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# Design of Wireless Charging Device for Electric Vehicle

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## Abstract

**Wireless Power Transfer (WPT) has been widely used in People's Daily life because of its advantages of safety, flexibility and reliability. Among them, magnetic coupled resonant radio energy transmission has a broad development prospect because of its long transmission distance and small power loss, and is one of the main means to break the bottleneck of development of wireless charging technology for electric vehicles, so it is of great significance to the structural design of the system. Based on the magnetic coupling resonant radio transmission system as the research object, the working principle of the first analysis of the system, respectively, using the coupled-mode theory and circuit theory analysis the influence factors of the system efficiency and transmission power, and then on the system's main circuit topology is studied, mainly including rectifier circuit, high frequency inverter circuit, the choice of the coupler, regulating circuit and the design, including mutual inductance value of the coupler by Ansys finite element analysis software. Finally, a complete circuit structure is built in Matlab for verification. The results show that the system can realize the wireless charging technology of ev and guarantee the transmission stability, meet the original side transmission efficiency value ≥75%, and the charging power is above 1kW.**

## Keywords

**Electric car, Magnetic coupling resonance, Wireless power transmission.**

## 1. Introduction

The generation and application of electric energy have brought great convenience to people's life and promoted the progress and development of the whole human society. The generator came into being in the 19th century. Since then, a variety of electrical appliances have appeared, which have added great power to people's production and life. Since the industrial revolution brought human beings into the "electric age", electricity is closely related to human life. Since the wide use of electric energy, the power supply between the power supply and the load has been wired. However, with the development of science and technology, people have realized that there are many disadvantages of wired power supply. For example, traditional wired charging requires that the power supply must be in direct contact with the charging load, so it will involve the problem of charging plug model matching[1-2]. In addition, the wired charging method is not convenient to use, easy to occur leakage, wear, heat, fire and other phenomena. In the application scenario of electric vehicles, the charging piles with matching models must be equipped. At present, dc charging is the most important charging method for electric vehicles, but there are many problems. Although the dc charging point takes a short time, the number of charging piles cannot meet the requirements due to the large number of cars to be charged. In addition, wired charging also has certain dangers, such as charging in rainy days, moving vehicles in charging areas with a large number of vehicles, and so on. Also, although some areas are reserved for charging, the number of cars waiting to be charged is still large, partly because of the time it takes to charge and partly because of the space required for charging. These charging problems have been plaguing the development of electric vehicles, and there is no better way to solve them before the emergence of new charging methods [3-4].

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Considering the limitations of wired charging, wireless charging has gradually become a research hotspot. The origins of wireless charging can be traced back to the early 20th century, when nikola tesla built the first wireless charging tower on long island, New York, to experiment with wireless power transmission. Radio energy transmission technology mainly USES electromagnetic induction theory to transmit electric energy through mechanical waves, magnetic fields or electric fields and other media. There is no metal wire connection between the power supply and the load, which provides a new way to solve the above problems.

## 2. Basic Theory of Radio Transmission

### 2.1. The Basic Structure

Magnetic resonance radio energy transmission is a non-contact means of power transmission based on the principle of electromagnetic induction. The system is composed of three-phase power supply, wireless charging transmitter, coupler, wireless charging receiver and load. The quality factor of the primary and secondary side coils of the system is the same. When the high-frequency ac current frequency after inverter is the same as the natural frequency of the primary and secondary side coils, resonance will occur in the system. At this time, the circuit impedance of the whole system is minimum, so that the energy of the transmitter is transmitted to the load resistance efficiently through the coupler. Coil model and system structure are shown in the following figure [5]:

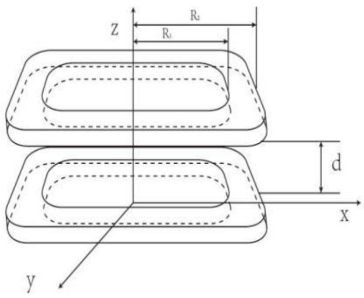


**Fig 1.** Coil model

Since the magnetic resonance WPT system is based on the circuit resonance principle for energy transmission, it is necessary to make the first or second sidecyclic coil work in the resonant state. The common method is to use the compensation capacitance to offset the reactance. According to the way the primary coil and the secondary coil are connected to the compensation capacitance, the system structure can be divided into parallel - parallel coupling (p-p), parallel - series coupling (p-s), series - parallel coupling (s-p) and series - series coupling (s-s).

The results show that the series coupling structure has the characteristics of constant pressure source under certain conditions, and the high efficiency of power transmission can be achieved without a large coupling coefficient. Therefore, this paper chooses series - series coupling structure as the research object for analysis. The s-s structure is shown in the figure below.

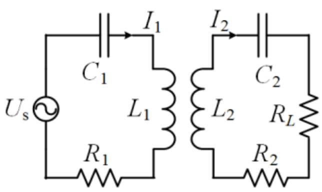


**Fig 2.** s-s structure

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### 2.2. Circuit Theory Modeling

According to kirchhoff's voltage law, the circuit circuit equation of the constructed s-s structure is:

$$U_S = (R_1 + R_2)I_1 + \mathrm{j}(wL_1 - \frac{1}{wC_1})I_1 - \mathrm{j}wML_2 \tag{1}$$

$$0 = \mathrm{j}wML_1 - (R_2 + R_L)I_2 - \mathrm{j}(wL_2 - \frac{1}{wC_2})I_2 \tag{2}$$

The series resonance condition is:

$$Im(Z(\mathrm{j}w)) = 0 \tag{3}$$

$$wL_1 = \frac{1}{wC_1} = wL_2 - \frac{1}{wC_2} = 0 \tag{4}$$

The system resonance frequency is:

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{5}$$

$$\begin{cases} I_1 = \dfrac{(R_2 + R_S)}{(R_1 + R_S)(R_1 + R_L + w^2 M^2}U_S \\ I_2 = \dfrac{\mathrm{j}wMR_S}{(R_1 + R_S)(R_1 + R_S) + w^2 M^2}U_S \end{cases} \tag{6}$$

The load power and system input power are:

$$P_L = I_2^2 R_L = \frac{w^2 M^2 R_L}{[(R_1 + R_S)(R_1 + R_L) + w^2 M^2]^2} U_S^2 \tag{7}$$

$$P_S = U_S I_1 = \frac{(R_2 + R_S)}{(R_1 + R_S)(R_2 + R_L) + w^2 M^2} U_S^2 \tag{8}$$

The transmission efficiency of the system is:

$$\tau = \frac{P_L}{P_S} = \frac{I_2^2 R_L}{U_S I_1} = \frac{R_L}{R_2 + R_L} \frac{w^2 M^2}{w^2 M^2 + (R_1 + R_S)(R_2 + R_L)} \tag{9}$$

## 3. Simulation of Magnetic Circuit and Circuit of Radio Energy Transmission System

### 3.1. Magnetic Circuit Simulation

It can be seen from the second chapter that the coupling degree of the coil is one of the important factors affecting the transmission characteristics of the WPT system. Therefore, it is of great significance to accurately analyze the characteristics of the WPT system and carry out

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relevant studies to obtain the exact mutual inductance. Some existing impedance analyzers can only measure the self-inductance of the coil, but the mutual inductance of the coil cannot be measured accurately, especially when the structure of the coupler changes. Mathematics analytic method, therefore, is now commonly used method, this method has the advantage of specifications, structure of some simple coil, coil, such as round, rectangle by following formula can quickly get the mutual inductance value, however, in the actual application of the radio can transmit the transmitter coil and receiving coils are hard to be coaxial alignment, in addition, the coil structure is not necessarily to regulate geometric structure, in such a case, using the mathematics analytic method process is complicated and tedious, it's hard to get the right conclusion[6].

Due to the disadvantages of mathematical analytical method which is difficult to eliminate, the method of mutual inductance simulation calculation by using Ansoft electromagnetic analysis software and finite element method has attracted more and more attention. Solution of the finite element analysis of the core is to be calculated area is divided into many finite element, the algebra method of simulation, finite element area for each get an approximation solution, because there was a link between the unit, after a lot of subdivision, correction, can be achieved with limited to solve the effect of unlimited, infinite close to true value is the result. The biggest advantage of finite element analysis is that it can calculate the mutual inductance of coupling coils in any shape and relative position, and it is suitable for the simulation of multi-coil structure. In addition, Ansoft has a high degree of automation and does not need to divide the grid manually. In practical applications, only the shape of the model, materials, transmission medium and related parameters of the system are required to be given, and Ansoft can automatically generate the dividing grid with high quality, greatly simplifying the entire simulation process.

Therefore, this paper USES Ansoft finite element analysis software to study the relationship between the mutual inductance and the distance of couplers in a double-coil structure system.

Model the coils in Maxwell, coil is set to 5.5 mm in diameter, outside diameter is set to 600 mm, for single turn single coil, the coil spacing starting value is set to 10 cm, with 5 cm as a unit, the largest spacing is set to 30 cm, coil shape as the rounded rectangle, on the one hand, this structure can make the uniform magnetic field distribution, on the other hand, due to the rounded corners where no overlap, can significantly reduce the subdivision computation time. The coil model and simulation results are as follows:

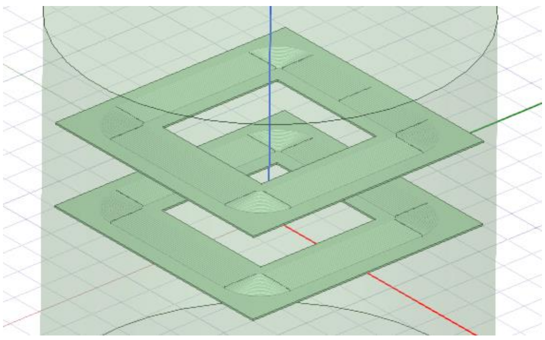

**Fig 3.** Coil simulation model

**Table 1.** Results of mutual inductance calculation

| Coil distance (cm) | 10 | 15 | 20 |
|---|---|---|---|
| Mutual inductance (μH) | 83.275 | 66.501 | 50.365 |

## 3.2. Circuit Simulation

System input power supply for the three-phase power frequency ac power, power supply, followed by a three-phase bridge rectifier circuit circuit USES capacitance inductance filter, not controlled rectifier for diode rectifier circuit, rectifier circuit connected to the single-phase inverter circuit, due to the alternating current frequency output, compared with IGBT, MOSFET is more suitable for high frequency occasions, so here using MOSFET as switching tube, high frequency current of inverter circuit output into the coupler, coupler for capacitance and inductance of type string resonance circuit, because of resonance capacitance and inductance voltage is very high, so in the inductive voltage monitoring stations set up. The secondary circuit consists of a side coupler and a single-phase bridge full control rectifier circuit. The output dc is connected to the load. Monitoring points are set for the voltage and power of the load.

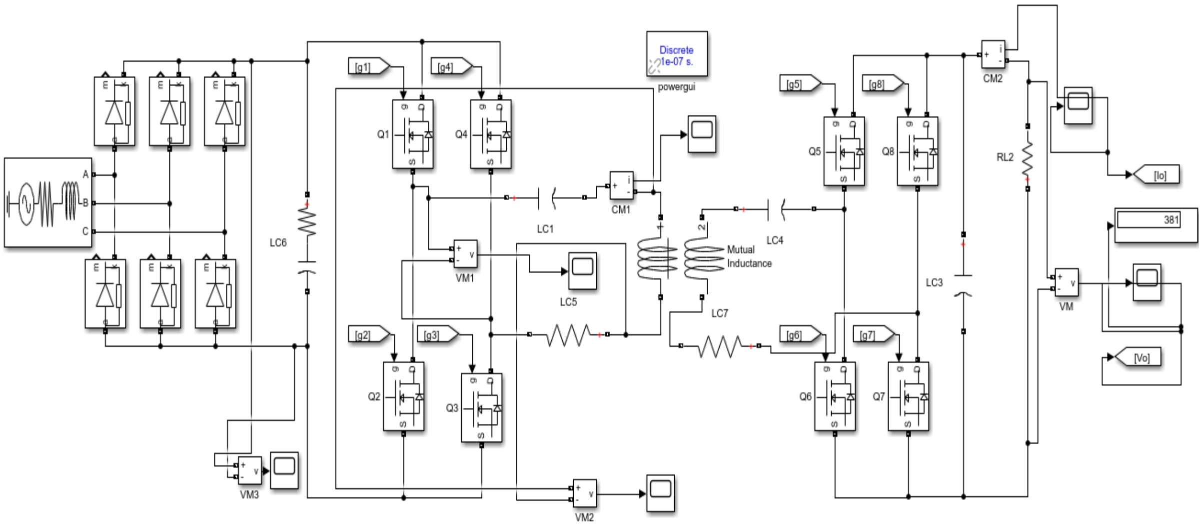


**Fig 3.** Circuit simulation

## 4. Conclusion

Based on the model S - S magnetic coupling resonant WPT system as the research object, the working principle of the system are analyzed respectively using the coupled-mode theory and circuit theory analyzes the system efficiency and the influence factors of transmission power, it is concluded that the efficiency of the system and the transmission power and coil self-induction, resistance, system working frequency, coupler mutual inductance value and other related factors; Then the main circuit topology of the system is studied, including the selection and design of the rectifier circuit, the high-frequency inverter circuit, the coupler, the voltage stabilizer circuit, etc., and the mutual inductance variation rule of the coils at different spacing is calculated by using the finite element analysis method. Finally, according to the designed system, a complete circuit structure was built in Matlab for simulation and verification. The results show that the system can achieve transmission power of 1kW and transmission efficiency of 90.9%. While we see the great advantages of wireless charging, we should pay more attention to the development bottleneck of wireless charging technology. Electric vehicle charging parking technology put forward higher requirements for the pilot, can let the parking location just to ensure that the former vice edge coil radial completely overlap will directly decide the charging efficiency of the system, and in addition, the mobile wireless charging technology can solve the problem of the battery capacity is too low, but the research in the field of the fledgling, especially how to guarantee the smooth transmission of electric energy in the process of moving and laying mobile charging road cost problem, not a good solution. Future studies can be carried out for the optimal design of couplers, such as determining the optimal coupling range of primary and secondary side coils, setting dynamic capacitance compensation

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system, enhancing the magnetic field coupling of primary and secondary sides, enhancing the robustness of the system and so on.

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