

# Overview of Wireless Charging Technology Optimization for Electric Vehicles

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**Abstract.** In recent years, electric vehicles (EVs) have attracted wide attention for their clean, energy-saving, quiet operation and high energy efficiency. Wireless charging technology achieves complete electrical isolation between the power supply and the electrical equipment. It not only has the advantages of safety and flexibility but also avoids a series of problems such as charging cable mismatch. It is one of the trends of the future development of electric vehicle power supply technology, but it needs to be further improved in terms of energy loss and safety. This paper first introduces the concept of wireless charging and then elaborates the principle of magnetic coupling charging, which is popular in electric vehicles. Secondly, in view of the energy loss and other problems, the author combs the resonant charging mode, increasing the trunk coil, and other ways to reduce the energy loss. Changing the shape of the motor controller and using synthetic materials to promote heat dissipation and reduce human radiation. Finally, the challenges of wireless charging of electric vehicles are explained, and the future development of electric vehicles is prospected.

**Keywords:** Electric vehicle, wireless charging, optimization.

## 1. Introduction

At present, there are three major types of charging methods in the development of new energy vehicles: wired charging, wireless charging and power change. The advantages of wireless charging technology lie in its convenience and security. However, due to the current insufficient charging efficiency, the technology needs to be broken through.

Wireless charging technology is also known as Wireless Power Transfer technology (WPT). Refers to the use of electromagnetic fields, electromagnetic waves, etc. in physical space distribution or propagation characteristics. Non-wire contact is adopted to achieve power transmission [1]. Dead-zone-free foreign object detection and anti-misalignment auxiliary systems ensure safe and reliable power transfer.

In addition, for the wireless charging scenario of electric vehicles, most literature only considers two-coil resonant wireless charging. This paper introduces the three-coil resonant charging mode, which has a great positive effect on the increase of transmission distance. In terms of safety, if the system loss is too large, it will lead to serious heating of the wireless charging system, accelerate the aging degree of the system, and even lead to excessive system temperature and damage. Therefore, this paper will optimize and analyze the wireless charging of electric vehicles from the aspects of charging mode, energy loss and safety.

## 2. Basic Principles of Wireless Charging for Electric Vehicles

There are two common wireless charging methods for electric vehicles: magnetic field coupling and electromagnetic induction. Although the electromagnetic induction wireless charging technology has some mature standards, compared with the magnetic coupling wireless charging, there are shortcomings such as limited charging distance, high alignment requirements and faster efficiency decline with the increase of distance. Therefore, the magnetic coupling is more widely used.

The magnetic coupled wireless charging system mainly consists of two parts: the transmitter (ground charging board) and the receiver (receiving device at the bottom of the electric vehicle). The transmitting end excites the primary coil by alternating current to produce a changing magnetic field,

and the receiving end secondary coil synchronizes with the magnetic resonance and the transmitting end coil to induce a current at the receiving end. Through the rectifier, the current is stored in the electric vehicle battery, so that the static charging process of the electric vehicle is completed.

The wireless charging system for electric vehicles is shown in Fig1. Through the transmitter coil installed on the ground, the high-frequency alternating current flows through this coil, generating a high-frequency magnetic field, which is installed in the receiving end of the car to receive energy. C1 and C2 in the figure represent the transmitting capacitance and the receiving capacitance. L1 and L2 represent the primary coil and secondary coil of the coupling coil, and M represents the mutual inductance coefficient of the two coils.

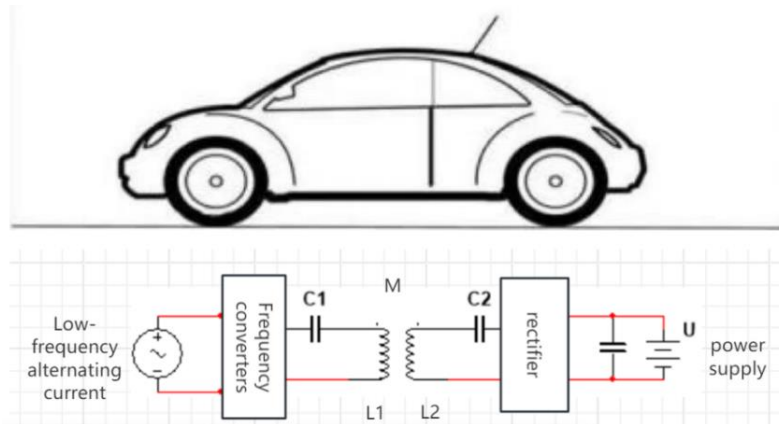


**Fig. 1** Schematic diagram of wireless charging for electric vehicles

### 3. Electric Vehicle Wireless Charging Optimization Analysis

#### 3.1. Optimization of Charging Mode

Compared with the magnetic coupling type and electric field coupling type, the optimal transmission distance is centimeters [2], and the resonant WPT system can reach the meter level, so it is more suitable for wireless charging of electric vehicles. The principle is shown in Fig 2. The device can be passed between the primary and secondary side coils by electromagnetic induction law, and then rectified to the load to realize a non-contact power supply.

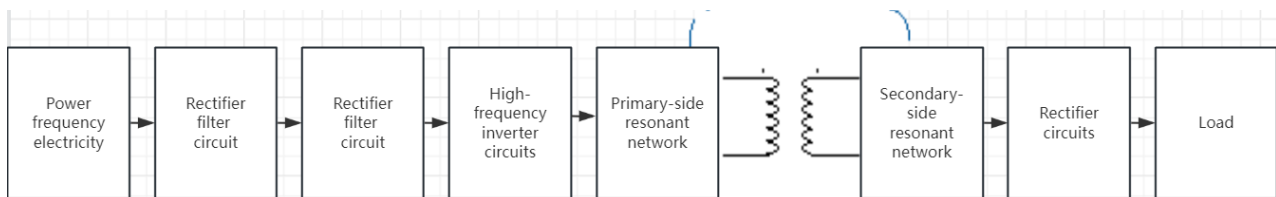


**Fig. 2** Schematic diagram of magnetically coupled resonant type

Wang Lei introduced the transmission efficiency formula (formula 1) and transmission power formula (formula 2) by modeling the two-coil resonance system and the three-coil resonance system (Fig3). It is concluded that under the condition of loop resonance, the transmission power and transmission efficiency are better than the transmission effect under the condition of non-resonance [3].

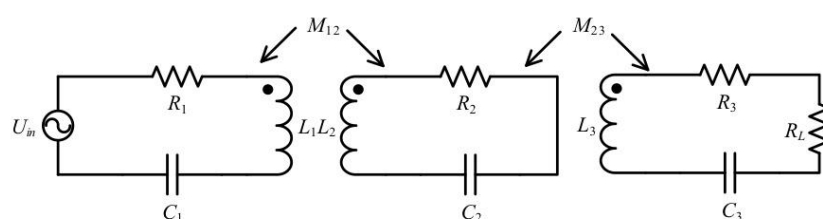


**Fig. 3** Circuit diagram of three-coil resonant system

$$\eta = \frac{(wM_{12})^2 (wM_{23})^2 R_L}{R_1 \left[ R_2 (R_3 + R_L) + (wM_{23})^2 \right]^2 + (wM_{12})^2 (R_3 + R_L) \left[ (wM_{23})^2 + R_2 (R_3 + R_L) \right]} \quad (1)$$

$$P_0 = \frac{(wM_{12})^2 (wM_{23})^2 U_{in}^2 R_L}{\left\{ R_1 \left[ R_2 (R_3 + R_L) + (wM_{23})^2 \right] + (wM_{12})^2 (R_3 + R_L) \right\}^2} \quad (2)$$

### 3.2. Optimization of Energy Loss

For wireless charging systems, energy loss increases with the increase in charging distance. In order to improve the transmission distance and efficiency, reducing the energy loss has also become the focus of research. Professor Marin Soljacic and his team in the United States proposed and demonstrated the "resonance magnetic coupling" technology in their research, which uses trunk coils to enhance the efficiency and distance of energy transmission [4]. Nenghong Xia et al. proposed an L-shaped trunk coil structure and studied the system transmission characteristics of three typical receiving coil positions. The relative position of the trunk coil and the transmitting coil was analyzed and optimized, thereby improving the transmission efficiency of the system [5]. Sun T describes a dual trunk coil structure in which the transmitting coil is in the same plane as one trunk coil and the receiving coil is coplanar with the other trunk coil. Through the four-coil design, the structure realizes the switching of the constant voltage and constant current output modes of the system to ensure a high transmission efficiency [6]. Liu X describes a new two-intermediate resonator radio Energy Transfer (WPT) system consisting of four coils: a sending coil, a receiving coil, and two trunk coils. A coupling coefficient adjustment scheme is also proposed to maximize the power transmission efficiency. The experimental results show that when the transmission distance is more than four times the diameter of the sending coil, the actual transmission efficiency of the system reaches more than 70% [7]. Sun Yue studied trunk coils with different coaxial planes and proposed a method to maximize the transmission efficiency of the system by optimizing the position of the trunk coil when the position of the transmitting coil and the receiving coil were known [8].

### 3.3. Security Optimization

#### 3.3.1. Heat dissipation optimization

Overheating of wireless charging coils can lead to reduced system efficiency, increased energy loss, accelerated component aging, and even possible safety hazards such as short circuits or fires. Therefore, coil thermal analysis is an important content in the design of electric vehicle wireless charging systems. Wen C used ANALYSIS software to build a coil model to simulate the temperature distribution on the coil surface when the electric vehicle wireless charging system is in normal use. Through simulation and comparison results, it is concluded that it is more appropriate to choose copper to make coils when charging 30 minutes combined with material cost [9].

The motor controller is the core equipment of electric vehicles, and their control performance has a decisive impact on the overall performance of electric vehicles. According to the actual three-dimensional model, Li Qinfeng established the thermal simulation model of the motor controller. He explored the influence of the shape and number of the substrate and fins on the heat dissipation performance and concluded that the heat dissipation performance of the staggered ribbed column radiator was better [10]. The author thinks that a layer of silver on copper wire based on the copper coil can further improve the conductivity and reduce the resistance. By reducing the heat caused by resistance or by using a hollow conductor (such as a hollow copper pipe) that allows the coolant to pass through, the heat can be effectively taken away.

#### 3.3.2. Optimization to reduce radiation

Wireless charging of electric vehicles will expose the human body to radiation, which will affect the human body. To reduce the radiation effect, shielding measures are needed in practice. The

electromagnetic radiation shielding of electric vehicle wireless charging systems can be divided into active shielding and passive shielding [11]. Active shielding affects system efficiency. Passive shielding mainly uses ferromagnetic materials to provide a new conduction path for magnetic flux or uses low-permeability metal conductor materials (aluminum, copper, etc.) to generate a magnetic field opposite to magnetic leakage. Campi T's study of this shielding method shows that the use of ferromagnetic materials can reduce magnetic field leakage on the one hand. On the other hand, coil self-inductance and mutual inductance can be increased, coupling performance can be enhanced, and system efficiency can be improved slightly [12].

### 3.4. Systematic Analysis of Optimization Methods

In terms of energy transmission, the resonant frequency of the trunk coil has a great influence on energy transmission when the three-coil structure magnetic coupling wireless charging is used. In the process of power transmission, the temperature of the coil will change the inductance value and thus the resonant frequency. Therefore, the temperature compensation element can be used to stabilize the performance of the coil to reduce the influence of the resonant frequency caused by temperature. In terms of safety, silver plating on the basis of copper as the coil material or hollow copper tubes is used to increase the coolant or change the shape of the motor controller. For human radiation, few scholars have conducted in-depth research on synthetic materials. It is possible that some synthetic conductive materials can greatly reduce radiation, but they have not yet been found to provide security for human safety. In the future, these technologies are expected to make electric vehicles more convenient and efficient into people's lives, bringing people a more intelligent and green travel experience. The use of ferromagnetic materials can form a shielding layer to reduce the radiation to the human body.

## 4. Challenges and Prospects

According to the NEW ALTAS report, the wireless charging technology of cars has been a breakthrough in research. According to the team, the wireless charging pad can transmit power to the car with an output power of 100kW, which can increase the battery charge status by 50% in 20 minutes. However, the domestic car wireless charging technology is far from the climate. The key factor restricting the development of wireless charging technology is power. Taking Hongqi E-HS9 as an example, it is equipped with wireless charging technology with a maximum transmission power of 10kW, which is only faster than home charging slow pile. Some models can only achieve 3.2kW system charging power, which is not convenient at all. In addition, charging efficiency and charging safety are also issues that car companies must consider. With current technology, car charging technology is not 100% efficient. The mainstream charging scheme based on the resonant magnetic induction coupling principle has a charging efficiency of about 90%, and the new technology will also have an energy loss of about 6%. Wireless charging of electric vehicles on the road, and the technology for electric vehicles to charge electronic devices, are still a long way off. The realization of these innovations will further change the way we transport and our daily lives, but technological challenges and infrastructure bottlenecks still need to be overcome.

## 5. Conclusion

Magnetically coupled resonant infinite energy transmission shows good characteristics in medium transmission power and transmission distance, which has important theoretical and research value. This paper first briefly introduces the current mode of wireless charging of electric vehicles, then deeply introduces the basic principle of the current mainstream magnetic coupling wireless charging, and summarizes the optimization method of today's scholars by reading a lot of literature.

In terms of charging, magnetic coupling resonant wireless charging is adopted on the basis of magnetic coupling wireless charging. By modeling two-coil resonance and three-coil resonance

charging, scholars can conclude that the transmission power and transmission efficiency under the condition of loop resonance are better than the transmission effect under the condition of non-resonance. In terms of energy loss, the trunk coil is used to increase transmission distance to reduce energy loss and the trunk coil position is optimized to achieve maximum transmission efficiency of the system. In terms of safety, it is optimized on the basis of copper coils, such as silver plating or using hollow copper tubes to add coolant, and changing the arrangement and shape of the electric controller

## References

- [1] ZHANG Xian, BAI Xuening, Sha Lin, Chen Zhixin, Yang Qingxin. Research on Evaluation Method of Interoperability between coils of Different structures of electric vehicle wireless Charging System. Transactions of China Electrotechnical Society, 2020,35(19):4150-4160.
- [2] Peng Jiangwei. Research on Efficiency Optimization of Radio Energy Transmission System for Electric Vehicles Master's Degree Thesis, Northeast Petroleum University,2023.
- [3] Wang L. Master of Magnetic Coupling Resonant Wireless Energy Transmission Technology Research (Dissertation, Harbin Institute of Technology), 2015.
- [4] AndréKursetal., Wireless Power Transfer via Strongly Coupled Magnetic Resonances. Science, 2007, 317: 83-86.
- [5] Xia Nenghong, Zhu Yimin, Cheng Zhiyuan. Design and Optimization of L-shaped wireless Charging Device Based on Vertical trunk coil Structure. Transactions of China Electrotechnical Society, 2019, 34 (13):2671-2678.
- [6] Sun T , Xie X , Li G , et al. A Two-Hop Wireless Power Transfer System With an Efficiency-Enhanced Power Receiver for Motion-Free Capsule Endoscopy Inspection. IEEE Transactions on Biomedical Engineering, 2012, 59 (11):3247-3254.
- [7] Liu X, Wang G. A Novel Wireless Power Transfer System with Double Intermediate Resonant Coils. IEEE Transactions on Industrial Electronics, 2016, 63 (4):2174-2180.
- [8] Sun Yue, Li Yuntao, Ye Zhaohong, et al. Position optimization of trunk coil in three-coil ICPT System [J]. Transactions of China Electrotechnical Society, 2016, 31 (13):164-171.
- [9] Wen, C.; Xu, Q.; Chen, M.; Xiao, Z.; Wen, J.; Luo, Y.; Zhao, X.; Liang, Y.; Liang, K. Thermal Analysis of Coupled Resonant Coils for an Electric Vehicle Wireless Charging System. World Electr. Veh. J. 2022, 13, 133.
- [10] Li Qinfeng. Research on Air-cooled Heat Dissipation Technology of Electric Vehicle Motor Controller [D]. Chongqing University of Technology,2024.
- [11] Zhu Chunbo, Jiang Jinhai, Song Kai, et al. Research progress on key technologies of dynamic wireless charging for electric vehicles. Automation of Electric Power Systems, 2017, 41 (2): 60-65.
- [12] Campi T, Cruciani S, Maradei F, et al. Magnetic shielding design of wireless power transfer systems, 2015 31st International Review of Progress in Applied Computational Electromagnetics (ACES), Williamsburg, 2015: 1-2.