Research and classification of wireless power transfer with relative application

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Abstract. In this paper, wireless power transfer (WPT) will be discussed in its research and application. The basic information like the reason why devices choose to use wireless power and the concept of typical WPT types is introduced. The wireless power transfer system can be divided into 5 diverse types by the theory of power transmitting, and the working principle will be introduced separately. Then, the detail of WPT via magnetically-coupled resonance is mainly discussed, including the analyzing methods, optimization scheme and the current problems. Finally, this paper give two examples on medical use and mobile phone battery charging. Using the technology of WPT, the problem of the medical tiny robots battery charging is solved, and it provides a more convenient method of charging the mobile phones without the cables. The wireless power transfer technique has potential advantages and broad prospects, which is of vital significance in power transfer development.

1. Introduction

With the consumption of the traditional fossil energy, we are facing the emergency of energy exhaustion, so that scientists began to search for reliable new energy to alleviate the current energy crisis. At present, electricity is the most ideal final energy form, which can be converted into the ultimate energy through clean energy such as wind energy, water energy, nuclear energy. Supported by various government policies and development of new technologies, electricity has been widely used in factory production, daily life, transportation energy and other aspects. [1-2] In recent years, the development of electric vehicles and the universal use of mobile phones have played a crucial role in promoting the development of wireless power transfer (WPT) technology.

The research on wireless power transfer (WPT) technology began in the 1980s. Nikola Tesla, an American scientist, first carried out WPT experiment. In 1899, he successfully lit a distant incandescent lamp with 50 kHz AC [3]. By the early 1960s, American Raytheon company William C. brown and others had done a lot of research on radio energy transmission, laid the experimental foundation of WPT and made this concept a reality [4]. In 1968, an American aeronautical engineer called Peter E. Glaser, proposed the idea of using microwave to transmit electric energy from solar satellites to the ground, that is, to establish a space solar power station (SPS) in geosynchronous orbit [5]. DOE and NASA jointly organized a study to demonstrate the concept of SPS program and affirmed its feasibility from 1977 to 1980. In response to the energy crisis, the United States, Japan and other major developed countries have successively carried out research on space solar power plants, which has greatly promoted the development of WPT technology [6-7]. And by the 1990s, the university of auckland conducted deeper research on WPT[8].

This paper will focus on the research and application of current wireless power transfer technology, especially WPT with magnetically-coupled resonance and give a brief introduce of the WPT technique.
2. Analysis

2.1. the background of developing WPT

WPT technology opens a broader research field for the development of modern energy. Compared with traditional wired power transmission, the wireless power transmission can solve a series of economic and security problems caused by transmission cable failure, and become more convenient for individuals. And with the growing consumer group, to a certain extent, the related industries have promoted the development of WPT technology. Wireless power transfer is a way to complete energy transmission without cable transmission for both transmitters and receivers. In comparison with traditional energy transmission methods, it has a lower integrated cost, effectively reduces environmental constraints, and a more prominent advantage is that it can accurately control the power outflow distance and also achieves the ability to transfer energy to a moving target, which is essentials to the fields of Aerospace.

For illustrations, its design of intelligent network, system structure to improve transmission efficiency, and the expansion and application of receivers are the current research direction. Along with the demand for electrical vehicles and mobile phones, wireless power transfer has a large percentage in the charging methods. In comparison with transmitting power through a cable, one noticeable merit of the WPT is able to charge the battery in relative shorter time with higher amount of energy. Until now it has been one century and the appearance of electric vehicles and mobile phones boosts the applications of wireless power transfer, which indeed refers to transmit energy or charge the battery [9]. Charging with wireless equipment usually refers to wireless power transfer. The battery of daily electronic devices, such as mobile phones, laptops, have requirements about close-distance WPT [10].

2.2. the classification of common WPT

The wireless power transfer technique can be divided into 5 different types, These will be discussed below [11].

2.2.1. WPT via inductive coupled

The fundamental frequency AC power is rectified, filtered, and converted into high-frequency AC power, which is input to the transmitter through the resonant compensation network, and finally supplied to the load with inductive coupling. The power is relatively high and it has a high efficiency in a short distance. The basic construction is shown below.

![Fig1. the basic structure of WPT via inductive coupled](image)

2.2.2. WPT via magnetically-coupled resonance

This is similar to the resonance of the sound, when it comes to this method, the transmitting winding will generate a resonance magnetic field at a specific frequency when the electricity is provided.

The working principle of the magnetically coupled resonance type WPT is that the high frequency power supply outputs high frequency alternating current to the transmitting antenna, and the receiving antenna and the transmitting antenna are coupled by the magnetically coupled resonance, which enables efficient wireless transmission of energy from the transmitting end to the receiving end. The received energy can be directly supplied to the load after rectifying and filtering by the load drive circuit[12-13].
Fig 2. Basic structure of WPT via magnetically-coupled resonance
(Source: Research Status and Application of Wireless Power Transmission Technology)

2.2.3. Laser wireless power transfer
The transmitter of the whole system convert the electricity into laser with Stimulated radiation. The laser with modulation will transmit to the receiver via the air. When the receiver gets the laser, the electricity will be used with photoelectric conversion. The laser can transmit the power at long distance, however, the transmitting efficiency is easily influenced by the quality of the atmosphere.

Fig 3. Basic structure of WPT via laser
(Source: Research Status and Application of Wireless Power Transmission Technology)

2.2.4. Microwave wireless power transfer
It is using transmit antenna to convert the electricity into microwave energy and transmitting it directly through the atmosphere to the receiver. The energy will eventually be used as DC power. It is able to achieve long distance transmission and has less energy loss.
2.2.5. Ultrasonic coupling wireless power transfer

This WPT is based on the electroacoustic conversion technique and the transmitter can convert electricity at certain frequency into acoustic energy, which will be used as electricity again in load with transducer.

With the fundamental systems of the wireless power transfer, several applications in this field have been used in life. Then, this paper will illustrate some development related to WPT technique.

2.3. The current development of WPT via magnetically-coupled resonance

2.3.1. two methods of analyzing

Magnetically induced coupled and magnetically coupled resonant WPT use the alternating magnetic field generated by the transmission coil to couple the energy to the receiving coil, thus realizing the radio power transmission to the load. These two transmission technologies are relatively mature. This paper mainly describes the magnetically-coupled resonance wireless energy transfer technology, which can be regarded as a special case of WPT via inductive coupled. It achieves high efficiency non-radiation energy transmission through the magnetic coupling resonance of the transmission receiving coil. The transmission distance is larger than the magnetic induction type, it belongs to the medium distance WPT technology and has a wide application[14].

So far, there are two main methods to quantitatively analyze the working principle of magnetic coupled resonance WPT, which can be divided into coupled mode theory and circuit theory. For the former one, we could established the equations of the coupled mode, which describes the transmission characteristics of the system. The equations are shown below[15].

\[
\begin{align*}
\frac{da_1}{dt} &= -j\omega_1 a_1 - \tau_1 a_2 + jka_2 \\
\frac{da_2}{dt} &= -j\omega_2 a_2 - \tau_2 a_2 + jka_1
\end{align*}
\]

a1 and a2 are the field amplitudes of resonant coils 1 and 2 respectively. \(\omega_1, \omega_2\) is the natural frequency of resonance coils 1 and 2. \(\tau_1, \tau_2\) is the inherent loss rate of resonant line, coil 1 and 2. \(k\) is the coupling coefficient between resonant coils 1 and 2.

And for circuit theory, it is easy to get the mathematical expression of the power and transmitting efficiency with KVL equations.
2.3.2. **Optimization scheme of WPT via magnetically-coupled resonance**

As for of magnetically coupled resonance WPT, the transmitting and receiving antenna is composed of induction coil and resonance coil, so that update the structure of transmitter and receiver or the material of the coil can be the Optimization scheme of improving transmission power and transmission efficiency.

In the magnetically coupled resonant WPT system, the influence varies according to the location of the relay resonant coil and the material of the relay coil [16]. Rafif E. hamam of Massachusetts Institute of technology first proposed adding a relay resonant coil between transmitting and receiving antennas. The results show that the electromagnetic radiation outside the system is reduced and the transmission efficiency of the system is improved. The University of Pittsburgh in the United States simulated and analyzed the relay resonator network and put forward the optimization strategy of relay resonator placement.

2.3.3. **Problems of current development**

The main problems of magnetically coupled resonant WPT usually refer to the sensitivity of system parameters, the identification of different loads and the impedance matching of multiple loads, the safety of electromagnetic environment and electromagnetic compatibility. The frequency splitting phenomenon exists in the magnetic coupling resonant WPT. The change of some key parameter like the self inductance, equivalent capacitance and the distance between resonant coils change can always obviously change the transmission characteristics of the system.

2.4. **Two applications of the WPT with magnetic field**

With the recently development the WPT is used in public’s daily life, here are two typical examples using wireless power transfer technology.

2.4.1. **WPT via magnetically-coupled resonance in medical use**

The applications of WPT in medical use is still in development in recent years. As for some certain tiny robots, the wireless power transfer technique provides convenience to the battery charging. For example, the intestinal robot used for testing, in the human gut fixed-point repair, the power supply has always been a tough problem. But the magnetic coupled resonance WPT make the technology become possible. The power transmit system is mainly consist of three parts: high frequency current transmitting part, wireless energy transmitting part and receiving coil power part. The system which is responsible for high frequency current is composed of high-frequency oscillation circuit and power amplification circuit. And before the current is eventually transmitted and consumed in the robot, the current need to be converted in the bridge rectifier circuit, filter capacitor and voltage stabilizing circuit[16].

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Fig5. Equivalent circuit of WPT via magnetically-coupled resonance
(Source: Research Status and Application of Wireless Power Transmission Technology)
2.4.2. **WPT for mobile devices**

At present, the WPT has some important develop directions. First is the way of transmitting. Electromagnetic induction and EMR wireless power transfer are quite normal, for the mobile phones are familiar to individuals. For a simple example, iPhone started to use wireless from iPhone X and iPhone 8/8 plus. A coil made of copper are installed behind the back. With the electromagnetic conversion and, the inner receiver use the coupling power to charge the battery with DC power. The back cover of the mobile phones turned the aluminum into a kind of material like tempered glass, which allows more electromagnetic wave to get through the back and reach the inner receiver with less energy loss, leading to relative higher transmitting efficiency.

![Image of iPhone X with wireless charging](image)

iPhone 12 installed the magnet which support the technique of ‘Magsafe’. So that with the application of electric vehicles and mobile phones battery charging, the technology is gradually matured and widely used. Take the smart home as an example, the wireless power transfer now can support multiple devices to charge at the same time, so that the electric home appliances could be better controlled with the system of WPT, and WPT technique will definitely have greater development in the future.

3. **Conclusion**

The basic description and development of the wireless power transfer technique are shown in this paper, except the concept related to the development and types, the current application is discussed as well. The modern lifestyle makes mobile devices more portable, this trend requires a charging method with less limitation. But for WPT, the main problem at present stage is that the efficiency is relatively low when compared with cable transmitting. With the continuous development, the potential advantages and broad prospects of wireless energy transmission technology are gradually reflected. WPT technology will be an important research trend of energy transmission in the future. Hope this paper can help readers to have a general understanding of WPT.

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