

# Wireless Power Transfer and Optimisation Path for Electric Vehicles

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**Abstract.** Electric vehicles (EVs) are becoming more and more popular in various fields because they have many advantages over traditional petrol vehicles. However, as EVs move towards intelligence, the limitations of traditional wired Power are exposed, not only do you need to manually plug and unplug the charging gun, but also are limited by the geographic location of the charging piles, range anxiety and lack of charging convenience are always the core issues affecting the user experience, and restricting the industry from making further breakthroughs. In this context, wireless power transfer (WPT) has become a key direction to solve the pain points. This paper focuses on WPT for EVs and systematically explains the principle of WPT (mainly electromagnetic induction and electromagnetic resonance). At the same time, it puts forward the core challenges faced by new energy electric vehicles, including improving WPT efficiency, reducing transmission loss, lowering cost, and finally provides some optimization directions for the future. With the advantages of convenience and compatibility of wireless power, it is expected to become the mainstream charging method for EVs in the future, and the research content provides scientific reference for the development of the EV industry.

**Keywords:** Wireless power transfer, Energy vehicle, Energy vehicle market, Magnetic coupling coil.

## 1. Introduction

Faraday in 1831 experiments found that when the magnetic flux in the conductor circuit changes, the circuit will produce induced electromotive force (i.e. "electromagnetic induction"), this discovery is summarized as the law of electromagnetic induction, which has become one of the core laws of electromagnetism. Porsche developed an 11kw WPT mat for electric vehicles, with a charging efficiency of about 90 per cent, supporting extreme environments of minus 40°C to 50°C, and equipped with foreign object detection and remote-control functions. Hangzhou Xiaoshan Asian Games Village built the first WPT station with integrated V2G function, equipped with 8 parking spaces. Seoul, South Korea, has applied dynamic WPT on some of its bus routes to improve operational efficiency and reduce carbon emissions. With the rapid growth of the EV industry, power transfer has become a key constraint to its popularity. Traditional plug-in charging relies on fixed charging piles, cable wear and tear, inconvenient operation and other issues, while WPT through non-physical contact to achieve energy transfer, with good convenience and scene compatibility, become the focus of the industry to break through the key direction. At present, EVs WPT mainly includes fast charging, slow charging, WPT and power exchange mode, each way in the efficiency and scene adaptability of the significant differences. Fast charging can be fully charged within 15 minutes to 1 hour, but it damages the battery life; slow charging is cheap but time-consuming, and is suitable for home scenarios; power exchange mode can quickly replenish energy, but the scenarios are limited and the cost is high; WPT is based on electromagnetic induction or magnetic resonance technology, and it is considered to be the most promising mainstream solution in the future [1]. This paper provides scientific ideas for the study of electric vehicle WPT, is committed to solving the feasibility of EVs WPT, reduce global energy pollution emissions, provide effective escort to the future of intelligent travel, and is committed to breakthroughs in electric vehicle WPT problems.

## **2. Overview of Wireless Power Transfer for EVs**

Electric vehicle charging methods are divided into two categories: wired charging and WPT. Wired charging is divided into slow charging and fast charging according to the charging speed: slow charging is based on alternating current (AC) as energy, which is mainly used in the home or workplace, and the charging time is longer; fast charging is based on direct current (DC), which can replenish a large amount of electricity for the vehicle in a short period of time, and is mostly seen in public charging scenarios [2]. Compared with wired charging, the core advantage of WPT is that it breaks through the limitation of physical connection. On the one hand, there is no need to rely on fixed charging piles, alleviating the problem of an insufficient number of charging piles; on the other hand, it avoids the cumbersome operation and cable wear and tear risk of plug-in charging, and improves the user experience and safety. In addition, the popularity of WPT is expected to promote the reduction of the battery volume of electric vehicles - the current electric vehicles to ensure range, the battery is designed to be large and bulky, not only to increase the cost, but also to enhance the risk of collision accidents, and the convenience of WPT to reduce the dependence on the battery storage capacity, to achieve the lightweight and cost optimisation of the vehicle.

## **3. The Basic Principle and Application of Wireless Power Transfer for EVs**

The core of WPT is through electromagnetic induction or electromagnetic wave transmission, to achieve the electric energy from the transmitter (power supply) to the receiver (power equipment) contactless transmission, the essence is "electric energy - magnetic field energy - electric energy" conversion and coupling process. Currently, the mainstream transfer is divided into electromagnetic induction and magnetic resonance type two.

Electromagnetic induction based on Faraday's law of electromagnetic induction, its working mechanism is the transmitting end through the alternating power supply so that the transmitting coil generates alternating current, and then form an alternating magnetic field; when the receiving coil is in the magnetic field, it will inductively generate an alternating current, which will be transformed into direct current after rectification, voltage regulator and other circuits, and then supply power to the car battery. The advantage of this transfer is the high efficiency of close-range energy transmission, within a few centimeters, the efficiency can reach 80% -90%, and the maturity of the transfer is high, and is currently widely used in mobile phone WPT boards and other scenarios. But the shortcomings are also more obvious, on the transmitter coil and receiver coil of the space and alignment accuracy requirements are very high, once the misalignment occurs, the efficiency will be significantly reduced, so it is not applicable to the alignment of the higher requirements of the fault tolerance of the electric vehicle charging scenarios. The magnetic resonance type uses the resonant coupling effect to achieve energy transfer by tuning the transmitting and receiving coils to the same resonant frequency. Specifically, the transmitting coil is fed with alternating current to generate an alternating magnetic field, and the receiving coil absorbs the energy efficiently due to its resonance characteristics. Compared with the electromagnetic induction type, the advantage of magnetic resonance type is reflected in two aspects, one is the transmission distance is farther, up to tens of centimeters, to meet the demand for the distance between the chassis of the electric vehicle and the transmitter on the ground; the second is the lower requirements for the accuracy of the alignment of the coils, the resistance to offset is stronger, even if the vehicle parking there is a certain degree of deviation, but still be able to maintain a stable energy transmission. However, its energy transfer efficiency is slightly lower, about 70%-85% [3], which is suitable for dynamic charging of electric vehicles (such as charging while driving) and other scenarios that require stable transmission within a certain distance.

## **4. Current Shortcomings of iVs**

### **4.1. High Cost and Difficult to Popularize**

Electric vehicle WPT industry is still in the early stage of exploration, according to the trend of the next few years most of the car companies or in the models equipped with the technology; the current core problem for the cost, power transfer upgrades and functionality to improve the high investment in the early stage, although the long-term scale of the cost can be reduced, but the current economic environment of high investment impediments are significant, the cost of problems through the whole chain. From technology research and development to hardware production, to infrastructure construction, the initial investment is significantly higher than the traditional charging method. For example, the transmitter coil and receiver coil need to use high permeability materials (such as nanocrystalline alloys) and high conductivity materials, manufacturing costs are much higher than the traditional charging interface; in order to achieve accurate alignment and efficiency optimisation, but also need to be equipped with high-precision sensors and intelligent control systems, further increasing the cost of a single system. Although theoretically scale production can reduce costs, the current EV WPT market penetration rate is low, mass production scale is limited, and short-term cost is difficult to significantly reduce. In the current economic environment, high investment has become the main obstacle for car companies and infrastructure operators to promote the technology.

### **4.2. Technology Maturity to Be Improved**

In addition to cost, there is still room for optimisation at the technical level. The efficiency of magnetic coils is not stable enough, and is affected by factors such as coil alignment accuracy, transmission distance, and ambient temperature, resulting in large fluctuations in energy transmission efficiency. For example, the efficiency of the magnetic resonance type will plummet when the distance exceeds the threshold or the coil is seriously misaligned; a low temperature environment will increase the resistance of the coil, further aggravating the energy loss [4]. The limitations of scene adaptation are also very limited, such as dynamic charging (e.g., charging while the vehicle is in motion), the relative position of the coil changes in real time, which is prone to impedance mismatch, resulting in energy reflection loss, and the current efficiency in this scenario is still difficult to meet the practical requirements.

## **5. Future Optimisation Direction of Wireless Power Transfer for EVs**

In view of the current technical bottlenecks, the future can be optimised in three dimensions: electromagnetic coupling efficiency, circuit conversion loss, and dynamic scene adaptation.

### **5.1. Enhancement of Electromagnetic Coupling Efficiency**

Magnetic coupling resonance WPT has become the core path of electric vehicle and industrial mobile equipment power supply due to the advantages of non-contact transmission and strong environmental adaptability, but its energy transfer efficiency is limited by the magnetic field coupling link. Studies have shown that the loss in this link accounts for 40%~65% of the total loss of the system, and magnetic leakage and coupling instability are the core constraints [4][5]. Leakage loss originates from the spatial diffusion characteristics of the magnetic field, only 60%~70% of the magnetic field generated by the alternating current of the transmitting coil can be captured by the receiving coil, and the remaining part of the radiation to the ground, metal components and other environments to form the "ineffective magnetic field", and the loss with the distance of the transmission is a non-linear growth, the transmission distance of 10cm leakage loss accounted for 25.3%, increasing to 25.3%. 25.3% when the transmission distance is 10cm, and 41.7% when it is increased to 20cm. Meanwhile, increasing the number of coils turn from 5 to 10 can reduce the leakage loss by 8.2%, but it is necessary to balance the DC resistance loss of the coil caused by the high number of turns [6][7]. The unstable coupling loss is caused by dynamic disturbances. In the charging scenario of an electric

vehicle, the coil coupling coefficient plummets from 0.8 to less than 0.3 due to parking offset (lateral  $\pm 150\text{mm}$ , longitudinal  $\pm 50\text{mm}$ ), coil tilting due to vibration of the chassis (tilt  $>5^\circ$ ), and the proximity of metallic foreign objects, which causes a significant drop in the efficiency [8]. In view of the above problems, the optimisation should focus on the improvement of electromagnetic coupling efficiency. Hardware level adopts  $4\times 4$  multi-group coil array, through the intelligent unit to adjust the current phase to achieve the dynamic convergence of the magnetic field, compared with a single coil to reduce the leakage loss by 30%, with nanocrystalline alloy cores (10-150kHz high-frequency conditions hysteresis loss is 30% lower than the traditional ferrite) constraints on the magnetic field path [5][6]; structure and technology level, the transmitter coil design for the rectangular or shaped structure of the vehicle chassis, effective coupling efficiency [8]. At the structural and technological level, the transmitter coil is designed as a rectangular or shaped structure to fit the chassis of the vehicle, which enlarges the effective coupling area by about 25%, combines the wide-range alignment technology of infrared positioning and magnetic field sensing, and corrects the offset through the motorized guide or current adjustment to ensure the coupling coefficient is stable at more than 0.6. The study shows that the optimised solution can improve the system energy efficiency by 15%~20%, and the positioning technology based on 3U-type auxiliary coils can achieve  $\pm 10\text{mm}$  alignment accuracy, which significantly reduces the positional deviation loss [6][9]. These technological improvements provide key support for the industrialization of magnetic field coupling link systems, especially in the dynamic charging scenario of electric vehicles, where excellent stability and efficiency characteristics are demonstrated [10].

## 5.2. Control Circuit Conversion Loss

Electricity from the grid to the battery needs to be converted many times, the switching and conduction losses of inverters, rectifiers and other devices are the main source of energy waste. The use of wide-band semiconductor devices and optimised topology can effectively solve this problem. Specifically, the introduction of GaN (Gallium Nitride), SiC (Silicon Carbide) and other wide-band semiconductor materials such as power devices, which have excellent high-frequency characteristics and low on-resistance, GaN devices can reach 5-10 times the switching frequency of the traditional silicon (Si) devices, and in the same rated current on-resistance of only 1/5 of the Si MOSFETs; SiC MOSFETs in the high temperature (150-200 degrees Celsius) under the conditions of on-resistance and switching losses. SiC MOSFETs maintain low conduction loss at high temperatures (150-200°C), and their Joule heat loss is more than 40% lower than that of Si devices of the same specification, which significantly reduces the energy dissipation during the device operation [11]. Optimised topology and soft-switching topology enable the device to switch at zero voltage or zero current, which reduces energy wastage during the conversion process and improves the conversion efficiency of the circuit to more than 80% [12].

## 5.3. Optimising Energy Loss in Dynamic Scenes

In the magnetically coupled resonant WPT system, dynamic situations such as vehicle travelling, parking offset, or battery load changes can easily cause impedance mismatch, which in turn generates energy reflection loss and lowers the system efficiency. In this regard, we can build a "monitoring - adjustment" closed-loop system through the sensor real-time capture coil position, circuit current and voltage and other key parameters, and then use intelligent algorithms to quickly adjust the capacitance, inductance and other components in the circuit, to achieve dynamic impedance matching, to reduce the waste of energy reflection. In addition, environmental factors will also affect the system performance, such as a low temperature environment, which will make the coil resistance increase, the core performance, resulting in a decrease in the efficiency of energy transfer [4]. Therefore, it is necessary to do environmental adaptive design, the coil and core temperature control module, in low temperature and other extreme environments to maintain their stability, to ensure that the energy transfer efficiency will not decline significantly!

## 6. Conclusion

WPT for new EVs has become an important direction to solve charging problems by virtue of convenience, safety and scene compatibility. Its core principle is based on electromagnetic induction and magnetic resonance technology, although currently facing high cost, efficiency and stability challenges, but through the optimisation of coil design, wide bandwidth semiconductor applications, intelligent algorithm adaptation and other technological innovations, is expected to gradually break through the bottleneck. In the future, as technology matures and scales production to promote, WPT cost will gradually decline, and its penetration in the field of new EVs will continue to improve. At the same time, dynamic charging and other scenarios of technological breakthroughs may reconfigure the energy supply mode of electric vehicles, to promote the industry to a more efficient, more intelligent direction. Vehicle enterprises and research institutions need to continue to focus on core technology innovation, accelerate the commercial application of wireless charging, and provide support for the sustainable development of the EV industry.

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