Wireless Charging Technology: Future Development Trend and Prospect Analysis

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Abstract. Charging efficiency stands as a pivotal metric influencing the usability of electronic devices. Enhancing the charging efficiency of electronic smart devices through wireless charging technology represents a significant contemporary challenge. This paper meticulously examines the current advantages and disadvantages of electromagnetic induction, magnetic resonance, and radio wave wireless charging technologies. Moreover, it scrutinizes the future development trajectory and prospects of wireless charging technology, drawing insights from the prevailing market landscape. Despite persistent challenges in wireless charging technology, ongoing scientific and technological advancements hold promise for enhancing both efficiency and safety. Anticipated improvements in wireless charging infrastructure and associated equipment are poised to further bolster the adoption and efficacy of wireless charging technology. The continuous evolution and innovation within the realm of science and technology are expected to catalyze advancements, paving the way for a future marked by heightened efficiency and safety standards in wireless charging technology, thereby enhancing the overall user experience.

Keywords: Wireless Charging, Electromagnetic Induction, Magnetic Resonance, Radio Waves.

1 Introduction

Wireless charging technology is an effective and convenient way to provide power to devices, widely used in various electronic devices. With the advancement of technology and the increasing demand from consumers, the wireless charging industry has shown broad prospects. This article will explore and compare the development trends and influencing factors of different wireless charging technologies.

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1.1 Electromagnetic Induction Wireless Charging

Electromagnetic induction wireless charging is a technology based on Faraday's law of electromagnetic induction to realize wireless charging of equipment by transmitting energy through electromagnetic fields. The technology uses a changing electromagnetic field to transmit energy to enable charging without a charging line. Electromagnetic induction wireless charging as a whole is composed of a transmitter, a charger, a receiver, a device. During the working process, a changing electromagnetic field is generated by the charger. When the electromagnetic field is induced to the receiver, an induced electromotive force is generated when a conductor moves in the changing magnetic field, thereby generating a current in the receiver to achieve wireless charging. Fig. 1 shows that electromagnetic induction wireless charging process.

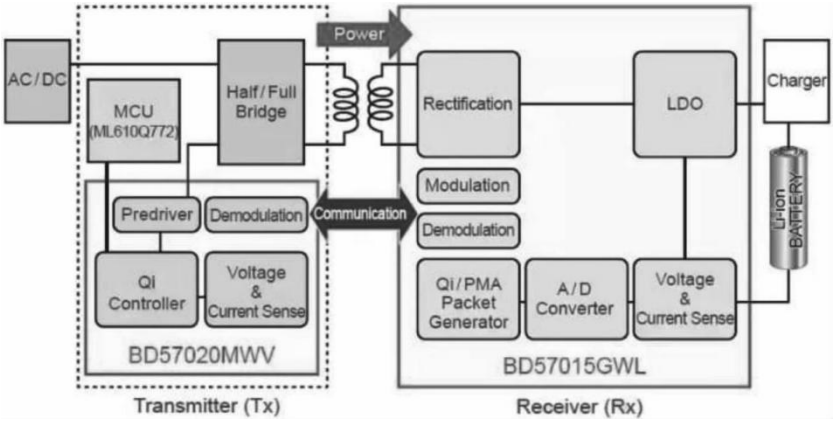

Fig. 1. Electromagnetic induction wireless charging procession [1].

This charging method abandons the use of traditional charging cable, makes charging more convenient, reduces the number of plug and plug of charging head, and improves the service life of equipment and charging head, because no charging cable makes charging cleaner. However, inductive wireless charging is usually less efficient, the charging distance is short, the charging speed is slow, and the charging efficiency must be aligned between the charger and the receiver, otherwise the charging efficiency will be affected, and some users will question the safety due to the existence of electromagnetic radiation.

1.2 Magnetic Resonance Wireless Charging

Magnetic resonance wireless charging is a kind of wireless charging method that realizes the ability transmission between electronic devices by using the resonance principle. The magnetic resonance wireless charging device as a whole is composed of a transmitter, a charger, a resonance coil and a receiver, a device. When the two

resonance devices have the same resonance frequency, energy exchange occurs between them. Let the charger generate a changing magnetic field, when the receiver is close to the charger, the resonance frequency of the two matches, and the energy transmission efficiency is maximized, and then the receiver will receive the magnetic field energy emitted from the charger into electrical energy to achieve wireless charging. Fig. 2 shows that magnetic resonance wireless charging process.

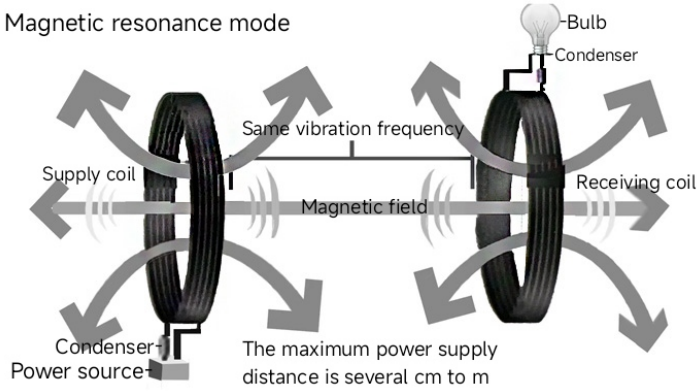

Fig. 2. Magnetic resonance wireless charging procession [2].

Compared with electromagnetic induction wireless charging, magnetic resonance wireless charging has higher energy transmission efficiency and is more stable, and the transmission range is wider, in addition, it is not limited by the location and direction, and the user can move the device more freely during the charging process. Although magnetic resonance wireless charging has improved the energy transmission efficiency compared with electromagnetic induction wireless charging, there is still a large energy loss, so the charging speed is slower than that of traditional wired charging. In addition, due to the relatively complex resonance devices, the magnetic resonance wireless charging system costs more than electromagnetic induction wireless charging and traditional wired charging systems.

1.3 Radio Wave Wireless Charging

Radio wave wireless charging is a wireless charging technology that uses radio waves to transmit energy. Different from traditional electromagnetic induction and magnetic resonance wireless charging, radio wave charging uses radio frequency energy transmission. Radio wave wireless charging is also composed of a transmitter and a receiver, but in this device, the transmitter will transmit an antenna through the circuit to generate radio waves, and the antenna in the receiver receives these radio waves, when the receiver is placed in the effective range of the transmitter, the radio waves transmit energy to the receiver. Finally, using the principle of RF energy transmission, the energy received by the antenna is converted into electrical energy to realize wireless charging. Fig. 3 shows that radio wave wireless charging process.

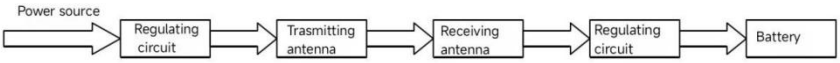

Fig. 3. Radio wave wireless charging procession [3].

Compared with the traditional electromagnetic induction wireless charging and magnetic field resonance wireless charging technology, radio wave charging has a wider transmission range and higher charging efficiency. Due to the penetrability of the RF signal, charging can be achieved without placing the device directly near the charger, making charging more convenient and convenient. However, radio frequency energy transmission may have some electromagnetic radiation, so it is necessary to meet the relevant radiation standards to ensure safety. In addition, due to the characteristics of RF signal transmission, that is, the signal strength will gradually decay with the increase of distance, so there will be a certain energy loss, which affects the charging efficiency. In addition, alignment between devices remains an issue to be overcome.

1.4 Comparison of Three Wireless Charging Technologies

For the convenience of analyzing the differences among the three mainstream wireless charging technologies mentioned above, Table 1 illustrates the comparison of the three wireless charging technologies.

Table 1. Three different kinds of wireless charging [3].

	Electromagnetic induction	magnetic coupling resonance	radio waves
principle	Electromagnetic induction	Magnetic coupled resonance	Electromagnetic wave spoke
Transmission power	0～5 W	0W～1KW	>100 mW
transmission distance	A few millimeters to a few centimeters	A few centimeters to a few meters	A few to a few thousand meters
advantage	High conversion efficiency	The transmission distance is long and the power is large	Long transmission distance
shortcoming	Short transmission distance	High requirements for coil design	High transmission loss
Application	Small electronic device charging	The mainstream way of wireless charging for electric vehicles in the future	Smart home field

2 Problems and Solutions Faced by Wireless Charging Technology

2.1 Problems Faced by Electromagnetic Induction Wireless Charging Technology

The basic principle of electromagnetic induction wireless charging technology is Faraday's law of electromagnetic induction, which has low potential safety hazards, relatively simple and mature technical principles, and low manufacturing costs. It is widely used in current household appliances, such as electric toothbrushes, smartphones, and electric shavers. Although electromagnetic induction has certain advantages in the above aspects, there are still some shortcomings.

Distance Limit between Power Supply Port and Receiving Port. The charging principle of electromagnetic induction is to generate a certain amount of induced magnetic flux between the charging base and the coil of the charging device terminal to generate current and store it in the receiving terminal, thus achieving the effect of wireless charging. However, in electromagnetic induction, the divergence ability of the magnetic field is strong, so when the device is far away from the charging terminal or there is a misalignment with the wireless charging pad, the magnetic field strength will decrease significantly with increasing distance [4], and the charging efficiency will be greatly reduced. Therefore, in real life, it is often necessary to keep the device at a close distance for a long time to ensure ideal charging effect.

Charging Equipment and Power Supply Equipment Need to Be Closely Fitted. The transmission distance of wireless charging is relatively short, and effective charging usually requires a range of a few centimeters to tens of centimeters. Due to the characteristics of electromagnetic induction, the divergence performance of the magnetic field is high, and precise alignment between the two coils is required during charging to achieve high efficiency power transmission. If the two coils are misaligned during charging, it will greatly affect the charging efficiency. Another important factor is that when applied to vehicle charging, different models have different base height designs, and electromagnetic induction wireless charging technology has strict requirements for charging distance and must remain static during charging [5].

Restrictions on Charging Equipment. When the charging contact material of the charging device is metal, the magnetic field between the coils will be disturbed by metal objects, resulting in magnetic field deflection, and affecting the charging effect. In addition, wireless charging devices will have some energy loss during charging and convert it into heat energy. Wireless charging requires energy transmission through air or other media, which inevitably results in some energy dissipating in the form of heat energy. The internal energy formula of a conductor is

$$Q = I^2Rt \tag{1}$$

In equation (1), Q represents internal energy. I is the current. From (1), it can be seen that when time and current are constant, the internal energy generated by the conductor is negatively correlated with the resistance value, and the material of the coil greatly affects the resistance value of the conductor. Therefore, finding more suitable coil materials to reduce the degree of energy loss has become a future research trend [4]. Moreover, when cutting alternating magnetic field lines, eddy currents are generated in the metal material, heating the metal. Combined with the good thermal conductivity of metals, when the charging surface carries metal, it is very likely to damage the charging equipment due to high temperatures.

2.2 Magnetic Resonance Wireless Charging

Magnetic resonance wireless charging technology consists of two induction coils that transmit and receive two systems. By adjusting the transmission frequency, the transmitting end vibrates, forming a non-radiate magnetic field. In the transmitting and receiving sections, a channel is formed to convert electrical energy into a changing magnetic field, which generates more voltage through co vibration. The receiving end receives energy in the magnetic field, forming a conversion from magnetic energy to electrical energy. At present, there are still several shortcomings in magnetic resonance wireless charging technology.

High Production Costs. Compared to electromagnetic induction wireless charging and traditional wired charging systems, magnetic resonance wireless charging technology has higher requirements for resonant devices, and resonant devices are relatively complex and require higher production costs due to the use of high-performance materials.

Vulnerability to External Influences. As the charging distance increases, the charging efficiency is easily affected by the external environment: factors such as metals and electronic devices in the external environment may interfere with the resonance of the magnetic field and affect energy conversion, reducing charging efficiency.

Safety Issues. At present, magnetic resonance charging still has certain electromagnetic radiation and interference, which may affect some people, such as patients wearing pacemakers; Long term exposure to the radio frequency electromagnetic field of smartphones can also affect the body temperature, which in turn affects the visual, cardiovascular, immune and other systems of the human body [5].

2.3 Radio Wave Wireless Charging

Unlike traditional electromagnetic induction and magnetic resonance wireless charging, wireless wave charging utilizes microwave transmitting and receiving devices to transmit energy from the transmitter to the receiver, which is then converted into electrical energy and supplied to the device for charging. At present, the defects of wireless wave charging include the following aspects:

Low Efficiency. At present, the charging efficiency of wireless wave charging is relatively low, and there will be certain energy loss during the energy transmission process. This loss is more pronounced during long-distance transmission and obstacle crossing transmission.

Security. Compared to magnetic resonance wireless charging, wireless wave wireless charging has greater radiation safety hazards. Therefore, in future technological research and development, attention should be paid to the impact of wireless wave charging on human health.

2.4 Solutions

Despite significant progress in wireless charging technology, it still faces the urgent issues mentioned above. The main reasons for these problems include technological bottlenecks, market acceptance, and the degree of industrial chain improvement. At the technical level, key technologies such as efficient energy transmission, long-distance transmission, and low-cost implementation of wireless charging still need to be broken through. At the market level, consumers still need to further improve their awareness and acceptance of wireless charging. At the level of the industrial chain, the standardization and industrialization process of wireless charging technology still needs to be accelerated.

Improving Charging Efficiency. Researchers can reduce energy loss during wireless charging and improve charging efficiency by optimizing coil design [6,7], improving material properties, and increasing frequency stability. For example, using high-performance magnetic materials and advanced circuit design can significantly improve the transmission efficiency and stability of wireless charging. In addition, the standardization and standardization of charging interfaces can effectively promote the expansion of investment and application of wireless charging stations, and to some extent improve the efficiency of charging [8].

Expanding Charging Distance. In order to achieve long-distance wireless charging, researchers are exploring new energy transfer mechanisms and technologies. For example, using the principle of magnetic resonance, high efficiency wireless charging can be achieved within a certain range. In addition, some studies have focused on utilizing wireless energy transmission methods such as lasers or microwaves to

achieve charging over longer distances. In wireless wave charging technology, studying the characteristics of changing transmission distance with wavelength has great potential for exploration [9].

Cost Reduction. In order to reduce the cost of wireless charging technology, researchers are committed to developing low-cost materials and manufacturing processes. Meanwhile, by optimizing product design and improving production efficiency, the manufacturing cost of wireless charging products can also be reduced. In addition, with the popularization of wireless charging technology and the expansion of market size, the improvement of the industrial chain will also help to reduce costs.

In summary, although wireless charging technology faces some problems, with the continuous progress of technology and the gradual maturity of the market, these problems are expected to be effectively solved. In the future, wireless charging technology is expected to be widely applied in more fields, contributing to people's livelihoods. Life brings more convenience and possibilities.

Improving Security. In order to improve the safety of wireless charging technology and reduce harm to the human body, research and development enterprises should strictly meet market testing safety standards for production, and enhance market supervision to reduce safety risks. Electromagnetic shielding technology can also effectively alleviate electromagnetic radiation [10]. In addition, radiation can be reduced by enhancing the design's electromagnetic compatibility capabilities.

3 Market Outlook for Wireless Charging Technology

3.1 Market Status and Development of Wireless Charging Technology

Wireless charging technology, as an innovative technology that can achieve power transmission without physical connection, has made significant progress in recent years. Its basic principles involve electromagnetic induction, magnetic field resonance, and radio frequency energy transfer. With the continuous progress of technology, the efficiency, distance, and stability of wireless charging have been greatly improved, making it widely used in multiple fields such as mobile devices, smart homes, and electric vehicles.

At present, there are many wireless charging products on the market, such as mobile phones, tablets, headphones and other consumer electronics products, all of which support wireless charging function. In addition, some high-end cars are also adopting wireless charging technology to provide power for vehicles. These practical application achievements fully demonstrate the broad prospects of wireless charging technology.

The wireless charging technology market is currently showing a rapid growth trend. The main driving forces include consumer demand for convenience, the

popularity of mobile devices, and the maturity and application promotion of wireless charging technology.

In the field of consumer electronics, wireless charging technology has become a standard feature for some high-end smartphones and other mobile devices. This technology solves the limitations of charging port wear and interface plugging caused by traditional wired charging, improving the user experience. At the same time, some car manufacturers have also started adding wireless charging devices in their cars to provide convenient charging services for passengers.

However, the wireless charging market still faces some challenges. The charging standards adopted by different manufacturers are not uniform, which may require users to purchase specific charging bases for wireless charging. In addition, current wireless charging technology is still unable to achieve long-distance wireless charging, and users still need to bring their devices closer to the charging dock. The efficiency and charging speed of wireless charging also need to be improved, and currently it is usually slower than wired charging.

According to a report from a market research company, it is expected that devices supporting wireless charging technology will become increasingly popular. For example, a report suggests that by 2024, the shipment volume of wireless charging devices will exceed 2 billion units, an increase of more than 15 times compared to this year. The global wireless charging market is expected to reach approximately $10 billion in 2024, and will maintain rapid growth in the coming years. In China, the market size of the wireless charging industry is also showing a rapid growth trend, and it is expected to maintain a high compound growth rate in the coming years.

3.2 Prospects for the Wireless Charging Technology Market

The future prospects of wireless charging technology are very broad, and it will have profound impacts in multiple fields. Here are some predictions for the future development trends of wireless charging technology:

Standardization and Popularization: Wireless charging technology is gradually achieving standardization, which will promote its popularization in various devices. With more manufacturers adopting wireless charging technology, consumers will be able to more conveniently enjoy the convenience brought by wireless charging.

Charging efficiency improvement: The charging efficiency of wireless charging technology will be further improved, reducing energy loss and making the charging process faster and more efficient [11]. This will greatly improve the user experience and reduce waiting time.

Security enhancement: The safety of wireless charging technology will receive more attention. With the continuous advancement of technology, wireless chargers will adopt more safety protection measures, such as over temperature protection, over charge protection, etc., to ensure the safety of users during use.

Expansion of application areas: Wireless charging technology will not only be limited to personal electronic devices such as smartphones and tablets, but will also expand to more fields. For example, in the field of smart homes, wireless charging technology can provide convenient charging methods for various smart devices,

avoiding the troubles brought by traditional charging cables [12]; In the automotive field, wireless charging technology will provide more convenient and efficient charging solutions for electric vehicles; In public places such as restaurants, cafes, airports, etc., wireless chargers can provide convenient charging services for customers and improve customer satisfaction.

The development of long-distance charging technology: With the continuous innovation of wireless charging technology, long-distance charging has become possible. In the future, users do not need to place their devices near chargers and can charge within a certain distance, which will bring more possibilities for the application of wireless charging technology [13].

4 Conclusion

In conclusion, wireless charging technology has broad development prospects and trends, but it also needs to overcome some technical and application challenges. With the advancement of technology and the increasing demand from consumers, wireless charging technology is expected to play a greater role in the future, bringing more convenience and efficiency to our lives.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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