Research on Optimal Design and Practical Application of Electric Vehicle Wireless Charging Technology

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Abstract. Electric vehicles are a further development of wireless charging technology and a promising application area. This method can take into account the user's charging satisfaction and the load pressure of the charging road, while meeting the requirements of power supply cost and power supply stability. This article introduces the research progress and application of wireless charging technology at home and abroad, then introduces the classification of wireless power transmission technology in detail, and then introduces the structure of the wireless power transmission system of electric vehicles in detail. Simulation results of the wireless charging technology of the car show that the advancement of charging technology will lead to the further development of new energy electric vehicles in the future. This article describes the development of new energy electric vehicle charging technology in recent years, and puts forward the development direction and development suggestions of new energy electric vehicle charging technology.

1. Introduction

Wireless energy transmission technology is developing faster and faster and is widely used in various occasions, such as electric cars, mobile phones, biomedical equipment, etc. Specifically, in the charging process of electric vehicles, the use of wireless charging technology can achieve electrical and mechanical isolation, reduce the use of cables and sockets, and avoid the risk of contact sparks, short circuits, and leakage. In addition, the use of wireless charging technology in the dynamic driving of electric vehicles can greatly reduce the battery's required capacity and charging time. Therefore, electric vehicle wireless charging technology will play an important role in the future development of the electric vehicle market [1]. The wireless charging technology for electric vehicles is a trend that has been developed in recent years. It has the advantages of safety and convenience, which can greatly reduce the battery capacity of electric vehicles, reduce the weight of the car body, reduce the initial purchase cost of electric vehicles, and make them no longer subject to The high cost factor of large-capacity batteries can make the market size of electric vehicles wider, and it is necessary to grasp the context of its technological development [2].
2. **Introduction to wireless charging technology**

Electric vehicles are currently being charged via cable connections. Although this provides a very efficient and secure connection, to the end user, the cable is heavy to carry, the plug connection is cumbersome, and there may be many usage restrictions such as defects, easy soiling, being lost or stolen. In some use cases, such as when vehicles are waiting at an airport or station, reconnecting cables is an impractical solution when cars are lining up or moving from one place to another. Wireless charging has the advantages of electric vehicle availability, charging convenience, and especially the advantages of parking in public places [3]. This makes wireless charging technology a good solution.

![Wireless charging system for electric vehicles](image)

**Figure 1.** Wireless charging system for electric vehicles

2.1. **Wireless charging technology works**

After the electric vehicle in the power grid obtains electric energy, the power at the transmitting side of the power source side can obtain DC power through rectification and filtering, and perform high-frequency inversion through an inverter, thereby realizing the power supply of the vehicle battery. For the wireless power supply system, its essence is similar to the loose coupling system of the transformer. The primary and secondary power transmission can be achieved through electromagnetic induction. Because the coupling coefficient is reduced, the frequency of the input power of the primary can be compensated [4].

2.2. **Application of Wireless Charging Technology for Electric Vehicles**

In the process of obtaining electrical energy, the transmitting end on the power supply side can work through the power grid, high-frequency oscillating current can be generated by the oscillator, and a non-radiative magnetic field will be formed in the transmitting coil. In this case, the electrical energy will gradually be converted into a magnetic field [5]. When the frequency inherent in the receiving coil of an electric vehicle is already close to the frequency of the obtained electromagnetic wave, a strong oscillation is formed in the entire circuit, which promotes the efficient conversion of electrical energy. In the ERPT system, the receiving coil and the transmitting coil both have self-oscillation. According to the characteristics of resonance, the system excites the resonance of the receiving end from the transmitting end, so that the power capacity does not need to consume too much during transmission [6].

2.3. **Wireless charging technology for electric vehicles**

2.3.1. **Inductive charging technology.** At present, inductive wireless charging design has been widely used in many electric vehicle charging technologies. Inductive wireless power supply technology has many characteristics, such as low operating frequency, usually between tens and hundreds of hertz,
wireless transmission of kilowatts of power can be better achieved, and the actual output power can reach 95% when performing short-range transmission [7].

Figure 2. Analysis of the development path of electric vehicle wireless charging technology

2.3.2. Resonant Wireless Charging Technology. The wireless charging system mainly absorbs the power energy in the power grid. Through high-frequency inversion and rectification filtering, power-frequency AC power can generate high-frequency AC power, which is then transmitted to the transmitting coil through the power amplification circuit and impedance matching circuit. When the same transmitting coil system frequency and self-resonant frequency are used, the transmitting coil will generate a very large current energy source, which will further increase the current of the magnetic field. The load battery can be recharged using the energy present in the rectification filtering and receiving coils [8].

3. Analysis of the development path of electric vehicle wireless charging technology

3.1. Static charging wireless charging technology
Static charging means that the electric vehicle is in a stationary state during the charging process. This charging method stems from the strict requirements of the relative position of the coils in electromagnetic induction charging and can only perform one-to-one charging. The energy transmission efficiency during charging is high and the transmission range is large. Due to the deviation in the distance and angle between the transmitting end and the receiving end, the charging efficiency will be reduced, and the foreign objects in the magnetic field region between the induction charging coils will also have a large effect on the charging efficiency. The charging space environment has a greater impact. Therefore, the wireless charging automatic parking positioning monitoring technology, foreign object detection technology, and the design of the shape and arrangement of the power transmission and reception coils are all problems that the existing research institutes and many enterprises are committed to research.

3.2. Dynamic charging wireless charging technology
Wireless charging technology enables electric vehicles to be charged in real time on the road, also known as dynamic wireless charging technology. This technology is based on the evolution of wireless charging technology and combines multiple technologies such as positioning sensing, wireless communication, and real-time control. To achieve mobile charging, an electric power transmitting device can be laid on the lower layer of the road, and the receiving device located on the body of the electric vehicle can obtain power without stopping. However, the current mobile power supply system still faces the problem of uneven magnetic flux distribution, which will result in different magnetic flux coupling efficiency in different positions and directions. Therefore, in order to achieve the equalization of the road emission magnetic field and improve the charging and receiving efficiency of dynamic charging of electric vehicles, the industry is concerned. It is necessary to improve the dynamic charging structure design, charging line road layout, and charging transmission methods in the future.
4. **Modeling and analysis of wireless power supply technology**

With the rise of magnetic resonance wireless charging technology, the location requirements in electric vehicle charging facilities have begun to decrease. As long as the transmitting and receiving ends reach the same resonance frequency, they can transfer energy and support one-to-many charging. This method makes the flexibility of wireless charging of electric vehicles begin to appear, but its technical disadvantage is that the energy loss is relatively large, and the greater the transmission power, the greater the loss. Therefore, at this stage, many companies focus on reducing the loss in the charging process in the research on improving the charging efficiency, and at the same time, research on charging control and positioning is also underway. The power transmitting device receives the instruction of adjusting the matching converter output by the vehicle ECU, and sets the impedance of the matching converter according to the power transmission efficiency between the power transmitting unit and the power receiving unit.

4.1. **Wireless charging technology modeling application**

At present, there are many researches on the wireless charging technology of electric vehicles, mainly in the two aspects of charging power control and circuit compensation topology research. In order to eliminate high-order harmonics and reduce inverter losses, especially in high-power situations, it is necessary to achieve zero voltage switching (ZVS) operation during the entire charging process. In order to improve the performance of wireless energy transmission (WPT) systems, some high-order compensation topologies are also proposed. By adding LC resonant circuits or additional resonant capacitors, the control strategy for suppressing overcurrent during the charging start-up period is sought by finding the optimal operating frequency range. As the rated operating frequency range, start charging at a higher initial frequency to achieve small current start-up during the startup process to suppress overcurrent, and then use the incremental PID controller to control the frequency to achieve ZVS operation of the inverter, and finally reach the battery pack stably Charging current voltage required for constant current and constant voltage charging.

4.2. **Power Analysis of Wireless Charging Technology System**

This study will analyze the two main performance indicators of the wireless power transmission system's transmission efficiency and output power. These two performance indicators are also the most commonly used evaluation indicators for the quality of electric vehicle wireless charging systems. The choice of design parameters will Impact on system performance indicators. The maximum power
transmission refers to the maximum output power obtained through the transmission and transformation of the electrical energy obtained from the power grid, and the maximum efficiency transmission refers to the highest efficiency of the system's electrical energy transmitted from the power grid to the output. Both maximum power transmission and maximum efficiency transmission can be used as system design goals, often with different choices in different scenarios.

4.3. Transmission efficiency optimization of wireless charging technology
If the transmission efficiency is selected as the first optimization target, other techniques such as adaptive impedance matching can be used to improve the power of the transmission. Therefore, it is recommended to focus on improving the efficiency of the initial design phase. The realization of the maximum transmission efficiency depends on the quality factor of the resonator and the coupling coefficient between the magnetic coupling coils. To achieve acceptable efficiency at large relative distances, a resonator coil with a high quality factor is required. Therefore, the operating frequency must be high enough and the AC resistance of the resonator should be low. However, higher frequency operation will increase the complexity of power electronic circuits, and the maximum transmission efficiency can be expressed as the following calculation formula.

4.4. Wireless power output power optimization
If the output power delivered to the load is selected as the first optimization goal, it will limit the maximum level of transmission efficiency that can be achieved, which is not desirable for electric vehicle wireless charging products. The transmitted power can determine the VA rating and thus the component ratings, especially the series capacitors and power converter switches. The input impedance of the coil varies with the coupling coefficient and the operating frequency. This happens when the source impedance matches the input impedance of the coil system. When operating at a self-resonant frequency, the maximum power transfer occurs at a specific coupling coefficient value called the critical coupling point, which is equal to the critical coupling value at a specific distance.

4.5. Analysis of Battery Charging State of Wireless Charging Technology
The load of the electric vehicle wireless charging system in this article uses lead-acid batteries. In order to prevent the battery from being overcharged or over-discharged and prolong the battery life, a three-phase charging method of constant current-constant voltage-trickle is used. 3-EV-225 series battery. The battery constant current charging current is 22.5A, and the constant voltage charging voltage is 90V.

![Figure 4. Wireless charging technology battery charging data analysis](image)

(1) Constant current stage 0-t1: The charging current of the battery is maintained at 22.5A, the charging voltage gradually increases from 82.5V to 90V, and the equivalent resistance of the battery changes from 3.67Ω to 4Ω.
(2) Constant voltage stage $t_1$-$t_2$: The charging voltage of the battery is maintained at 90V, the electric current gradually decreases from 22.5A to 6A, and the equivalent resistance of the battery changes from 4Ω to 15Ω.

(3) Trickle stage $t_2$-$t_3$: When the current drops from the constant voltage stage to 6A, the charging state enters the trickle stage. At this time, the charging voltage drops to 85V, the charging current drops from 5.67A to 3A, and the charging ends. Equivalent Resistance change is 15Ω-28Ω.

Figure 5. Wireless charging technology battery charging time status analysis

Through the analysis in this study, the actual system is required to be in the ZVS state to make the system work well. It is necessary to keep the system phase angle greater than zero. The power requirements of the electric vehicle wireless charging system studied in this paper are relatively large. Considering the total system loss and the minimum phase angle, in the analysis, the reference ZVS angle is selected to be 20º to ensure the safe and stable operation of the system. The operating frequency of the system increases with the increase of the self-resonant frequency $f_1$. When $R_L=3.6Ω$ and $f_1=0.88f_0$, the minimum operating frequency required to maintain the target phase angle is 72.92kHz. When $R_L=3.6Ω$ and $f_1=1.08f_0$, the maximum operating frequency is 100kHz. Therefore, you can consider setting the rated operating frequency range of the electric vehicle wireless charging system to be 50kHz~100kHz. In order to achieve small current startup control, the initial operating frequency of the system should be set to 100kHz.

Figure 6. Required operating frequency range for different equivalent resistances

If you start at a frequency higher than 97kHz, the system startup current will approach zero. At this time, the phase angle cannot be detected, causing the system to be out of adjustment and unable to...
operate normally. When considering extreme conditions, such as when the parking position is completely deviated, which is equivalent to the disappearance of the receiving end, start the system charging at the proposed initial frequency. The current at the instant of startup will not be too large, but the current will be slow during the phase angle adjustment. Slowly increase to the occurrence of over-current, so set over-current protection, to provide sufficient pre-protection time for possible over-current situations during the adjustment process after the system starts with a small current.

![Diagram](image1)

**Figure 7.** Analysis of battery charging modeling software for wireless charging technology

4.6. **Wireless Charge PID Controller Process Design**

For battery charging, which is a process control with a slowly changing current and voltage, the control speed is not very high. At the same time, considering the long time for wireless charging of electric vehicles, the adjustment time during the startup phase is not much compared with this. Influence, but the control in the startup phase can effectively suppress overshoot, prevent overcurrent problems, and play an important role in system protection. Considering that the control delay is difficult to avoid, for this reason, the PID control period is set to 50ms.

![Diagram](image2)

**Figure 8.** Wireless Charging Technology Battery Charging MATLAB Modeling Software Image Analysis

Taking into account a certain margin, the adjustment limit range for limiting the frequency at the same time is 50kHz to 100kHz. By establishing the MATLAB Simulink model of the system, the PID controller simulation of the charging startup phase is performed (the initial frequency is set to 100kHz and the initial voltage is set to 50V). The control effect of the controller Under the condition of satisfying a small overshoot amount and a certain control speed, the proportional, integral and differential
coefficients of the PID controller at the startup stage are set to $k_p=0.75$, $k_i=0.25$, $k_d=0.01$, and the incremental PID incremental method is inferred by establishing a mathematical model.

5. Conclusion
With the rapid development of the electric vehicle industry, it is becoming increasingly important to solve the problem of electric vehicle charging. Wireless charging of electric vehicles has gradually become a development trend, and the construction of wireless charging parking spaces has also played a vital role in the promotion of electric vehicles. At this stage, the wireless charging method of electric vehicles is developing in the direction of efficiency, intelligence and flexibility. Although China's electric vehicle charging has started relatively late, China's electric vehicle charging patents are constantly improving, and the scale of related companies is also expanding, which can promote the development of electric vehicle wireless charging technology in a better direction.

References
[1] Teng Letian. Design of electric vehicle charger Ge Jiayu. Beijing: China Electric Power Press, 2016, 6, 12, pp. 21-26.
[2] Xiao Chaoxia, Liu Jie. Research on Wireless Charging System for Electric Vehicles Based on Microgrid. Transactions of China Electrotechnical Society, 2017, 9, 10, pp.110-113.
[3] Chen Chen, Huang Xueliang, Tan Linlin, et al. Evaluation of electromagnetic environment and safety during wireless charging of electric vehicles. Transactions of China Electrotechnical Society, 2018, 5, 12, pp.226-228.
[4] Xia Yu. Research Report on China's New Energy Vehicle Industry. Xinhua News Agency Think Tank, 1999, pp, 2017, 11, 23, pp.169-171.
[5] Li Lu. Analysis of patent application for electric vehicle wireless charging technology. Electronic Intellectual Property, 2018, 6, 8, pp.65-69.
[6] Xiang Qingqi. Research on patent layout of wireless charging technology. Xiangtan: Xiangtan University, 2017, 3, 9, pp.121-123.
[7] Dong Fulu, et al. Overview of wireless charging couplers for electric vehicles. Electrical Switch, 2016,6,16 pp.331-336.
[8] Liu Bo et al. Overview of wireless charging technology for electric vehicles. Cars and Accessories, 2018, 8, 14, pp.116-119.