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Design of Electric Vehicle Wireless Charging System Based on Series Resonant Circuit

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Abstract

With the rapid development of new energy vehicles, traditional wired charging methods are facing challenges in terms of safety and convenience, while wireless charging technology has become a research hotspot because of its convenience and security. In this paper, the wireless charging system of electric vehicle is taken as the research object, and the wireless charging system with RLC series resonant circuit as the core is designed. In this paper, the basic principle and characteristics of the resonant circuit and the working principle of the coil are analyzed. The corresponding circuit structure is designed, and the performance of the system 's power transmission is verified by simulation. The simulation results show that the system has high power factor and transmission efficiency in the resonant state, which verifies the feasibility of the design and provides a reference for the design and optimization of the wireless charging system for electric vehicles.

Keywords

wireless charging, electric vehicles, series resonance

1. Introduction

With the continuous growth of new energy vehicle sales, the average annual use of charging piles is also rising rapidly [1]. However, at the same time, the traditional wired charging method has gradually exposed the problems of cumbersome insertion and extraction, cable winding and safety hazards. In order to break through the above bottlenecks, wireless charging technology realizes non-contact energy transmission through resonant coupling and other technologies, which has obvious advantages in safety and convenience [2]. Its core significance lies in the complete liberation of the user, so that the owner can bid farewell to the tedious insertion of the charging gun and realize the ' non-inductive ' replenishment.

In recent years, wireless charging technology for electric vehicles has become a research hotspot in the electrical field at home and abroad. Foreign countries started commercial exploration earlier. Represented by Tesla, the company has made it clear that wireless charging is the key support for autonomous vehicles such as CyberCab. Through UWB technology, it can accurately align, realize parking and charging, and complete automatic energy replenishment. In China, it has also entered the stage of industrialization from research and development. Taking Hongqi Automobile as a typical representative, FAW Hongqi E-HS9 model is equipped with 11 KW magnetically coupled resonant wireless charging technology [3], the innovative application of beacon alignment technology enables the system to automatically start charging after the vehicle is automatically parked in the charging position. On this basis, Hongqi intelligent minibus and dynamic wireless charging road have been put into operation in many scenarios, marking the formal entry of domestic wireless charging technology into a new stage of industrial application.

In this paper, the design of wireless charging for electric vehicles based on series resonant circuit is studied. Starting from the resonance principle, a model of the circuit of the system is established. Then, the characteristics of the resonant frequency and the influence of the coil on the system are analyzed. Finally, the simulation circuit of the system is built and the feasibility is proved. This study improves the application system of RLC series resonance in the field of wireless charging and promotes the industrial application of wireless charging technology.

2. The Basic Principle of Electric Vehicle Wireless Charging

2.1 General Design Idea

In this paper, a system of wireless charging for electric charging based on series resonant circuit is designed. The magnetic coupling resonance technology is adopted. The system is composed of a series resonant network at the transmitting end, a resonant coupling mechanism, a receiving end rectifier circuit and a load, and the operating frequency is set to 100 kHz.

The transmitter circuit is composed of AC power supply V1, capacitor C1 and transmitter coil. The power supply is set to output 100 kHz high frequency AC power [4]. In order to convert electric energy into magnetic field energy and transmit outward, the circuit forms a series circuit of C1 and transmitting coil. According to the resonance condition, C1 = 25.33 nF is taken, and L1 = 100 uH is obtained.

The resonant coupling mechanism is composed of a receiving coil and a transmitting coil, and the energy is transmitted between them through magnetic field coupling. Due to the distance between the two coils in practical application, the coupling coefficient k is set to 0.25 [5].

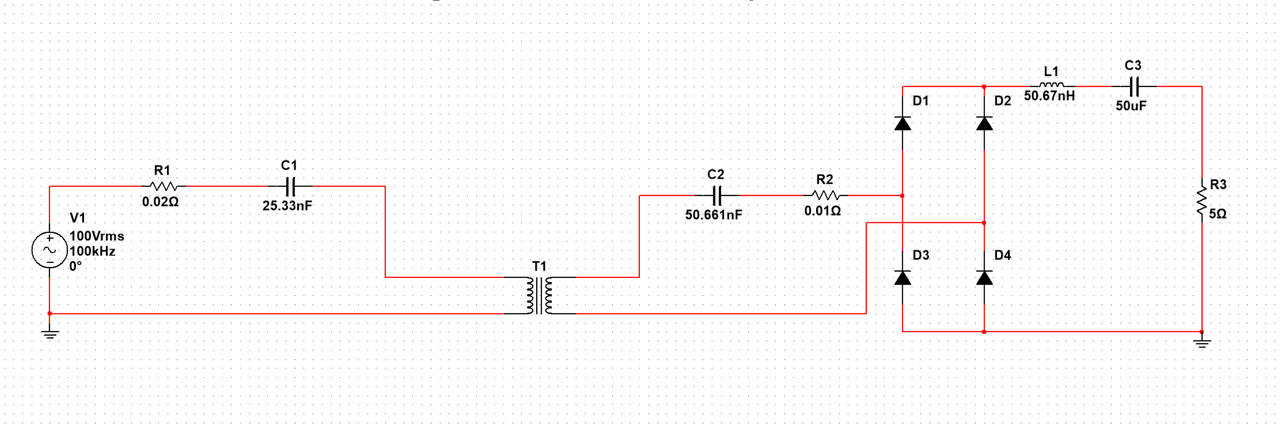
The receiving end includes receiving coil, capacitor C2, whole bridge circuit D1-D4 and load end. When the receiving coil receives the energy of the magnetic field, it generates an induced voltage. To maximize energy reception, capacitance and inductance are connected in series. The AC power picked up at the receiving end is converted into DC power through the rectifier bridge and supplied to the load.

In the wireless charging system of electric vehicles, the transmitting coil is often installed below the parking space ground, and the receiving coil is installed on the chassis of the car. When the car is parked in the corresponding parking space, there is a certain gap between the two coils. At this time, the electric energy is converted into magnetic energy through the transmitting coil, and then the magnetic energy is converted into electric energy through the receiving coil.

2.2 The Overall Structure of the Circuit

The overall circuit structure of the system is shown in Figure 1.

Figure1: The overall structure of the circuit



It is mainly divided into two parts: the transmitting circuit and the receiving circuit, and the energy transfer is carried out by magnetic field coupling. The transmitting circuit is composed of high frequency power supply V1, capacitance C1, resistance R1 and transmitting coil in series. The receiving circuit is composed of receiving coil, capacitance C2, resistance R2, rectification circuit D1-D4 and load end. The load end includes inductance L1, capacitance C3 and resistance R3, which are connected in series with each other.

3. Circuit Design and Analysis

3.1 The Basic Principle of RLC Series Resonant Circuit

3.1.1 Composition of the Circuit

The RLC series resonant circuit is the core foundation of a system of wireless charging in this paper. It is composed of three basic components in series: resistance R, inductance L and capacitance C.

In the design of this paper, two RLC series circuits are included. In the transmitting circuit, the inductance C1, the resistance R1 and the transmitting coil are connected in series, which can convert the electric energy into the magnetic field energy and emit outward. In the receiving circuit, it is composed of the receiving coil, the compensation capacitor C2, the resistance R2 and the subsequent rectifier load network. The receiving coil and C2, R2 constitute the basic RLC series structure, which can receive more magnetic field energy. After passing through the rectifier bridge, the energy will eventually supply the load end composed of inductance L1, capacitance C3 and resistance R3 in series.

3.1.2 Characteristics of Resonance

When the power frequency changes, the RLC series resonant circuit will show different characteristics [6]. The inductance XL of inductance L increases with the increase of frequency, while the capacitance Xc of capacitance C decreases with the increase of frequency. When the frequency meets certain conditions, UL = Uc and the phase is opposite, it is in the resonant state.

When the circuit resonates, the current and voltage are in the same phase, the circuit is resistive, the reactance reaches the minimum value, the loop current reaches the maximum value, and the receiving coil can receive more energy. At this time, UL = Uc = QU, the voltage of L and C is Q times of the power supply voltage, Q is the quality factor, the greater the Q, the more significant the voltage rise.

3.1.3 The Role of Resonance in Wireless Charging

In the wireless charging system of electric vehicles, series resonance can enhance the magnetic field strength and improve the transmission efficiency and distance [7]; It can resist the inductive reactance of the coil and make the circuit resistive; it can also suppress harmonic interference and improve the system's ability to resist interference.

This paper is to use the above characteristics to achieve efficient energy transmission.

3.2 The Working Process of the Coil

3.2.1 The Role of the Coil

In the wireless charging system, the core component of energy transmission is the coil. The system designed in this paper has two coils: transmitting coil and receiving coil. At the transmitting end, the high frequency alternating current is connected, and the alternating magnetic field is generated by the coil according to the principle of electromagnetic induction, and the electric energy is converted into magnetic energy. At the receiving end, the coil is in an alternating magnetic field. Based on the Faraday 's law of electromagnetic induction, AC voltage and current are generated, and the magnetic energy is converted back into electrical energy. Finally, the battery can be charged.

In general, the transmitting coil converts electricity into magnetism, and the receiving coil converts magnetism into electricity. The two cooperate with each other to realize the wireless transmission of electric energy [8].

3.2.2 Influence of the Coil on the System

As the core component in the design, the parameters and performance of the coil directly determine the transmission efficiency and speed of the whole system, which mainly affects the following aspects:

1) Resonance frequency:

If the coil inductance does not meet the design value, the resonant frequency of the system will deviate from 100 kHz, resulting in detuning. In this state, the current decreases and the transmission efficiency decreases.

2) Quality factor:

In the system, the quality factor of the coil can reflect the ability of energy storage and energy consumption. The higher the Q, the smaller the coil energy loss and the higher the energy transmission efficiency.

3) Coupling coefficient:

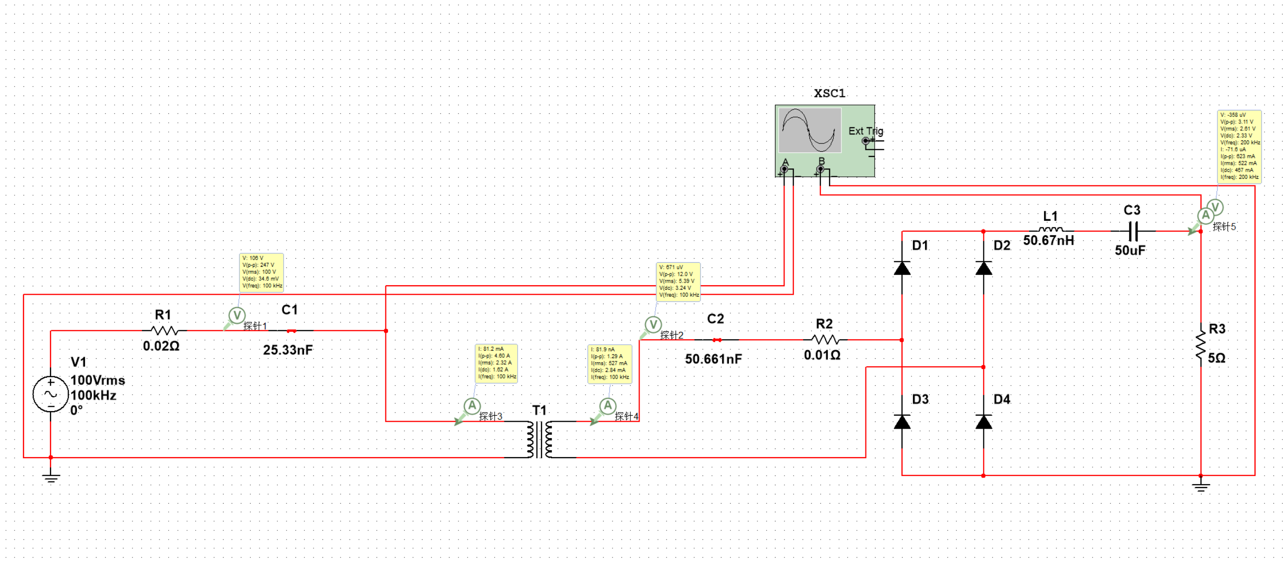
The coupling coefficient of the coil can reflect the strength of the mutual induction. The farther the coil is, the smaller the k. The parameter design of the coil will directly affect the stability of the system resonance [9]. In the subsequent simulation, the above effects are further verified.

4. The Process and Result Analysis of Simulation

4.1 The Design Process of Simulation Circuit

In order to verify the feasibility of the wireless charging system based on series resonance mentioned above, this paper uses Multisim simulation software to build the circuit shown in 2 [10].

Figure 2: Simulation circuit of the system



The specific parameter design is shown in Table 1.

Table1: Parameter setting

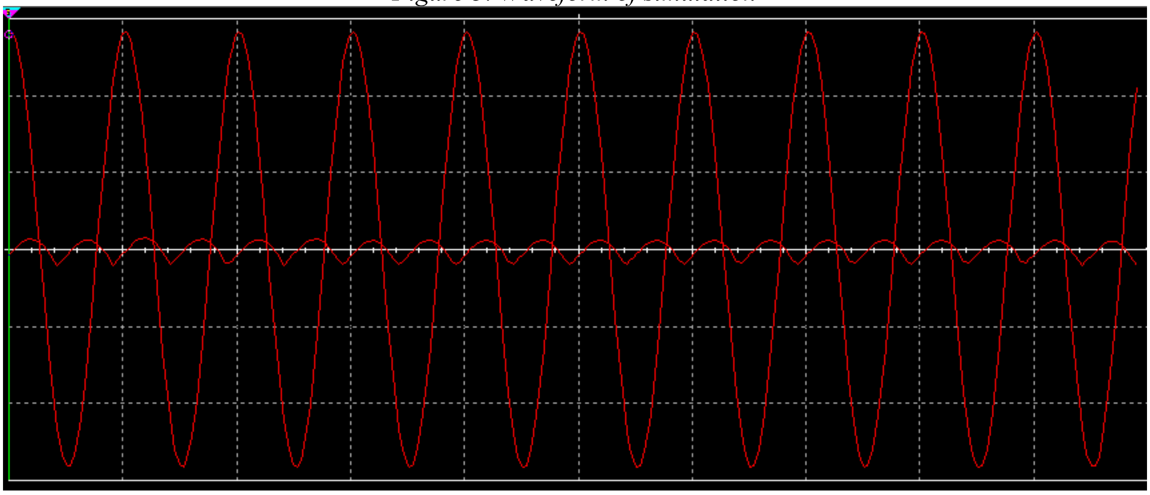
	Launching circuit	Receiving circuit	Load end
C	25.33 nF	50.661 nF	50 uF
R	0.02 Ω	0.01 Ω	5 Ω
L			50.67 nH
V1	100 V 0° 100 kHz		

In the transmitting circuit, the selection of this frequency refers to the wireless charging working frequency band specified in the international standard SAEJ2954, which is in line with the typical application scenarios of wireless charging for electric vehicles. In the receiving circuit, the rectifier bridge structure is composed of four diodes. At the load end, the load resistance R3 is used to simulate the equivalent impedance of the electric vehicle battery in the constant current charging stage. In practice, the internal resistance of the power battery is low at the initial stage of charging, and the 5 Ω load can better reflect the electrical characteristics of this stage. The coupling coefficient k of the coupling mechanism between the transmitting coil and the receiving coil is set to 0.25.

5. Result and Discussion

After running the simulation, the waveform is shown in Figure 3.

Figure 3: Waveform of simulation



The phase of the power supply voltage in the transmitting circuit is basically the same as that of the transmitting coil current, indicating that the circuit is in a resonant state. At this time, the effective value of the voltage is 100 V. The waveform in the receiving circuit presents full-wave rectification characteristics, and the frequency is twice the frequency of the power supply.

Through the above simulation waveforms and data, it can be seen that the wireless charging system designed in this paper is feasible. The current and voltage of the transmitting end are in phase, which proves that the resonant frequency of the transmitting and receiving circuits is 100 kHz. The load at the receiving end obtains a stable DC voltage, which proves that the wireless transmission of energy is successfully realized from the transmitting end to the receiving end. The simulation results show that the wireless charging system designed in this paper has high transmission power in the resonant state, and its circuit structure is relatively simple and the volume is small, which is suitable for the wireless charging application scenario of electric vehicles. However, the system is extremely sensitive to the operating frequency. Once it deviates from the set resonant frequency, the transmission efficiency of the system will be significantly reduced. In the follow-up study, the following aspects can be carried out: optimizing the circuit parameters to improve the frequency adaptability of the system; build a physical model for experimental verification; explore the design based on multi-coil structure to provide more powerful support for the application of electric vehicle wireless charging system.

6. Conclusion

In this paper, A system of wireless charging based on RLC series resonant circuit is designed for the wireless charging demand of electric vehicles. This system is based on the RLC series circuit as the core, through the resonant state of the circuit, to achieve efficient transmission of electric energy. Under the working frequency of 100 kHz, the feasibility of this design is verified by Multisim simulation. This paper improves the stability of the system with a simple resonant structure, which can effectively support the intelligent upgrade of new energy vehicle charging. At the same time, it will help China 's electric vehicle wireless charging technology to achieve large-scale application and industrial breakthrough faster.

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Conflicts of Interest

The authors declare no conflict of interest.

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