Comparative Study on the Efficiency of Wireless Charging Structures

Xinyue Zheng *

Shengli No.1 Middle School of Dongying, Shandong, China

* Corresponding Author Email: zxysddy@ldy.edu.rs

Abstract. With the increasing popularity of various electronic devices, people's demand for the portability of device charging is also increasing. Wireless charging technology has emerged and is showing a rapid development trend. Wireless charging technology utilizes the conversion effect of electric and magnetic fields, transmitting electrical energy wirelessly from the transmitting end to the receiving end, charging the battery of the receiving device. There is no need for a wire connection between the charging device and the electrical device, and the charging device and the electrical device's conductive contact points can be fully enclosed. This paper first introduces the origin and development of wireless charging technology. Then, it introduces the mainstream standards of wireless charging technology. The author mainly analyzes the structure and principle of two types of wireless charging technologies: electromagnetic induction and resonant. Then, it compares the two types of wireless charging technologies in terms of principle and transmission parameters. This paper summarizes the characteristics of both technologies above.Finally, it summarizes the application scenarios of wireless charging technology. This paper aims to provide literature support for the research on wireless charging technology.

Keywords: Wireless charging technology; standard; electromagnetic induction type; magnetic resonance type; application scenarios.

1. Introduction

The origin of wireless charging technology dates back to 1890. Physicist Nikola Tesla first tested the wireless transmission technology. In 2007, the research team of the Massachusetts Institute of Technology used resonance technology and successfully lit a bulb 2m away after many experiments [1]. In 2009, Japan's Showa Aircraft Industry Company used the principle of electromagnetic induction to produce a non-contact power supply system. In 2010, Fujitsu of Japan produced a wireless charging device based on magnetic resonance technology [2]. In 2011, South Korea trial-operated the first wireless charging electric vehicle in Seoul Park. In 2012, Nokia released two smartphones that could be charged wirelessly. In 2013, the capital airport of Finland provided wireless chargers for passengers for free. In the same year, Apple applied for a patent for an invention called "Integrated Inductive Charging Technology for Protective Covers". In 2014, computer manufacturer Dell joined the A4WP camp to achieve wireless charging for Ultrabooks. In 2017, Apple launched three new smartphones that support the Qi standard, enabling wireless charging.

In China, in 2004, Bin Zhou designed a new type of charging device. This device can not only realize wireless charging for smartphones and PDAs, but also for laptops. In 2007, Jianping Yu designed a new type of lithium battery wireless charger. This charger does not require precise positioning and can charge multiple different electrical appliances simultaneously. The charging transmission is unidirectional [3]. Since then, various wireless charging patent technologies have emerged. So far, by searching for the keyword "wireless charging" on the National Intellectual Property website, the number of related patent applications is as high as 68,854. Many domestic enterprises have invested a lot of research in the wireless charging technology for electric vehicles. In 2014, ZTE New Energy Vehicles achieved a maximum output power of 60kW, with an efficiency of 90%. In 2015, Zhonghui Chuangzhi Wireless Power Supply Technology Co., Ltd. began to research the kW-level wireless charging system for electric vehicles and designed a wireless charging system with an output power of 1-30kW and a transmission efficiency higher than 90%. Huawei has made a breakthrough in wireless long-distance microwave directional charging technology,

successfully realizing directional charging within 100 meters, with an energy transmission efficiency of up to 99.4%. It can charge electric vehicles while they are driving. At the same time, this technology enables traditional charging piles to be equipped with Huawei's microwave directional charging device to charge multiple electric vehicles within 100 meters simultaneously. At the 19th Asian Games, State Grid Hangzhou Power Supply Company built the country's first charging station with high power, wireless charging, and V2G functions, and put it into operation in Hangzhou Asian Games Village. In the field of wireless charging, Maxic Technology (Beijing) Co., Ltd. has a leading position in the industry, has surpassed foreign manufacturers in the field of wireless charging, and has become the main supplier for many well-known mobile phone, watch, Bluetooth headset, and tablet computer brand customers. In 2024, Harbin Institute of Technology made significant progress in wireless charging technology and developed a contactless intelligent compact wireless charging system, making wireless charging truly contactless. Statistics show that from 2016 to 2021, the scale of wireless charging in China has increased by more than three times, and wireless charging technology has achieved rapid development and popularization.

This paper first introduces the origin and development of wireless charging technology. Then, it introduces the mainstream standards of wireless charging technology. This paper mainly analyzes the structures and principles of two types of wireless charging technologies: electromagnetic induction and resonance. Subsequently, it compares the transmission parameters between electromagnetic induction and resonance. This paper summarizes the advantages and disadvantages of the two types of technologies. Finally, the application scenarios of wireless charging technology are summarized. The purpose of this paper is to provide literature support for the research on wireless charging technology.

2. The Principle of Wireless Charging

2.1. Wireless Charging Technology Standard

The main wireless charging technologies include electromagnetic induction type, magnetic resonance type and electromagnetic wave type. In order to improve production efficiency, reduce production costs, and enhance the universality and safety of products, wireless charging requires a unified standard. The unified standard is more conducive to promoting the popularization and application of wireless charging technology.

There are currently three mainstream wireless charging standards: Qi standard, PMA standard, and A4WP standard. Some domestic enterprises have also launched their own standards, such as iNPOFi technology and Wi-Po technology [1].

The Qi standard adopts electromagnetic induction technology and was launched by the Wireless Power Consortium (WPC) in August 2010. Wireless charging devices that comply with this standard are convenient and universal. As long as there is a product with the "Qi" logo, regardless of the brand, it can be charged with a Qi wireless charger. Currently, the Qi standard is mainly applied to smart phone products in China.

The PMA (Power Matters Alliance) standard adopts the principle of electromagnetic induction. It was initiated by Duracell Powermat Company. This standard establishes a wireless power supply standard for mobile phones and electronic devices that comply with IEEE. It is a leader in the field of wireless charging.

The A4WP standard adopts electromagnetic resonance technology and was jointly created by companies from the United States, South Korea, and Israel. Wireless charging devices that comply with this standard are suitable for charging portable electronic products and electric vehicles.

The iNPOFi technology uses an electric field to transmit electrical energy and is a brand-new wireless charging technology from Dalian Guizhan Company in China. In January 2013, the standard product made its debut. It is different from the principle of electromagnetic conversion and is the only wireless charging standard without radiation in the world.

The Wi-Po technology adopts magnetic resonance wireless charging technology and was launched by Ningbo Wei'e Electronic Technology Co., Ltd. Its effective charging distance can reach 5cm and it can penetrate common materials except metals. This technology uses the space magnetic field as the carrier and will not cause electromagnetic wave radiation harm to the human body.

2.2. The Principle of Electromagnetic Induction (ICPT) Wireless Charging

The current wireless charging for mobile phones mostly uses electromagnetic induction technology. Its charging principle is similar to the transformer principle. The principle of the transformer is shown in Fig. 1.

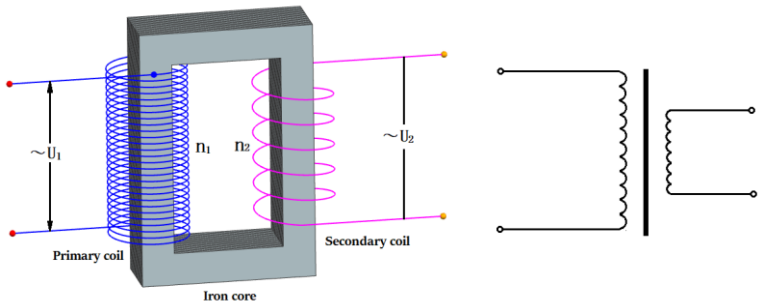

Fig 1. Schematic diagram of transformer.

Transformers are mainly composed of primary coils, secondary coils, and iron cores. When an alternating voltage U1 is applied to the primary coil, an alternating current is generated in the primary coil. Then, an alternating magnetic field is generated in the iron core. The alternating magnetic field induces an alternating voltage U2 on the secondary coil [4]. If the output end is connected to an electrical device, the electric energy has been transmitted.

Separate two coils and place them in separate devices, aligning them closely together. When an electric current is applied to the primary coil, a current is induced in the secondary coil due to electromagnetic induction. It can power connected devices [4]. The transformer uses the iron core to transfer the magnetic field, while Wireless charging transfers the magnetic field through the air.

Hubei University of Technology submitted a patent application in 2023, designing an electromagnetic induction wireless charging system based on a multilevel inverter, and presenting the schematic diagram as shown in Fig. 2 [5].

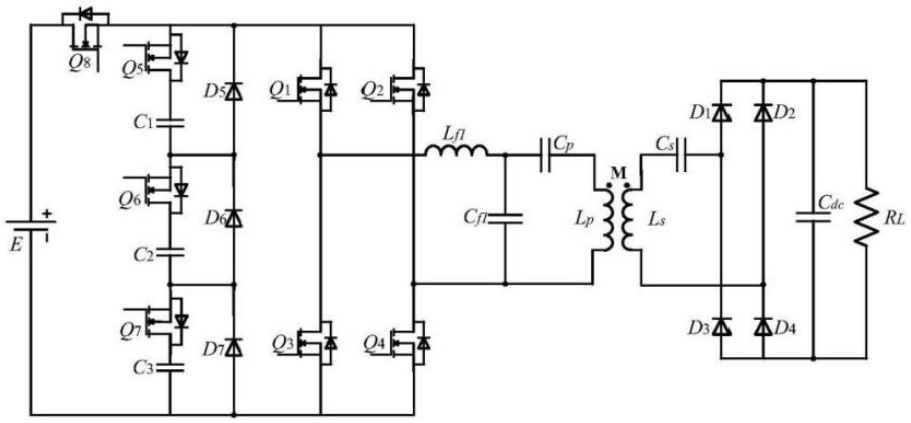

Fig 2. An electromagnetic induction wireless charging system based on multi-level inverter [5].

The electric charging system depicted in Fig. 2 comprises a multi-level power input section, inverters, controllers, and more. The multi-level power input section generates multiple stepped voltage levels. The inverter performs inversion on these stepped levels. The controller governs the duration of each voltage level and the driving signals for the inverter. By adjusting the time of each individual level within the multi-level power input section to optimal values, high-efficiency wireless power transmission can be achieved.

The following Fig. 3 provides a simplified diagram. It illustrates the principle of electromagnetic induction-based wireless charging technology.

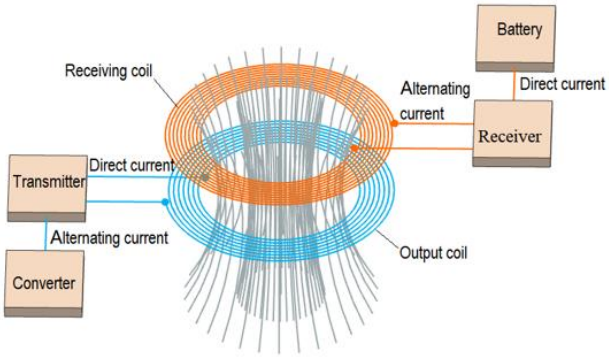

Fig 3. Structure diagram of electromagnetic induction wireless charging.

As shown in Fig. 3, the power supply is converted into direct current after AC/DC conversion, and then supplies power to the output coil after being processed by the transmitter for inverter frequency modulation, generating an alternating magnetic field. The receiving coil that is close and aligned with the output coil generates an induced current under the action of the magnetic field. After being rectified and voltage regulated by the receiver, it becomes direct current to charge the connected battery.

2.3. The Principle of Magnetic Resonance Type (ERPT) Wireless Charging

Magnetic resonance, also known as magnetic resonance, is based on Maxwell's equations and belongs to the magnetic induction technology. This charging technology utilizes the principle of resonance. Magnetic resonance occurs when the receiving coil and the transmitting coil have equal frequencies. Energy is transmitted through magnetic resonance.

The structure of the magnetic resonance wireless charging system mainly includes the transmitting antenna (transmitting coil) and the receiving antenna (receiving coil), etc. After being energized, the transmitting coil generates an alternating magnetic field, and the receiving coil resonates in the alternating magnetic field to generate electrical energy [6].

Guilin University of Electronic Technology submitted a utility model patent application for a magnetic coupling resonant wireless charging device in 2016. This device has adaptive adjustment capabilities [7]. The application provides the schematic diagram as shown in Fig 4. Jianfeng Li and others provided the principle diagram shown in Fig 5 in their paper "Research on Wireless Charging Technology for Electric Vehicles." Qingchang Yu and others provided the system architecture diagram shown in Fig 6 in their paper "Research on Optimization Methods of Magnetic Coupling Resonant Wireless Charging Coils."

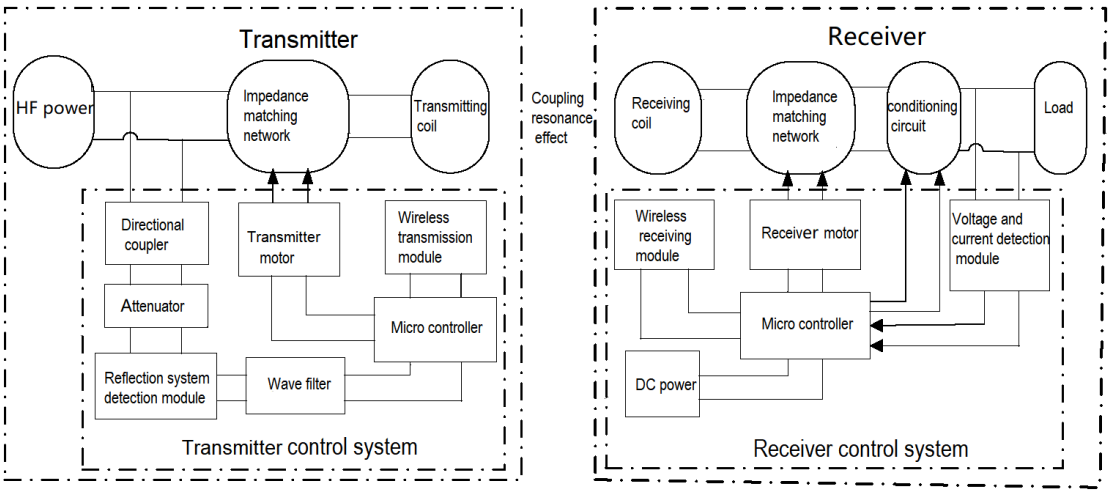

Fig 4. Magnetic coupling resonant wireless charging device with adaptive adjustment capability

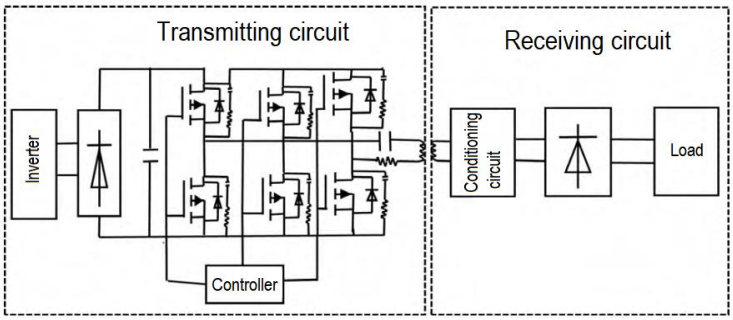

Fig 5. Schematic diagram of magnetic coupling resonant wireless power transmission system.

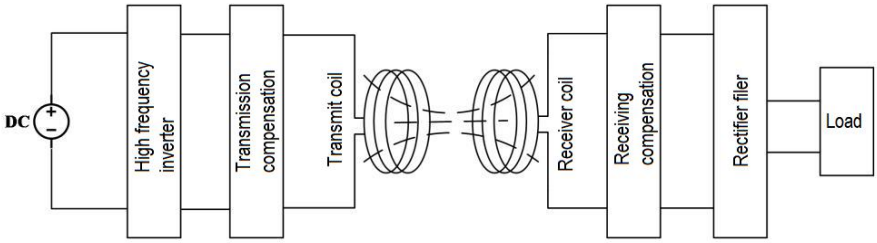

Fig 6. Basic structure of resonant wireless charging system.

As shown in Fig 6, the resonant wireless charging system is mainly composed of a DC power supply, a high-frequency inverter, compensation on the transmitting side and the receiving side, transmitting and receiving coils, a rectifier and filter circuit, etc. [8] The DC power supply input is converted into square-wave AC power by the high-frequency inverter. Then, through the resonant effect of the coils and the compensation network, wireless power transmission is achieved, and finally, it is rectified and filtered for use by the load.

2.4. Comparison of Electromagnetic Induction and Magnetic Resonance Wireless Charging Technologies

The electromagnetic induction method utilizes the induced magnetic flux generated between the power transmission side and the power receiving side to transfer power and is the most commonly used wireless power supply method. This method has the advantages of a simple circuit structure, high efficiency, miniaturization, and low cost. The disadvantage is that the charging efficiency is significantly limited by distance, and the working range is only within a distance of several millimeters to several centimeters. As the distance increases, the magnetic field rapidly weakens. As shown in Fig 7, the increase in distance also leads to a loss of magnetic flux in space. The greater distance results in induced currents far below the expected value and lower energy efficiency [9]. The electromagnetic induction method is also easily affected by positional deviation. As shown in Fig 8, the horizontal distance offset will cause the magnetic flux to dissipate and cannot charge effectively. Therefore, precise alignment is required during charging. In addition, electromagnetic induction wireless charging technology can only achieve one-to-one charging.

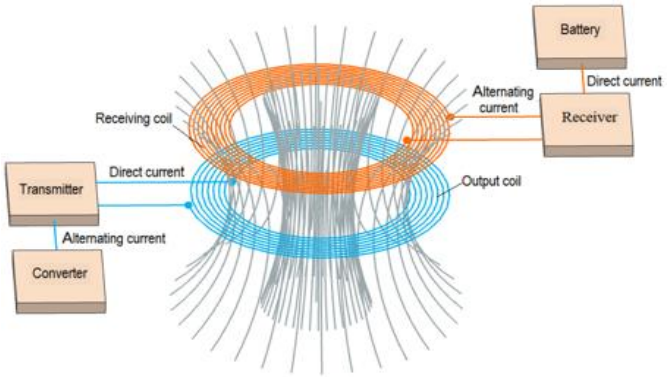

Fig 7. The loss of magnetic flux caused by vertical distance.

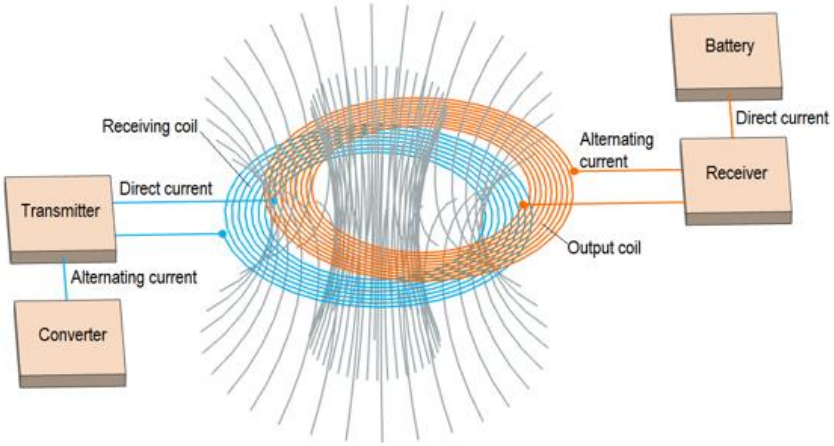

Fig 8. The loss of magnetic flux caused by horizontal position.

The resonant wireless charging technology and the electromagnetic induction type have similarities in principle, both utilizing the electromagnetic effect. However, the resonant wireless charging technology utilizes the resonance principle. Due to the fact that resonant objects have low requirements for spatial positions, the transmission distance of resonant wireless charging is much greater than that of electromagnetic induction. Resonant wireless charging has a high power and can charge multiple devices simultaneously. But the resonant charging technology also has drawbacks, mainly manifested in its lower charging conversion rate, greater design difficulty, and higher maintenance cost [10]. Since resonance is susceptible to electromagnetic waves, in order to prevent interference from electromagnetic waves of the same frequency, frequency band protection is also required.

Based on multiple literature materials and patent technology documents, Table 1 provides a comparison of data for two wireless charging technologies.

Table 1. Comparison of magnetic induction and resonant wireless charging technologies.

Wireless power supply method	Magnetic induction type	Resonant type
Theoretical basis	Electromagnetic induction law	Maxwell's equations and electromagnetic induction law
Principle	The high-frequency alternating current sent out by the power supply after AC/DC conversion and inverse modulation generates an alternating magnetic field in the transmitting coil, and induces current in the receiving coil located in the same magnetic field.	The transmitting coil is energized to generate an alternating magnetic field, and the receiving coil with the same resonance frequency resonates in the magnetic field. The resonance effect generates current in the coil for energy transmission.
Ttransmission power	W	W-KW
Transmission distance	mm-cm	cm-m
Usage frequency	100-375KHz	100KHz-13.56MHz
Charge efficiency	75-85%	80%
Number of rechargeable devices	one-for-one	one-to-many
Advantage	Short distance charging with high conversion efficiency	Suitable for long-distance high-power charging
Disadvantage	Fixed position, metal induction contact generates heat	Low conversion efficiency, safety and health issues

3. Application Scenario Analysis

Wireless charging technology is increasingly being used in today's society, especially in portable communication, medical devices, transportation, aviation and aerospace, underwater exploration, and other fields [2].

Wireless charging technology achieves electrical isolation and has the characteristics of safety and flexibility, which can charge underwater equipment such as unmanned submersibles, underwater autonomous robots, and underwater wireless sensors more conveniently.

The development of wireless charging technology has also changed the charging mode of electronic products. Commonly used electronic products in daily life, including mobile phones, tablet computers, MP3 players, electric shavers, electric toothbrushes, etc., have all attempted the wireless charging mode. Wireless charging products mainly include transmitter and receiver products. The transmitter product is the common wireless charging dock. The receiver product is generally embedded in the electronic devices. The wireless charging coil and conversion circuit in small electronic products such as mobile phones, computers, and electric toothbrushes are a type of receiver.

Currently, electric vehicles are becoming more and more popular in China. But the short cruising range and limited charging piles still restrict the development of electric vehicles. If a breakthrough can be achieved in wireless charging technology, it is bound to lead to a new round of industrial growth of electric vehicles. In 2011, at the International Consumer Electronics Show held in Las Vegas, Fulton Innovation Inc. exhibited wireless charging technology for electric vehicles [1]. In 2009, Chery Automobile Co., Ltd. submitted two patent applications related to wireless charging technology for electric vehicles. On November 11, 2013, BYD Co., Ltd. submitted a patent application for invention, "Wireless Charging System and Method for Electric Vehicles to Electric Vehicles". Other domestic brands also have involvements in the field of wireless charging. Wang Guanyu mentioned in the paper "A Brief Analysis of the Main Classifications and Current Applications of Wireless Charging Technology" that Zhejiang Province will build China's first hyper highway, named Hang-Shaoxing-Ningbo Expressway. It is expected to be completed and open to traffic by 2020. The road is equipped with electromagnetic induction coils underneath. It allows cars to charge their batteries while driving at high speeds. This design saves a significant amount of space and can charge more vehicles, thereby solving the problem of limited charging pile numbers to some extent [1].

In the medical field, implantable devices such as cardiac pacemakers, brain nerve stimulators, and cochlear implants still mostly rely on battery power. These devices need to be implanted into the human or animal body through surgery. It is unrealistic to either put the battery into the body or frequently remove these devices from the body to replenish energy. Using wireless charging technology can charge low-power implantable devices, avoiding secondary surgeries. At present, G.X. Wang has developed a wireless power supply device for artificial retinas, and Masaya Watada has also developed a wireless power supply system for left ventricular assist devices. In the future, wireless charging technology will be widely applied in various medical devices to meet their safety and sustainability requirements [1].

4. Conclusion

This paper first introduces the origin and development of wireless charging technology. It also introduces the mainstream standards for wireless charging technology. Then it analyzes and compares the structures and principles of electromagnetic induction and resonance-based technologies. This paper also summarizes the advantages and disadvantages of both types of wireless charging technologies. Finally, it concludes with a summary of the application scenarios for wireless charging technology. Although wireless charging technology currently has its shortcomings, it will experience new breakthroughs as technology continue to develop. In the future, wireless charging technology is bound to penetrate into all aspects of human society.

References

[1] Guangyu Wang. A Brief Analysis of the Main Classification and Application Status of Wireless Charging Technology [J]. China New Telecommunications, 2018, 20(18): 99-100

[2] Liping Gu. The Anticipated Wireless Power Transmission and Its Development [J]. China Radio, 2012, (1): 27-30

[3] Jianping Yu. CN200720117925.X [U]. 2008-02-27

[4] Haobo Yuan. A Brief Analysis of Wireless Charging Technology for Mobile Phones [J]. Digital Communication World, 2017, (09): 191-192

[5] Wencong Huang, Tianbiao Rao, Fan Meng, Xiaoyu Li, Quan Shen, Cheng Shu, Wenrui Lin, Yufang Chang, Huaicheng Yan. Hubei University of Technology. CN202310248321.2 [P]. 2023-07-18

[6] Yuhao Ye. The Principle and Application of Wireless Charging Technology [J]. Scientific and Technological Innovation and Productivity, 2023, 44(11): 119-122

[7] Xingming Fan, Erju Jia, Xin Zhang. Guilin University of Electronic Technology. CN201620406314.6 [U]. 2016-10-12

[8] Qingchang Yu, Haoran Li, Yuyu Zhu. Research on the Optimization Method of Magnetic Coupling Resonant Wireless Charging Coils [J/OL]. Journal of Power Supply. https://link.cnki.net/urlid/12.1420.TM.20240425.1639.002

[9] Min Huang. Vehicle Wireless Charging System Based on Electromagnetic Induction [D]. East China University of Science and Technology, 2016

[10] Jianzhong Bi, Tianguo Ye. A Brief Analysis of the Principle and Application of Wireless Charging Technology [J]. Computer Knowledge and Technology, 2019, 15(27): 219-220