Comprehensive Analysis of Wireless Charging Technology in Electric Vehicles

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Abstract. In this new era, transportation vehicles mainly uses non renewable primary energy - fossil fuels. In order to avoid energy shortages, electric vehicles using clean energy have emerged. New electric vehicles require fixed charging stations for charging, as traditional technologies such as fixed charging stations cannot be charged on the move and have longer charging cycles, acquire high equipment and environmental requirements, and require manual intervention, resulting in higher costs. Therefore, people urgently need new ways and mechanisms to optimize the charging process, reduce human intervention, and make the charging process safer, automated, and intelligent. Wireless charging WPT technology has just made up for many shortcomings of traditional charging stations, and can achieve high-speed and mobile charging. This article provides an overview of the technologies and principles applied in wireless charging of electric vehicles, as well as a comparison of different wireless charging technologies and their possible future development directions.

Keywords: Wireless power transmission, electric vehicles, induction, laser, capacitive, optical, dynamic, charging.

1. Introduction

To confront the upcoming shortage of fossil fuel in recent years, electric vehicles have been used widely in the 21th century as a kind of new transportation. Unlike previous fuel powered vehicles, electric vehicles are powered by on-board power sources and use electric motors to drive the vehicle forward, which will reduce various greenhouse gas emissions. Relevant data research can support this viewpoint [1, 2]. According to count, in 2020, the total carbon emissions from the life cycle of China's passenger car fleet were approximately 670 million tCO2e, of which the fuel cycle accounted for 74%. The vast majority of carbon emissions generated during the fuel cycle come from gasoline vehicles, accounting for 98% [3].

Although new resource vehicles can reduce green house air emission and are more affordable compared to most fuel powered vehicles, most drivers still prefer to purchase fuel powered vehicles because they are mostly concerned about the various difficulties caused by insufficient battery capacity or inconvenient charging of electric vehicles, with long charging time and safety being the main issues. In our country, we put vehicle and ac charging together to charge the electric car. The main charge modes are these:

Slow charging: Use portable charging devices equipped with the vehicle for charging, which can be powered by a household power source or a dedicated charging station. The charging current is generally around 16-32A, and can be DC or two-phase AC or three-phase AC. Therefore, the charging time is 5-8 hours depending on the capacity of the battery pack.

Fast charging: By directly charging the battery with high current through an off board charger, the battery can be charged to around 80% of its capacity in a short period of time, hence it is also known as emergency charging. The representative of the fast charging mode is the Tesla Supercharging Station. The current and voltage of the fast charging mode are generally between 150-400A and 200-750V, and the charging power is greater than 50kW.

Fast change: Also called mechanic charging, in addition to conventional direct vehicle charging, the battery can also be charged by replacing the power battery. When the power battery runs out of charge, replace the low charged battery pack with a fully charged one.

But shortcomings pf these ways are obviously too. Among them, slow charging cycles are longer, fast charging safety is lower, and fast swapping requires unified battery specifications from various manufacturers, all of which cannot meet the needs of certain drivers. Moreover, the current popular wired charging technology has potential safety issues and high requirements, making wireless power transmission (WPT) technology a more excellent choice. Unlike traditional wired transmission, WPT technology greatly reduces the risks during the transmission process and is more convenient and convenient. Traditional wired charging requires carrying cables and having extremely high current flow during charging, which is very unfavorable in harsh weather such as thunderstorms. Wireless power transmission technology greatly avoids this risk and is an excellent skill for simpler and safer battery charging. It does not use wired electrical contacts that may cause unnecessary sparks or even provide dangerous current to users, and does not require frequent cable plugging and unplugging, Replacing the charging gun, when transmitting power from the source to the battery or other loads, a strong electromagnetic field (EMF) will occur. It can achieve charging of mobile devices, avoiding tedious charging processes and long waiting times. It can also intelligently manage charging devices, which is more effortless and effortless. These advantages are reasons why people choose electric vehicles. From now, the technology of WPT are used in Implantable medical power supply, household appliances and so on.

When using the technology of WPT need to consider these limitation:

The magnetic field strength is inversely proportional to the cube of the distance between the transmitter and receiver, resulting in very low efficiency over long distances

Personnel safety is a significant limitation, as prolonged exposure to magnetic fields can cause significant harm to human bodies

Each load requires overload protection as a current limiter

Load protection is extremely difficult

The principle of WPT technology and power transformer is very similar, and to achieve WPT technology, two components are required. The first is the transmitter, which uses a circuit to convert current into the optimal frequency and is connected to a coil that generates a magnetic field. The second component is the receiver, and the coil is used to capture the generated magnetic field. WPT technology can be roughly divided into four types: inductive coupling, resonant inductive coupling, microwave power transmission, and laser, as shown in Fig. 1 [4,5].

This passage mainly introduce the background of the technology of WPT, the development of technology, the comparation between different WPT technologies, the problem and future development.

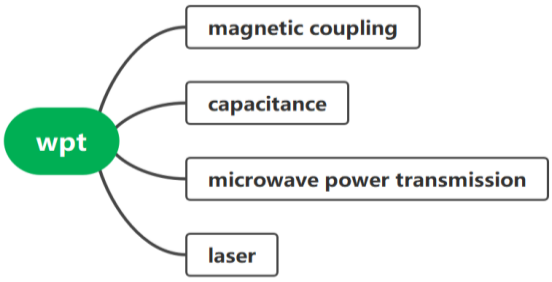


Fig. 1 Different types of wireless charging technologies [4]

2. Different Wireless Charging Technologies

2.1. Magnetic Coupling

Also known as magnetic coupling wireless energy transmission, it is a technology that transfers energy from one device to another by establishing a magnetic field. It mainly relies on establishing a resonant magnetic field between two devices to transmit energy. This technology typically uses two coils, one is the transmitting coil and the other is the receiving coil. Passing alternating current through

the transmitting coil will generate an alternating magnetic field. Resonance can be achieved by adjusting the inductance and capacitance. The transmitter converts 50Hz alternating current into a frequency suitable for magnetic coupling and generates a changing magnetic field through the coil. The receiver captures this magnetic field through a coil and generates electromotive force between its terminals, thereby achieving wireless transmission of electricity. However, the parameters of inductance and capacitance need to be strictly controlled and carefully calculated. When the frequency matches the resonant frequency, the receiving coil will be induced to generate a current, thereby achieving energy transfer.

Through the different ways of the magnetic field correspondent, the technology of WPT can be divided to 2 main different ways:

Inductive coupling and resonant inductive coupling.

Inductive coupling: This technology mainly uses in short distance transformation, because it depends on the magnetic field between two coils transmits electricity. When the current pass through the coils, it will set up a variant magnetic field, this magnetic field induces the electromotive force in the receiver coil, thereby achieving wireless transmission of electricity.

Resonant inductive coupling: This technology always uses in long distance transformation and applications with high transmission efficiency. It achieves wireless transmission of electricity by establishing a resonant circuit between the receiver and transmitter, allowing the magnetic field to transmit between the two coils. This technology can transmit electricity more effectively because it is based on the principle of magnetic resonance and can reduce energy loss during transmission,

Through change the strength of the current through the coils could control the energy of transmission so that control power, avoid of the waste of energy and heat. As shown in the fig2 is the principle of the magnetic coupling.

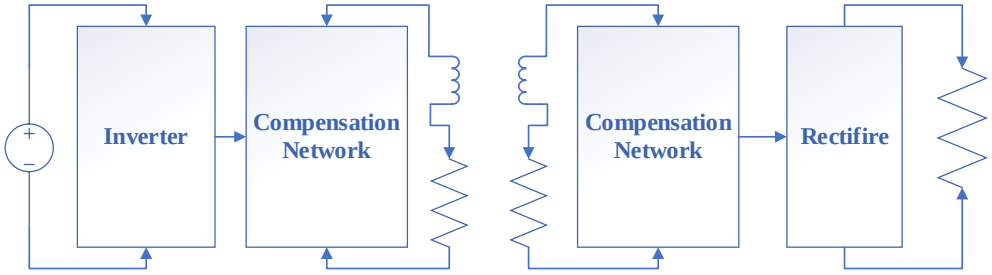


Fig. 2 The principle of magnetic coupling [4].

2.2. Capacitance

Different with the magnetic coupling, mainly depends on the electric field. The system of transmission include the transmitting electrode and the receiving electrode establish an alternating electric field around them by applying an alternating voltage, and the receiving electrode extracts electrical energy from the induced electric field. Electric energy can be directly transmitted to the receiving end without the conversion of inductance, resistance, and capacitance components, resulting in higher efficiency.

The working principle of this technology is as shown in the Fig. 3 is the principle of the capacitance). The transmitting end: apply a certain frequency of a certain ac current through the electric board On the two plates of the emission capacitor, an electric field is formed between the plates, and the intensity of the electric field varies with the distance between the plates. The receiving end: charge is also induced on the two plates of the receiving capacitor, and the amount of charge depends on the coupling coefficient between the two capacitors and the frequency and amplitude of the alternating current. By adjusting the position and distance of the receiving capacitor, it is possible to receive the transmitted signal and effectively transmit electrical energy.

But it may limited by the polarity of the electrode and its figure. This technology also requires capacitor matching to determine the resonance frequency and improve energy transfer efficiency. The power can also be controlled by adjusting the voltage on the emission electrode. The size of the

electric field decreases inversely with the square of the distance, making it suitable for applications with specific shape objects over shorter distances. The shape of the object greatly affects transmission efficiency.

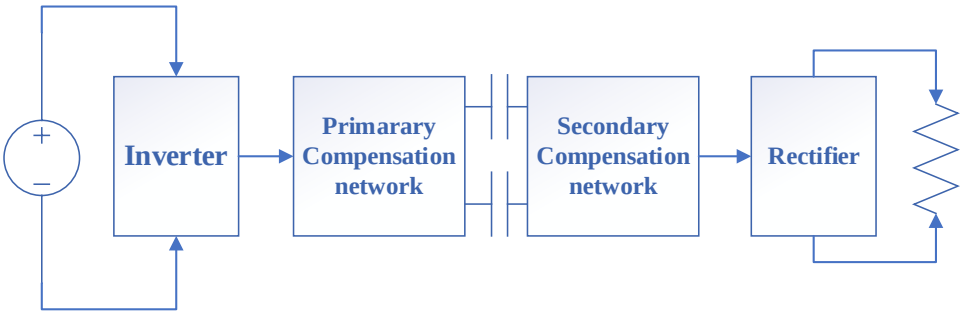


Fig 3. The principle of capacitance [5].

2.3. Microwave Power Transmission

This technology uses the signal to transfer energy, it can transfer in a long distance. The principle is to use microwave signals serve as carriers to transmit energy, and the transmitting end converts electrical energy into microwave signals through microwave antennas, transmitting the microwave signals to the receiving end. At the receiving end, the microwave signal is recycled and converted into electrical energy.

The procedure of this technology is:

Transmitting end: Converts electrical energy into microwave, usually using a power amplifier to amplify the microwave signal to a sufficient power level, and then transmits it through an antenna system.

Transmission path: Microwave is transmitted in free space and is affected by the atmosphere, clouds, and other obstacles, so precise orientation and tracking are required.

Receiving end: Using an antenna system to receive microwaves and convert them into electrical energy, usually using a rectifier to convert microwaves into direct current.

Microwave power transmission typically operates in the RF frequency band, with a frequency range typically between 300MHz and 300GHz. The commonly used frequencies include 2.4GHz and 5.8GHz. Choosing an appropriate microwave frequency can ensure a balance between transmission efficiency and distance. The most important aspect of this technology is the design of the transmitting and receiving antennas, which requires precise calculations. By using waveform beam forming technology, microwave energy can be focused in a fixed direction to reduce losses. However, it is important to pay attention to the radiation effects of microwaves on humans and control them within a safe range. The efficiency of transmission will decrease with the increase of distance, although long-distance energy transmission can be achieved, economic efficiency should be considered. Microwave based WPT technology can be applied to different scenarios and needs, including mobile device charging, electric vehicle charging, solar power stations, and so on. As shown in the Fig. 4 is the principle of the microwave transmission.

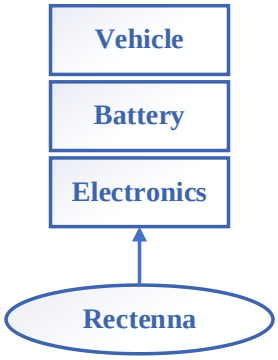


Fig 4. The principle of the microwave transmission [5].

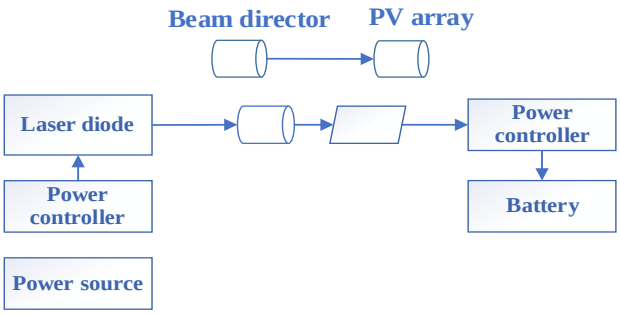


Fig 5. The principle of the laser [5].

2.4. Laser

A technology that utilizes laser beams to transmit energy. By transmitting energy from the laser source to the receiver, efficient and long-distance wireless energy transmission can be achieved. Laser wireless energy transmission is based on the energy transfer of photons. The laser generates a high intensity laser beam, which is focused on the receiver. The energy of photons is absorbed by the receiver and then converted into electrical energy for use by equipment. In order to achieve efficient energy transmission over long distances, a focused beam is required. By using optical components such as lenses or mirrors, laser beams can be focused on smaller areas, thereby improving transmission efficiency. Designing an effective laser transmission system requires consideration of the selection and layout of optical components to ensure that the laser can maintain high energy density and stable beam quality during transmission. As shown in the Fig. 5 is the principle of the laser.

The workflow of laser WPT technology is as follows:

Emitter: Converts electrical energy into laser, typically using a laser to emit laser light. After the laser generates the laser, the laser beam is compressed and focused through an optical system, forming a high energy density beam.

Transmission path: Laser is transmitted in free space and is affected by the atmosphere, clouds, and other obstacles, thus requiring precise orientation and tracking.

Receiving end: Use an optical system to receive laser and convert it into electrical energy. Photovoltaic cells are usually used to convert lasers into electrical energy, and other types of receivers can also be used.

Laser wireless energy transmission can achieve efficient energy transmission over long distances. However, the transmission distance is still affected by atmospheric absorption, scattering, and other factors, so these factors need to be considered in design. Due to the high energy density of laser beams, safety needs to be strictly considered when using lasers for energy transmission. Measures must be taken to ensure that lasers do not cause harm to humans or the environment. Factors such as humidity and particulate matter in the atmosphere may affect the transmission efficiency of laser beams. These factors need to be considered in system design and may require the use of adaptive techniques to adjust the transmission parameters of the beam. Laser WPT technology can be applied to different scenarios and needs, including the charging of small electronic devices, remote operation of industrial equipment, solar power plants, and so on.

Table 1. Comparison of different wireless charging technologies

	Advantages	Disadvantages
Magnetic coupling	High transmission efficiency	Heating needs to be placed in a specific position; Short distance
capacitance	High transmission efficiency; Multi devices charging	The volume of charging system is bigger; Short distance
Microwave transmission	Long distance	May cause hurt to human health; Low transmission efficiency
laser	Long distance	Expensive; Low transmission efficiency

3. Analysis and Comparison

The advantages and disadvantages of different types of Wireless charging technology is shown in Table 1 [6].

3.1. Magnetic Coupling

This technology uses resonate coupling to transmit the energy of high frequency, when the state of the resonate coupling, it can complete long distance transmission, it would not limited by the choice of wires and locations. The core of this technology is the mechanism of electrical coupling requires different structural designs and is relatively complex according to different application scenarios and purposes. Continuous optimization is needed to improve the energy and efficiency of transmission. It has high transmission power. And it is currently the most mature charging technology for electric vehicles, which can transmit energy while moving.

3.2. Capacitance

The capacitor in capacitance WPT technology is connected to the battery to achieve wireless charging. It has an obvious advantage that it can transfer energy during the situation of metal shielding meanwhile the cheaper cost because it do not need ferrite. It has a high transmission power. But the disturb between different devices may exist.

3.3. Microwave Power

The process of increasing the power of microwaves and utilizing rectifying antennas to absorb high-energy microwaves, directly supplying power to the load without the need for wires is achieved. Long distance power transmission can be completed. However, in the process of long-distance transmission, high power rectifier antennas may encounter difficulties in research and development, making it difficult to implement. It is also necessary to ensure that other daily activities are not disturbed, such as signals for daily communication, high-altitude vehicles, and organisms. And due to the need for a rectifying antenna, energy transfer cannot be achieved during movement. The charging efficiency is low, and the high electromagnetic radiation generated may affect physical health.

3.4. Laser

Be directed against a certain frequency laser's energy collection to transfer electronics. A diode is used to generate light waves, which ultimately reach the receiver through a beam splitter. This method has relatively low power loss, but the laser will attenuate through the atmosphere, resulting in lower transmission power and efficiency. The transmission distance is relatively long but cannot be charged on the move, so the cost-effectiveness is not very suitable.

4. Security Issues

4.1. Environment

The technology of WPT has a high requirement of the environment. Some WPT technologies, such as microwave power transmission, requires high-level wind protection measures and metal rust prevention measures, which can also lead to a significant increase in system cost [7].

4.2. Safety of Human Body

The strong electromagnetic field generated by electromagnetic coupling technology can interfere with some small electronic instruments such as pacemakers, and the extremely strong energy may affect the human body. Long term exposure to strong electromagnetic fields can cause health problems and endanger human safety. In order to reduce magnetic field strength, it is necessary to

optimize the design of wireless charging devices, such as using new technologies such as multi coil arrays [8].

4.3. Safety Certification

Some wireless charging systems may be connected to the Internet of Things, and if there are network security vulnerabilities, they may be exploited by hackers to steal data or interfere with control system intrusion. Attackers may invade the control system of electric vehicles through networks or physical interfaces, manipulate the vehicle's core functions such as acceleration, braking, and steering, leading to vehicle loss of control and accidents. Data leakage: Electric vehicles collect a large amount of sensitive data about user driving habits and location information, and attackers may steal this data through the internet, thereby infringing on user privacy and security [9,10].

4.4. Compatibility

The devices used in different wireless charging technologies are not compatible with each other, and improper use of the devices may lead to device damage and unstable charging. Incompatible device charging may generate electric sparks and cause a fire.

5. Materials and Future improvement Directions

5.1. Materials

At present, the main wireless charging technology used in the market is magnetic coupling WPT, which mainly uses materials such as ferrite and resonance coils. Among them, ferrite is mainly used to make chargers and devices, which are the magnet parts of transmitters and receivers. Resonant coils are used to emit and receive electromagnetic energy to ensure charging without cables.

5.2. Improvement Direction

5.2.1 Improvements of charging efficiency

Currently, all four WPT technologies have a certain degree of energy loss in the process of energy transfer, extending charging time. Technology can be improved by improving coil structure and reducing future energy waste [11].

5.2.2 Adaptability to distance and location

Currently, more efficient charging methods such as magnetic coupling and capacitance cannot achieve long-distance power transmission. Our main goal in future research is to study how to achieve efficient charging without being limited by terrain and distance [12,13].

5.2.3 Multi device charging:

Develop WPT technology to connect multiple devices that require electricity into a single power supply system, and use one device to supply multiple users, improving power supply efficiency and saving economic losses.

5.2.4 Mobility and portability

The main problem faced by electric vehicles nowadays is that they cannot meet people's travel needs due to long charging times. According to research, "pure electric vehicles only carry power batteries and generally require long-term charging to drive. Only 21.88% of 1005 anonymous online users surveyed accepted pure electric vehicles. Therefore, if power supply can be achieved in long-distance mobility and the volume of power supply equipment can be reduced, it will further increase the market share of electric vehicles [14,15].

6. Conclusion

This article mainly introduces the relevant background of electric vehicles and the principles and characteristics of several wireless charging technologies, compares their advantages and disadvantages, and analyzes the safety of wireless charging technology. Through comparison, it can be seen that these wireless charging technologies have their own advantages and disadvantages. However, the room magnetic coupling wireless charging, which is currently the most widely accepted by the market and scientific forefront, has high charging efficiency and mature technology, and can be charged while moving, solving a major challenge of wasting time when charging at a fixed charging station. And wireless charging technology does not require too much human intervention, achieving automated charging, reducing charging time and reducing wear and tear on car parts due to the lack of cable insertion and removal, increasing the working life of cars and related equipment, and ensuring the cleanliness of the charging environment. Overall, compared to wired charging, it is a more environmentally friendly and convenient technology. There is great development and research space. In the future, it will be widely applied in smart homes, medical technology, and aerospace, making significant contributions to human progress.

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