieve 92% efficiency with a 30 kw transmission power reduction in the 14cm air gap interval. Moreover, prominent Japanese automakers have conducted research on horizontal side shift-capable wireless charging systems using magnetic field resonance technology, which can achieve an efficiency of approximately 90%.

2.2 .Overview of research on domestic new energy electric vehicle wireless charging technology

As a result of the collaboration between businesses and universities, the disparity between domestic and foreign wireless charging technologies continues to close. Tsinghua University, Harbin Institute of Technology, Southeast University, and Chongqing University, among others, have devoted many years of research to the design of electromagnetic couplings, shielding and compatibility with electromagnetic waves, foreign body detection, and system modeling and control. These technical domains have yielded numerous breakthroughs and innovations. Southeast University professor Huang Xueliang led a group in 2013 that invented the nation’s first new energy vehicle using wireless energy transmission. In the same year [2], Prof. Sun Yue and his team from Chongqing University proposed an energy mutual charging system specifically for new energy vehicles. Furthermore, Prof. Zhao Qiming and his team at Tsinghua University conducted extensive research on wireless charging systems specifically designed for new energy vehicles. Regarding wireless charging technology for new energy electric vehicles, domestic academic institutions, including SAIC Group, Wanan Electronic Technology Beijing, Have Sense Technology Limited Liability Company, and ZTE New Energy Vehicle, among others, have conducted extensive research. With varying degrees of success in integrating their wireless charging technologies into new energy electric vehicles and having already introduced a portion of their wireless charging technologies to the market, each of these companies has made distinct advancements in the wireless charging functionality of electric vehicles.

3.An Examination of the Operational Mechanism of Wireless Charging Technology for Electric Vehicles Powered by New Energy

Based on the transmission principles used, we can currently categorize wireless charging technology into four distinct varieties: electromagnetic induction, electric field coupling, magnetic coupling resonance, and radio waves. Because the four wireless charging technologies have varying merits and demerits, their implementation is contingent on the specific circumstances at hand.

3.1 .Operating Principles of Electric Field

Coupling

The electric field coupling wireless charging technology involves the utilization of a metal pole plate to establish a coupling capacitance for wireless energy transmission. This makes it possible to change grid AC power to DC using a rectifier filtering process and then get high-frequency alternating current (HFAC) using a high-frequency inverter. A compensating network then supplies the HFAC to the transceiver. This results in the generation of a displacement current [8], which facilitates the transmission of electrical energy. The compensation network achieves output characteristics of constant voltage or current by reducing the reactive power that the transmitter and receiver plates produce during the transmission process. This electric field coupling technology, in contrast to magnetic field coupling, does not require the formation of a closed loop; consequently, it emits minimal radiation towards the human body. However, due to the small equivalent capacitance value of the two pole plates, its transmission power is low[5], and it is challenging to achieve a 15-cm transmission distance. Fig. 1 illustrates the block diagram of the electric field-coupled wireless charging system.

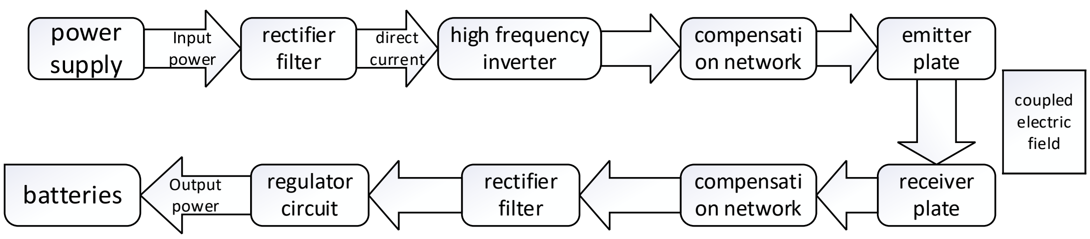

Figure 1. Block diagram of a wireless charging system coupled to an electric field

3.2 .Working principle of electromagnetic induction

Electromagnetic induction wireless charging technology is a type of wireless charging technology that utilizes a magnetic field as the charging medium and the electromagnetic induction principle as its fundamental theoretical foundation. The wireless charging infrastructure of new energy vehicles presently incorporates this technology. To implement this technology, one must synchronize the electrical energy transmitter and subterranean induction coil, and install the reverse induction coil within the electric vehicle [12]. Specifically, the system operates based on the principle of electromagnetic induction, producing high-frequency alternating current using a high-frequency inverter. This, in turn, operates on the primary side of the high-frequency alternating magnetic field, utilizing coils in the magnetic field coupled with each other to form the secondary side of the corresponding induction current. To generate electricity, the electromagnetic induction wireless charging system receives power input from the national grid. The system can directly convert the current to direct current after rectification and filtering processes. The primary and secondary coils of the induction coil then receive a straight magnetic flux, regulating the rectification and filtering of the car's internal circuit to ensure proper operation. The power conversion efficiency of electromagnetic induction wireless charging technology, as well as the charging efficiency, is higher. However, horizontal deviation and angular tilt drastically reduce the transmission efficiency, which further decreases as the distance increases due to the high requirements placed on the relative position of the two coils. Electromagnetic induction wireless charging technology continues to be a significant component of wireless charging systems for new energy electric vehicles in situations where a smooth traveling road surface and a lengthy transmission distance are not prerequisites. Figure 2 illustrates the block diagram of the wireless charging system utilizing electromagnetic induction.

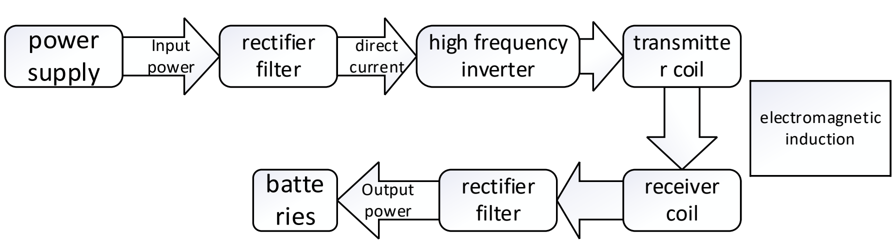

Figure 2. Block diagram of a wireless charging system utilizing electromagnetic induction

3.3 .Working Principles of Resonance-Type Magnetic Coupling

Presently, domestic and international research on magnetic coupling resonance wireless charging technology is relatively brief; however, the technology has a novel innovation that distinguishes it from other technologies and may even have a significant impact on the field of new energy electric vehicles in the near future. Based on the theory of electromagnetic resonance, magnetic coupling resonant wireless charging technology lets the two coils react in a way called resonance when the sending and receiving coils work at the same frequency of resonance. This is made possible by a compensation network on both ends. A high-frequency inverter transforms the DC power into AC power after rectification of the power supply. The compensation network transmits the power between the receiving and transmitting coils, ensuring that both coils resonate at the same frequency. The compensation network subsequently regulates the received power of the coils to align with the voltage-regulating circuit and the operational state of the automobile battery. With a longer transmission distance, lower energy loss, and a maximum transmission efficiency of over 90%, magnetic coupling resonance wireless charging technology stands out as the most advanced new energy charging technology currently available. Figure 3 illustrates the block diagram of the wireless charging system utilizing magnetic coupling resonance.

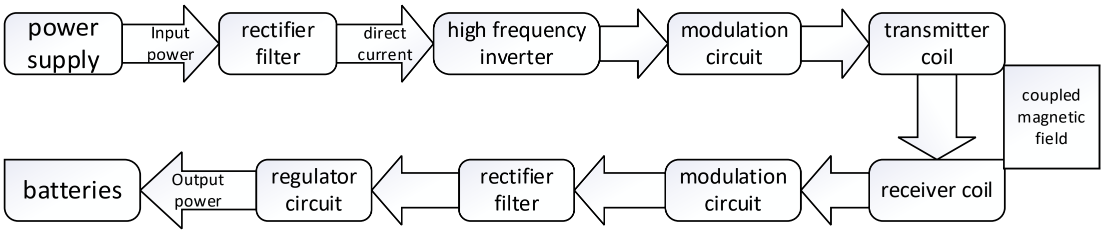

Figure 3. Block diagram of a wireless charging system utilizing magnetic coupled resonance

3.4 .Operational Mechanism of Radio Wave Type.

Radio wave wireless charging technology utilizes microwave frequencies ranging from 300 MHz to 300 GHz to transmit electrical energy. The national grid generates alternating current based on the radio fundamental principle, which the rectifier circuit then converts to direct current. Subsequently, the rectifier circuit modulates the alternating current, and a high-frequency inverter circuit transforms it into a DC microwave. Lastly, the transmitting device emits microwave energy. The modulation circuit then converts the directional reception of microwave beams into electrical energy. Finally, the rectifier circuit converts the electrical energy into power regulation, as the car battery requires current to charge. To achieve longer-distance power transmission, radio wave wireless charging technology will utilize microwave power transmission. However, due to the relatively dispersed and all-directional propagation of microwaves in space, power loss during transmission is relatively high, leading to a relatively low transmission efficiency and significant human body radiation. Therefore, experts deem the technology unsuitable for new electric vehicles. Other specialized fields, including aerospace and aviation, have specific application prospects. Figure 4 illustrates the block diagram of the radio wave wireless charging system.

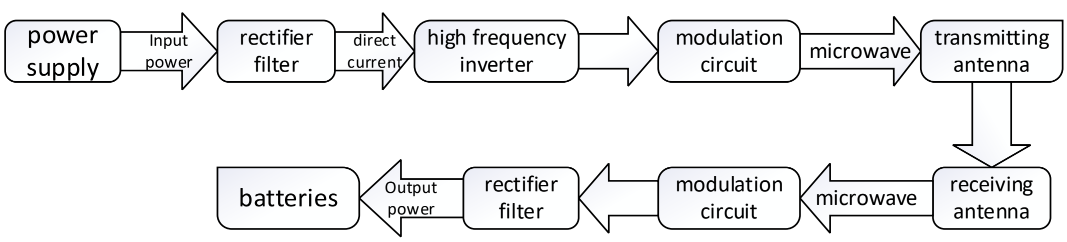

Figure 4. Block diagram of a wireless charging system utilizing radio waves

3.5 .A comparative analysis of multiple wireless charging technologies

This wireless charging technology, which uses capacitance between the electrode plate and electric field coupling to transmit power, is unsuitable for the new energy electric vehicle sector because of its low transmission power and excessively large volume, despite its high transmission efficiency and allowance for coil relative position variation. Despite the relatively short power transmission distance and the need for a higher relative position between the transmitting coil and the receiving coil, electromagnetic induction wireless charging technology maintains a low cost and a transmission efficiency of up to 99 percent in close proximity. Therefore, it can serve as the primary wireless charging technology for new energy vehicles in specific scenarios.

Magnetic coupling resonance wireless charging technology, which has emerged as a late-stage innovative research development, possesses a moderate transmission distance and an efficiency exceeding 90%. As a result, it has emerged as a significant technological advancement in the realm of new-energy electric vehicle wireless charging. We anticipate fruitful results in the future from further investigation into the potential applications of magnetic coupling resonance technology in the context of new energy vehicles.

Radio-wave wireless charging technology has the greatest transmission range, spanning several kilometers. However, due to its relatively low transmission efficiency and propensity to emit radiation that is more hazardous to human health, this technology is not suitable for implementation in the realm of new electric vehicles.

Table 1. Comparison of four wireless charging technologies

	Electric field coupling type	electromagnetic induction type	magnetic coupled resonance (MCR) type	radio-wave (electronics)
principle	Coupling of electric fields between capacitor electrodes	The principle of electromagnetic induction	Resonance of magnetic coupling between the coils	microwave-induced heat
transmission power	hang down	relatively high	high	hang down
transmission distance	shortness(cm)	shortness(mm~cm)	relatively long(cm~m)	length(km)
transmission efficiency	relatively high (70%~80%)	high(85%~95%)	high(80%~90%)	hang down(30%~40%)
vantage point	Greater efficiency with reduced relative coil position requirements	Several watts to tens of kilowatts of transmission power with a high conversion efficacy	Extended transmission distance, elevated power, and minimal stipulations regarding the coil's relative position	Maximum transmission distance with no location specifications
weak point	Low transmission power and too large	Limited transmission distances and stringent requirements regarding the coils' relative positions	Excessive design specifications for coils, elevated cost, and heightened control challenges	Low transmission efficiency, high transmission loss, and the radiation generated is harmful to the human body
application scenario	Primarily found in low-power electronic devices, including mobile phones.	Implantable medical devices and diminutive electronic devices	The future standard for wireless charge of new energy electric vehicles	Satellites, drones, and additional aerospace disciplines

Comparing the aforementioned four wireless charging technologies, Table 1 demonstrates that electromagnetic induction and magnetic coupling resonance are the most promising technologies for wireless charging of new energy electric vehicles. However, magnetic coupling resonance is superior to electromagnetic induction and transmission power, and permits the relative position of the coil to be deviated. advancements in technology.

4.We design a magnetic coupling resonance system for wireless charging.

4.1 .*Wireless charging system architecture*

The wireless charging system's hardware circuit comprises various components, such as a rectifier filter circuit, voltage regulator circuit, high-frequency inverter circuit, compensation network, transmitting coil, receiving coil, power supply circuit, control circuit, and drive circuit. Figure 5 illustrates the process of converting the current from the national grid to DC through rectifier filtering, and then to high-frequency AC via a high-frequency inverter circuit [15]. Resonance then transmits the electrical energy from the transmitting coil to the receiving coil, and after rectifier filtering, the control circuit conveys it to the power supply. This sequence of events allows for the charging effect to be implemented.

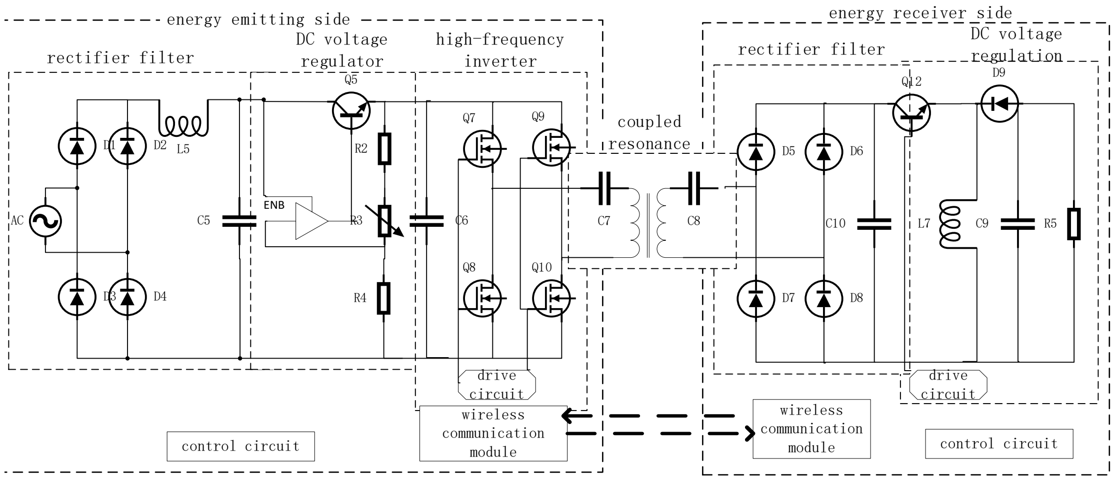

Figure 5. Block diagram of the simulation of the wireless charging system

4.2 .Outline of the wireless charging compensation network

Magnetic coupling wireless charging technology sets up a non-contact resonant converter by using a compensation network and coil interaction to make a resonant circuit. The compensation network on one side of the coil serves to improve transmission efficiency while also isolating DC power. On the other side of the coil, the compensation network aims to improve the grade of the power supply equipment's volt-ampere capacity. To achieve this, the compensation networks of both sides of the coil and the coupling coil form a circuit, ensuring that the frequency of both coils is identical and facilitating the transmission process. Typically, the interaction between the coil and the compensation network addresses the issues of limited transmission distance and transmission power loss during electric energy transmission, leading to a reduction in transmission distance. Single-coupling compensation networks and composite compensation networks are the two primary classifications of compensation networks.

4.2.1 .Networks for Single-Coupling Compensation

1) Series-Series Coupling (SS Coupling). As illustrated in Figure 6, the SS coupling compensation network comprises a series connection between the transmitter and receiver coils and a capacitor [19]. The design of the structure is more straightforward, and the receiver circuit does not influence the transmitter's resonance condition. Consequently, the receiver does not impact the transmitter's input, the output power is greater, and the device operates over a comparatively broad frequency range. Furthermore, it is well-suited for situations involving stable coupling coefficients, short transmission distances, and minimal load variations.

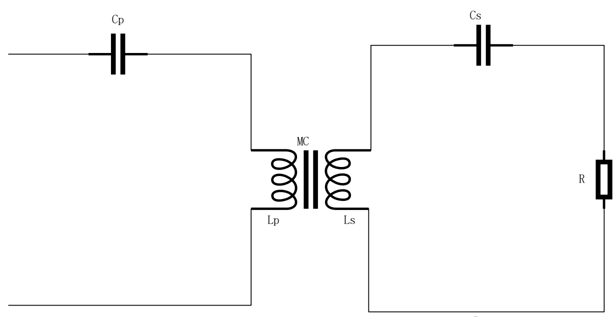

Figure 6. Circuit schematic of the SS compensation network

2) Series-parallel coupling (SP coupling). The SP coupling compensation network structure, as illustrated in Figure 7, consists of a series connection between the transmitting coil and the capacitor, and a parallel connection between the receiving coil and the capacitor. Although this configuration is limited to a narrow frequency range, it achieves transmission efficiencies exceeding 85%. Consequently, it is well-suited for applications involving more stable loads, shorter coupling coefficients, and long transmission distances.

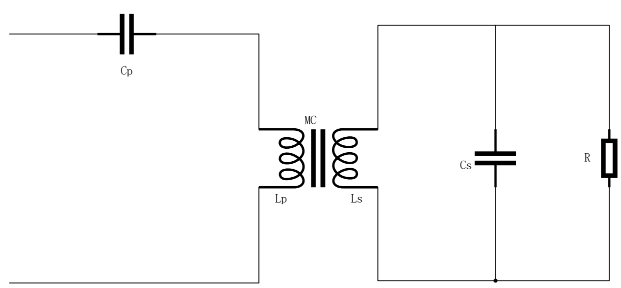

Figure 7. Circuit schematic of the SS compensation network

3) Parallel-Series Coupling (PS Coupling). Figure 8 depicts the PS coupling compensation network structure, which consists of a parallel connection between the transmitting coil and the capacitor, and a series connection between the receiving coil. Although this configuration can function across a broad frequency spectrum, an increase in resistance results in a significant reduction in the circuit's output efficiency. However, it significantly reduces the power output when compared to SS coupling and SP coupling. Consequently, it is most appropriate for use cases involving substantial coupling coefficients, short transmission distances, and negligible loads.

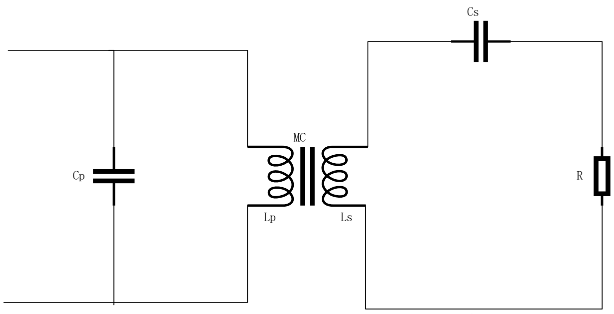

Figure 8. Circuit schematic of the SS compensation network

4) Parallel-to-Parallel Coupling (PP Coupling). The PP coupling compensation network structure depicted in Figure 9 involves a parallel connection of the transmitter coil and receiver coil with a capacitor. This structure exhibits a rapid decrease in output power as the frequency of operation increases. Although the face of the load changes, the output power remains constant, resulting in lower overall power and efficiency. While the coupling coefficient remains stable and the magnitude of load changes is substantial, the transmission does not place a significant demand on efficiency and power.

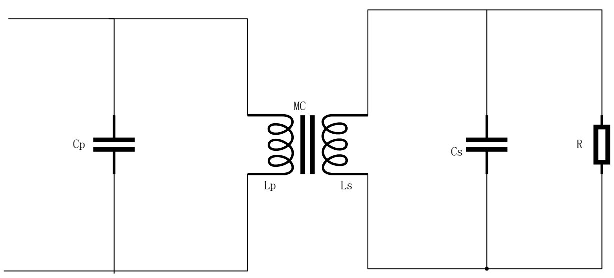

Figure 9. Circuit schematic of the SS compensation network

4.2.2 .Network for Composite Compensation

The wireless charging system's four fundamental compensation networks invariably exhibit certain shortcomings. However, the composite compensation network attempts to circumvent these shortcomings by combining the benefits of multiple coupling methods. We employ this network to enhance the power transfer efficiency and system stability of the wireless charging system. The primary components of a complexity compensation network are the LCC-P and LCC-S compensation networks, as well as the LCL-LCC compensation network. This paper will present the structure of a bilateral LCC compensation network, as depicted in Figure 10.

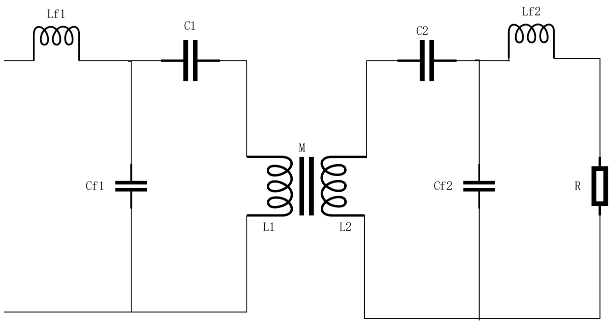

Figure 10. Circuit model of a bilateral LCC compensation network

5.Challenges with Wireless Charging

5.1 .Inconsistent charging standards

There have been five primary wireless charging standards utilized thus far: the PMA standard, A4WP standard, Qi standard, Wi-Po technology, and iNPOFi technology [4]. Uniform charging standards are crucial for the advancement of wireless charging technology. The lack of standardization is currently impeding its progress. It is imperative to unify charging standards nationwide to ensure the future growth of this technology.

5.2 .Increased cost of charging equipment

Wireless charging technology is still in its development stage and has not yet gained widespread adoption or mass production. The cost of a wireless charging equipment set is around 300,000 yuan, while a fast charging station can range from 100,000 to 200,000 yuan. On the other hand, a home-wired charging station can be obtained for as little as 2000 to 5000 yuan. Wireless charging equipment tends to be more expensive, which can hinder the development of this technology. However, as technology advances, we can expect the cost of wireless charging equipment to decrease in the future.

5.3 .Safety Hazards

Wireless charging technology, while converting electric energy into electromagnetic waves, can potentially emit radiation that may have some negative effects on the human body. Additionally, if there are metal objects or small animals that interfere with the charging device during its operation, it can lead to failures and pose certain security risks at both the transmitting and receiving ends of the energy. We can effectively reduce potential safety hazards by detecting live animals and metal objects on the charging pad.

6. The wireless charging development trend.

Wireless charging technology has become a general trend in the field of new energy-efficient vehicles, with promising application prospects. As automotive intelligence advances, the wireless charging industry will expand even more. Future developments in wireless charging technology should focus on optimizing the coil structure to improve power transmission efficiency and charging system stability. In the future, wireless charging technology will become one of the primary charging methods for new energy electric vehicles, and the application scene will become more diverse, not only in automotive applications but also in cell phones, aerospace and aviation, and so on, allowing us to enter a wireless era.

7.Summary

Wireless charging technology is an innovative charging method that offers a novel approach to fueling new energy-efficient electric vehicles. This alternative is both more convenient and safer than conventional wired charging technology. The article provides an overview of four distinct wireless charging technologies, namely electromagnetic induction, magnetic coupling resonance, electric field coupling, and radio waves. It assesses the merits and demerits of each technology from various angles and arrives at the following conclusion: in the realm of automobiles, magnetic field coupling resonance is the most suitable wireless charging technology, followed by electromagnetic induction and radio waves. The company utilizes a network and wireless charging system to compensate for these shortcomings. The new energy electric vehicle industry can create many benefits for the wireless charging community by doing in-depth research and development on wireless charging technology for these vehicles. This research and development should focus on areas such as safety, intelligence, and commercialization, as well as lowering costs, improving power transmission efficiency and distance, and creating a single wireless charging standard. In addition to responding to the national call for energy conservation and emission reduction, wireless charging technology has a transgenerational impact on the new energy electric vehicle industry. In the future, it may be possible to bury charging equipment to achieve the charging effect while driving, thereby making the charging of new electric vehicles more convenient and secure. In the foreseeable future, there is an optimistic outlook regarding the progressive maturation of magnetic coupling resonance wireless charging technology in the domain of new energy electric vehicles. We anticipate this development to yield favorable outcomes for numerous sectors of society.

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