

# Design and Application of Early Warning Model for Electric Vehicle Charging Safety

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**Abstract**—In order to improve the charging safety of electric vehicles, it is necessary to design the early warning model of charging safety, so as to overcome the overload defects in the charging process of electric vehicles. An electric vehicle charging safety warning model was proposed based on contactless charging design. The electromagnetic induction coil and electromagnetic coupler installed on the charging pile are used to design the electromagnetic coupling induction with the driving electric vehicle tire wire, and the electromagnetic coupling control and charging stability adjustment of the electric vehicle are carried out by using the inductive power transmission technology. The test results show that the proposed method has good control performance and can effectively realize the wireless energy transmission of 100W in 100cm, the charging efficiency and the charging safety are improved.

**Keywords**-*Electric Vehicle; Charging Safety; Early Warning Module Design; Electromagnetic Coupling Induction*

## I. INTRODUCTION

In actual use, the charging facilities will be used in spring, summer, autumn, winter, wind, frost, rain and snow. However, the charging insulation materials will be affected by temperature, vibration, harmful gases,

chemicals, humidity, dust, radiation and other factors. The car stops at the right place at the end of the journey, trying to avoid direct sunlight and cold weather. In winter and summer, the climate is more harmful to the battery, and the damage to the battery seriously affects the safety of charging. Therefore, we must take appropriate measures to cure the safety of charging. In order to solve the above problems, an electric vehicle charging safety warning model based on contactless charging design is proposed in this paper.

## II. WORKING PRINCIPLE OF ELECTRIC VEHICLE CHARGING SYSTEM

Firstly, the input power is converted into a high frequency power supply, and then the primary emission induction coil and the electromagnetic coupler installed on the charging pile side are converted into the electromagnetic power source after the energy shunt. The primary resonance is then radio-transmitted to the secondary resonance in the automobile tire<sup>[7]</sup>. The receiving coil induces the energy of the secondary resonance link and performs magnetoelectric transformation. The received electric energy is then adjusted to charge the car battery.

1) The inverter frequency of electromagnetic induction power transmission is generally less than 100K Hz, which is determined by the performance of magnetic core and the switching frequency of inverter power supply. The magnetic resonance mode generally uses signal generator and power amplifier to provide power supply, so the inverter frequency of the energy conversion link can be greatly increased to 10MHz.

2) Compared with the electromagnetic induction mode, there are only two coils for electromagnetic induction, and two resonance links are added to the magnetic resonance power transmission mode. The resonance coil uses its own distributed capacitance to realize resonance in an open circuit. In this case, the topology of the system is relatively fixed<sup>[1]</sup>. The magnetic resonance mode system topology of the electric vehicle charging safety warning system designed in this paper is shown in figure 1.

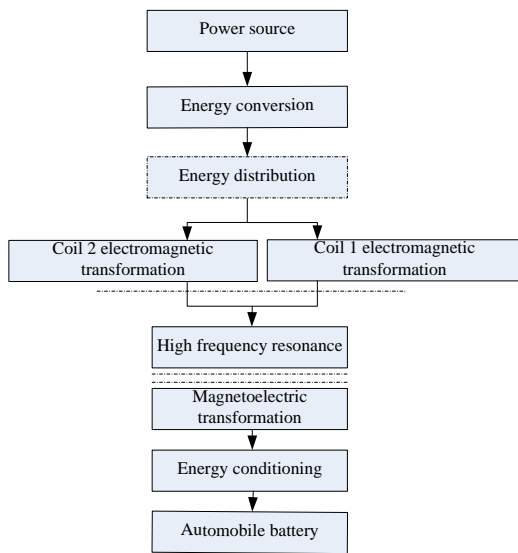


Figure 1. Schematic diagram of magnetic resonance mode radio energy transmission system for electromagnetic induction coils and electromagnetic couplers

### III. ELECTROMAGNETIC COUPLING INDUCTION DESIGN AND STABILITY CONTROL OF ELECTRIC VEHICLE CHARGING SAFETY

#### A. Electromagnetic coupling induction design

During the use of the battery, assuming the existence of over discharge will increase the probability of the difference of the battery. During the over-discharge of the lead-acid battery, the terminal voltage drops faster, which easily leads to the appearance of coarse grain lead sulfate in the electrode plate. It can be found that the battery can reduce the battery capacity and service life even if the battery is switched off. Because of the timeliness and reliability of the interrupt voltage monitoring, the battery energy management system cannot complete the discharge control better, so the problem of over discharge of the battery with lower capacity cannot be avoided. Because of the increasing gap in the battery capacity, the battery with lower capacity will over discharge more and more seriously<sup>[9]</sup>.

In this paper, a new method of electromagnetic resonance radio energy transmission using automobile tire wire is presented. In this method, the transmitting coil is fixed on the charging pile to form an electromagnetic induction coil and an electromagnetic coupler, and the energy is transmitted by electromagnetic resonance with the automobile tire<sup>[10]</sup>. The topological structure used in the system is shown in figure 2.

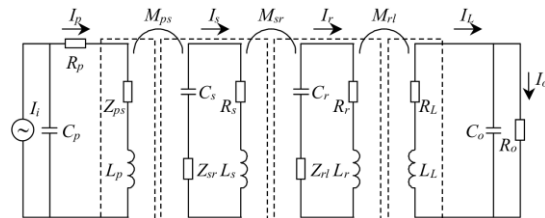


Figure 2. Topological structure of magnetic resonance power transmission system

The electromagnetic induction coil and electromagnetic coupler installed on the charging pile are used to design the electromagnetic coupling induction with the driving electric vehicle tire wire, and the electromagnetic coupling control and charging stability

adjustment of the electric vehicle are carried out by using the inductive power transmission technology<sup>[11]</sup>. According to the overvoltage regulation of the load during the electric vehicle charging, the overload interruption control of the electric vehicle charging is carried out by using the mutual inductance coupling method, and the ohmic loss and radiation loss of the electrified coil will be produced at high frequency. In this system, the ohmic loss is much larger than the radiation loss, so the radiation loss is ignored and only ohmic loss is considered. In this paper, parallel capacitors are used to carry out resonance at the energy pickup end<sup>[2]</sup>. When the coil is in resonant state, the resonant angular frequency is  $\omega_0$ . Assuming that the effective value of the transmitting coil current is  $I_p$ , the effective value of the coil 1 current  $I_s$ , the current RMS value on the resonance coil 2 is  $I_r$ , and the current effective value on the load  $R_o$  is  $I_o$ , they are calculated respectively as:

$$I_s = \frac{\omega_0 M_{ps} I_p}{R_s + Z_{sr}} \quad (1)$$

$$I_r = \frac{\omega_0^2 M_{ps} I_p}{R_s + Z_{rl}} \quad (2)$$

$$I_o = \frac{M_{rl} I_r}{L_o} \quad (3)$$

The reflection impedance of the electromagnetic induction coil on the charging pile is  $Z_{rl}$ :

$$Z_{rl} = \frac{M_{rl} R_o}{L_l^2} - j \frac{\omega_0 M_{rl}^2}{L_l} \quad (4)$$

In parallel, the reflective impedances between the electromagnetic coupler and the moving electric vehicle tire are  $Z_{rl}$ ,  $Z_{sr}$ ,  $Z_{ps}$ , calculated as follows:

$$Z_{rl} = \frac{M_{rl} R_o}{L_l^2} \quad (5)$$

$$Z_{sr} = \frac{\omega_0^2 M_{sr}^2}{M_{rl} R_o / L_l^2 + R_r} \quad (6)$$

$$Z_{ps} = \frac{\omega_0^2 M_{ps}^2}{Z_{sr}} \quad (7)$$

The output power of electric vehicle charging pile mutual inductance coupling is expressed as follows:

$$P_o = \frac{\omega_0^4 M_{ps}^2 M_{sr}^2 M_{rl}^2 L_l^2 I_p^2 R_o}{(\omega_0^2 M_{sr}^2 L_l^2 + R_s R_r L_l^2 + R_s R_o M_{rl}^2)^2} \quad (8)$$

The transmission efficiency of electric vehicle during charging is expressed as follows:

$$\eta = \frac{P_o}{I_p^2 (Z_{ps} + R_p)} \cdot \frac{\omega_0^4 M_{ps}^2 M_{sr}^2 M_{rl}^2 L_l^2 I_p^2 R_o}{h_1 (\omega_0^2 M_{sr}^2 L_l^2 R_r + \omega_0^2 M_{ps}^2 M_{rl}^2 R_o + h_1 R_p)} \quad (9)$$

$$\text{Where, } h_1 = \omega_0^2 M_{sr}^2 L_l^2 + R_s R_r L_l^2 + R_s R_o M_{rl}^2.$$

### B. Stability control of electric vehicle charging safety

According to the overload regulation of electric vehicle during charging, the overload interruption control of electric vehicle charging is carried out by using mutual inductance coupling method, and the resonant frequency and mutual inductance coefficient during charging are analyzed. The coils internal resistance and other parameters are controlled by parameter steady-state adjustment method<sup>[3-4]</sup>. The main charging circuit uses the step-down chopper circuit. The working principle is to output PWM wave from MSP430F2274 single chip microcomputer and complete the FET control by using the MOSFET drive circuit. The charge and discharge operation of the battery is effectively completed, the main circuit in the actual operation of the circuit can use the appropriate capacitance and inductance and PWM wave frequency, at the same time, it can effectively shorten the charging time and enhance the voltage leveling. The potential difference information of the motor system at  $t_0$  time is calculated by PID control. The formula is expressed as follows:



way to increase the transmission power is to increase the resonant frequency. Therefore, there is an optimal mutual inductance  $M_{sr}$  value to maximize the output power. Make:

$$\frac{dP_o}{dM_{sr}} = 0 \quad (16)$$

The parameter optimization design of electric power transmission system in electric vehicle charging process is carried out. According to the result of parameter optimization, the electric vehicle charging safety early warning test is realized, and the maximum power of transmitting electromagnetic induction coil and electromagnetic coupler is obtained. The mutual inductance value under the transmission target is:

$$M = \left[ \frac{h_2(\omega_0^2 M_{ps}^2 L_l^2 R_r + \omega_0^2 M_{ps}^2 M_{rl}^2 R_o + R_p h_2)}{\omega_0^4 L_l^4 R_p} \right]^{\frac{1}{4}} \quad (17)$$

The electromagnetic induction coil and electromagnetic coupler mounted on the charging pile are used to transmit the electric magnetic resonance radio energy with the automobile tire wire to realize the charging of the electric vehicle in motion, and the early warning protection of the charging safety is realized.

## V. SYSTEM EXPERIMENT AND PERFORMANCE ANALYSIS

The magnetic resonance power transmission mode experiment is designed by Matlab 7, in which the transmitting electromagnetic induction coil and the electromagnetic coupler are composed of two coils. The distance between the two launch coils is about 2500m for the front and rear wheelbase of the ordinary sedan, and the diameter of the launching coil and the receiving coil simulates the diameter of the automobile tire, about 700mmm. The distance between the receiving coil and the transmitting coil varies from 500mm to 1000mm. At the same time, in order to simulate the charging performance of the vehicle, the receiving coil and the transmitting coil have a certain angle. At the same time, the system performance is measured under two different excitation modes, one is phase excitation and the other is different excitation mode. In order to enhance the contrast, the transmission performance of a single coil was also tested. In this paper, the power shunt device is used to supply the two coils, and the inverse device is used to realize the two excitation modes. The mutual inductance values corresponding to the coil distance from 50 cm to 100 cm are shown in Table 1.

TABLE I. PARAMETERS OF MAGNETIC RESONANCE POWER TRANSMISSION SYSTEM

Transmitter terminal 1	Transmitter terminal 2	Resonance coil 1	Resonance coil 2	Receiving terminal
$L_{p1} = 2.1\mu H$	$L_{p2} = 2.3\mu H$	$L_s = 40.5\mu H$	$L_r = 55.6\mu H$	$L_l = 2.1\mu H$
$C_{p1} = 405pF$	$C_{p2} = 403pF$	$C_s = 12.6pF$	$C_r = 14.6pF$	$C_o = 356pF$
$R_{p1} = 45\Omega$	$R_{p2} = 44\Omega$	$R_s = 2.5\Omega$	$R_r = 3.2\Omega$	$R_o = 30\Omega$
$f = 27MHz$	$f = 27.06MHz$	$f = 27.05MHz$	$f = 27.08MHz$	$f = 27.8MHz$

The output power and output efficiency curves corresponding to the distance change are shown in Figures 4 and 5. It is shown from the experimental results that the relationship between the transmission efficiency and the power and distance of the magnetic resonance energy

transmission system is not linear, and there is an optimization value. As can be seen from table 2 and figure 5 and 6, the relationship between the transmission efficiency and the power and distance of the magnetic resonance energy transmission system is not linear. The mutual

inductance of the output power and efficiency is similar with the reality. Because the theoretical calculation neglects the high frequency radiation loss, and there are certain errors in the winding and measurement of the coil, the experimental result is different from the theoretical value. It can be seen that the mutual inductance between the resonance coils is increased by increasing the resonance frequency of the resonance coil, and the common mutual inductance between the resonant coils is increased. The internal resistance of the vibration coil can improve the efficiency of the radio energy transmission system in magnetic resonance mode. The simulation results show that the proposed method can

effectively realize the electric vehicle charging safety warning.

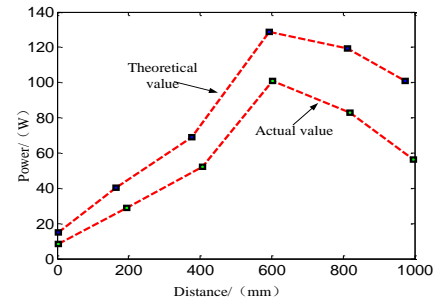


Figure 4. Transmission power versus distance curve

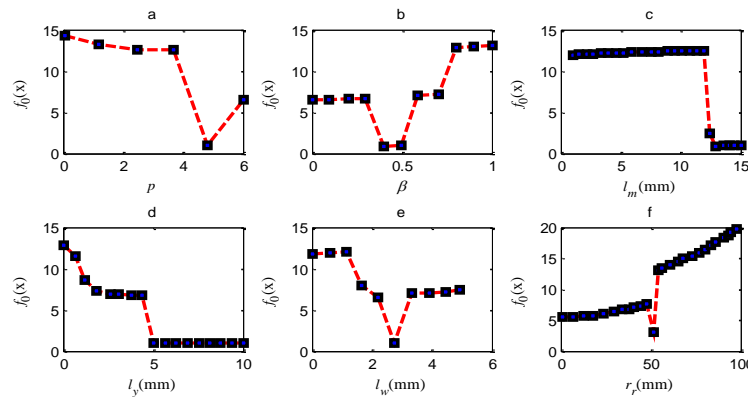


Figure 5. Parameters change process of Electric vehicle charging safety warning

## VI. CONCLUSIONS

In this paper, an electric vehicle charging safety warning model is proposed based on contactless charging design. According to the overload regulation of electric vehicle during charging, the overload interruption control of electric vehicle charging is carried out by mutual inductance coupling method, and the parameters such as resonance frequency, mutual inductance coefficient and coil internal resistance during charging are analyzed. The experimental analysis shows that the method in this paper can effectively realize the electric vehicle charging safety warning, and the charging safety is guaranteed.

## ACKNOWLEDGEMENT

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