DOI: 10.54254/2753-8818/5/20230264

Principles and applications of wireless energy transmission

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Abstract. In this day and age, people's lives are inextricably linked to electricity, which is being used more and more in everyday life. The traditional transmission of electrical energy usually uses materials such as metal wires and cables as the transmission medium, and the losses and potential damage (line deterioration, tip discharges) caused by this transmission medium are inevitable. The introduction of radio has been very effective in reducing this situation, and the development of Wireless Power Transfer (WPT) technology has seen three major developments since then, with Tesla lighting a phosphorescent lamp at the Colombian World's Fair in 1893, igniting hopes for WPT. This new way of transmitting electrical energy has expanded the imagination of people in terms of power supply methods by making it possible to provide more freedom in situations where cable charging is not suitable.The working theory, fundamental design, and potential applications of wireless energy transmission technology are covered in this study. By doing this, it offers insight into the development and use of wireless energy transmission technology as it is now. In the end, it is envisaged that the market will adopt wireless energy transfer technology extensively.

Keywords: wireless power transmission, key problems, application status .

1. Introduction

1.1. Principles of wireless energy transmission

Wireless transmission technology transmits electrical energy to the receiving end by means of electromagnetic fields or electromagnetic waves, and can achieve the transmission of electrical energy from low to high power levels, from near to long distances and from low to high frequency bands. Depending on the transmission principle, the main technologies include long-distance microwave or laser wireless transmission, medium-distance magnetic resonance coupled wireless transmission and short-distance electromagnetic induction coupled wireless transmission.

Wireless Power Transfer Technology (WPTT) was first proposed by the famous electrical engineer Nikola Tesla in the mid to late 19th century as a means of transmitting electrical energy from the power source to the consumer by means of invisible soft media in space (e.g. electric fields, magnetic fields, sound waves, etc.). It is considered to be a revolutionary advance in energy transmission and access, as it is safer, more convenient and more reliable than the traditional way of transmitting electrical energy by cable [1].

1.2. Current status of research at home and abroad

The current domestic wireless power transmission technology is mainly reflected in various means of transportation, some car parks are open for electric vehicles with wireless charging parking spaces, medium power medium distance applications such as smart homes, biomedical devices tiny power near distance applications, sensors small power long distance applications and power system applications [2]. Domestic research institutions are still researching and exploring the technology as well as application areas of wireless power transmission in the hope that it can be applied in more places.

In 2007, Professor Marin Soljacˇi´c's research team at MIT pioneered a new direction in wireless energy transmission by proposing magnetically coupled resonant wireless energy transmission. The team applied coupled-mode theory to the principle of magnetically coupled resonant wireless energy transfer and achieved a wireless transmission of 60 W of power over a range of 2m with a transmission efficiency of 40%, demonstrating that wireless energy transfer technology at the meter scale can be investigated on a practical basis.

Electric vehicles, maglev trains, high speed trains and other means of transport are part of the magnetic resonance wireless power transmission technology. Applications in high-power proximity requirements are generally in the kW to MW power class, with transmission distances of less than 20 cm. Wireless charging systems for kilowatt-class electric vehicles have been developed by the University of Tokyo (2009), Witricity (2010), Nissan (2010) and Qualcomm (2012) [2, 3].

Based on the existing literature, this paper reviews the current research status and applications of the three most widely used WPT technologies - magnetic induction coupling, magnetic coupling resonance and microwave radiation. From the basic structure, the current research status of the three mainstream WPTs is explained in detail, and the application prospects of the three mainstream WPTs are discussed on the basis of the existing research status.

2. The main transmission methods and their advantages and disadvantages

2.1. Basic structure of magnetically coupled resonant power transmission

The schematic diagram of magnetically coupled resonant electrical energy transmission is detailed in Figure 1. In terms of the structural device situation, the main components are two coils, an independent self-oscillating system forming one coil and the transmitting device located to the left of the neutral position of the device, connected to the energy source end. The transmitter unit propagates the emitted electromagnetic waves by playing the role of a transmitting coil. Depending on the function of the transmitting device, it does not have the function of emitting electromagnetic waves to the outside. The receiving device is present on the right side of the neutral position of the device and has a fixed frequency of use. Once the frequency of the received electromagnetic wave is the same as the fixed frequency, an oscillating current is present in the receiving circuit and the current is continuously enhanced and eventually reaches an optimum state. In radio energy transmission systems, magnetically coupled resonant technology has important applications and an important step in energy conversion is the coil resonator performance. This enables the efficient conversion of electrical energy to magnetic fields and ensures that the transmission of electrical energy is efficient, safe and fast [4, 5].

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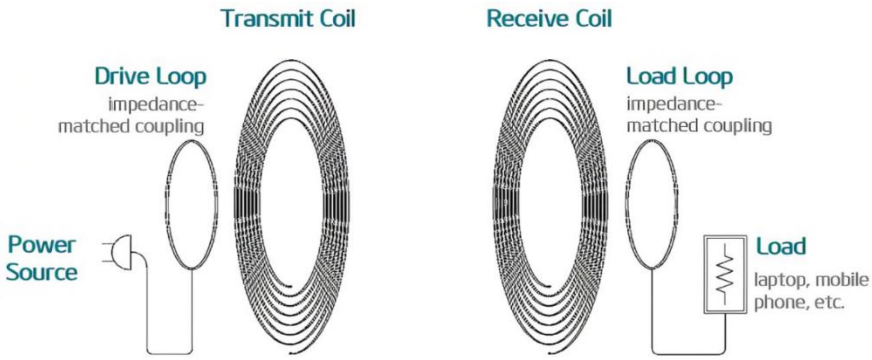

Figure 1. Basic structure schematic diagram of WPT via magnetically-coupled resonance.

2.2. Basic structure of electromagnetic induction power transmission

The basic structural schematic of the magnetically inductively coupled WPT is shown in Figure 2. The components of an electromagnetic induction WPT system include rectifier filtering, high frequency inverter, primary compensation, separable transformer, secondary compensation and current regulation. The principle of operation of the induction WPT is to convert the AC input from the grid into high frequency alternating current after rectification and inversion, and input it to the primary winding of the separable transformer, and then under the inductive coupling action of the high frequency electromagnetic field, transmit the electrical energy to the secondary side of the separable transformer [4].

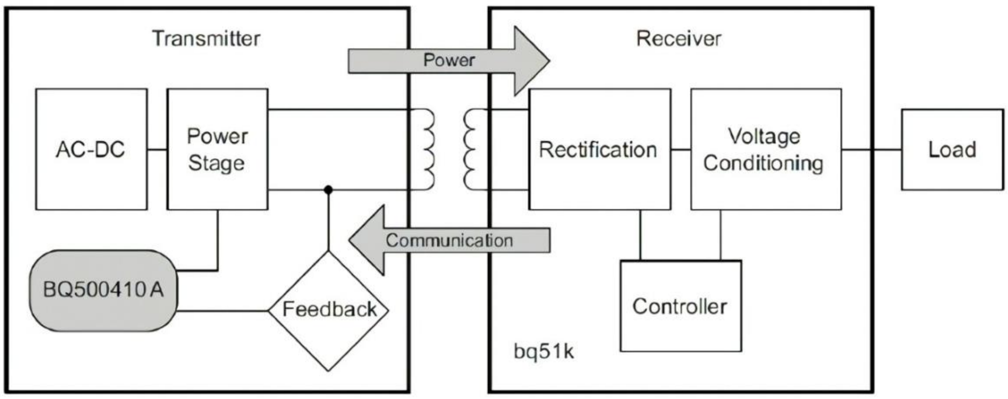

Figure 2. Basic structure schematic diagram of WPT via inductive coupled.

2.3. Basic structure of electromagnetic radiation-based radio energy transmission

The basic structure of a microwave radiating WPT is shown in Figure 3. A transmitting antenna, a rectifying antenna, and a microwave power source make up a microwave radiating system. The rectifier antenna is made up of a receiving antenna, a low-pass filter, a rectifier diode, and a DC filter; the transmitting antenna is divided into a phased array antenna and a directional antenna array with a directional function in accordance with the directional control method, and typically uses a parabolic antenna structure to achieve its high focusing capability. The microwave power source also includes a DC power supply and a DC-RF converter.The working principle of microwave radiating WPT is that the transmitting antenna efficiently concentrates the microwave energy produced by the microwave power generator before efficiently emitting it to the rectifier antenna. The rectifier antenna receives microwave energy that travels across empty space, and the rectifier antenna's rectifier filter circuit converts that energy into DC power to power the load [4].

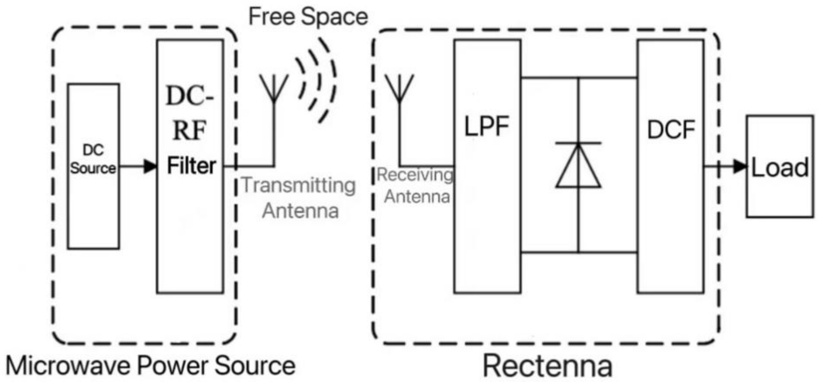

Figure 3. Basic structure schematic diagram of WPT via microwave radiation.

3. Applications in various areas

3.1. Medical treatment

The majority of medical devices currently use implantable electronic systems, which are becoming more and more complex and consume more and more power, and which can be useful for short-term work, but for long-term work the implantable systems cannot meet the requirements due to insufficient battery life. The main application in the medical field is Radio Frequency Power Transmission (RFPT) [6], which can be used to recharge nuclear batteries in artificial hearts, power cochlear implants, etc. In medical electronics, direct energy transfer is possible using RFPT technology, which uses the electromagnetic coupling between two coils outside the body and inside the body to transmit electrical energy and reduce the risk of infection.While static resonance wireless charging of gadgets deep within the digestive tract is still in the research stages, static induction wireless charging of implants under the skin is now more advanced in the field of wireless energy transmission technology. Miniaturizing the receiver size, integrating the circuit structure, and developing materials that are biocompatible within a safe power range without causing harm to biological tissue are the hurdles in this field.

3.2. Underwater area

As seawater is a benign conductor, its resistance is influenced by the frequency, and as the operating frequency increases, the conductive area of the seawater decreases the current flow through the cable, resulting in greater power losses in underwater power transmission [6]. When using radio energy transmission technology in the underwater sector, seawater can be considered as a coaxial turn chain with the primary winding and the current path can be restricted by increasing the coupling, thus reducing the loss of coupled seawater. When used in aquatic situations, wireless energy transmission technologies become unstable. The transmitter and receiver exchange energy through high frequency electromagnetic fields, and seawater as a good conductor will generate eddy currents, resulting in energy loss. Due to the influence of water currents, the relative position and distance of the transmitter and receiver are constantly changing, which will result in a decrease in the energy efficiency of the system. In order to study a reliable and effective wireless energy transmission scheme appropriate for underwater applications, it is crucial to take into account the role of seawater medium, eddy currents, pressure, and other factors. This can be done by conducting an analysis of the coupling of multiple physical fields.

3.3. Smart homes

"Tail-less" household appliances are being suggested in an effort to eliminate the drawbacks of conventional charging wires and to increase convenience and user-friendliness. such as wireless mouse that require no batteries and wireless charging stations for laptops and smartphones.By replacing the conventional method of using electrical energy, which involves plugging and unplugging cables, wireless energy transfer technology plays a significant role in product intelligence while also enhancing the user experience and spatial environment. Static inductive wireless charging solutions dominate the market for smart homes, and the technology is reasonably developed and widely used. However, because household appliances have such a wide range of load power levels, pick-up end locations and load power demands are unpredictable, and efficiency requirements are high, more optimization is required in terms of operating frequency, roughly constant primary resonance current and load output voltage, and efficiency optimization. Operating frequency, roughly constant primary resonant current, load output voltage, and efficiency optimization all need to be improved.

3.4. Electronic products

In the field of consumer electronics, 2017 was the first year of large-scale commercial application of WPT technology in the field of consumer electronics. Since Apple announced a wireless charging board AirPower in September, which can power devices such as iPhone8, iPhoneX, AirPods and Apple Watch that support wireless charging, there have been a number of mobile phones supporting WPT technology [7, 9]. With the early release of the Motorola DroidBionic and the Google nexus4, there have been more than 90 mobile phones using WPT technology since its introduction. According to the Wireless Power Consortium (WPC), the growth trend of the global wireless charging market from 2017 to 2026 is summarized and forecast, covering both transmitter shipments and receiver shipments, with both growing exponentially year on year, with receiver shipments several times higher than transmitter shipments. In 2018, approximately 550 million receivers and 200 million transmitters were sold [10].

3.5. Cars

In the automotive sector, BMW was the first to commercialize WPT technology for charging high-voltage batteries in electric vehicles in July 2018, with the new 530eiPerformance model equipped with the inductive wireless charging system being the first production model to feature WPT technology. With a charging power of 3.2kW, the new 530eiPerformance model takes approximately 3.5h to fully charge, with a charging efficiency of 85%. The wireless charging system consists of two main components: the induction base and the charging unit underneath the vehicle [8]. The induction base can be installed in a garage or outdoor car park with a charging gap of approximately 8cm. The vehicle can then be parked in the correct position above the sensor base according to the colored lines, and charging can be started by pressing the charging start button.

3.6. Unmanned Aerial Vehicle

A Unmanned Aerial Vehicle (UAV) is an unmanned aerial vehicle (UAV) that can be controlled by real-time radio control or by its own pre-stored programs, has the ability to carry a wide range of functional equipment to perform a variety of tasks, and can be used multiple times. With its unique advantages of small size, low cost, flexibility and adaptability, it is widely used in both civilian and military applications. However, UAVs with long endurance are still a challenge due to the limitations of energy storage batteries and conventional power supply methods. Researchers have then investigated the use of radio energy transfer technology for the resupply of energy to UAVs [11].

4. Conclusion

This paper begins by describing the basic structure of the three current mainstream WPT technologies, followed by a summary of research into their application in the fields of transport, medical electronics, consumer electronics and UAVs.Wireless energy transmission technology is not a new concept, but the introduction of new technologies and applications is gradually making it a new research discipline. In the areas of electric vehicles, medicine, manufacturing, and electronics, the advancement and continued development of this technology will have a significant effect. Although magnetically coupled resonant radio energy transmission technology has steadily come into existence in recent years, there are still a lot of issues and research that want a more thorough analytical approach. The instabilities caused by high quality factor resonator coils to the system's operation have not yet been adequately addressed, nor have the issues of system control and optimization been resolved. There is still a lot of room for growth as a wireless method of transferring energy across medium distances.

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