

# Mode on Power Distribution of a Dynamic Dual Pickup Wireless Charging System for Electric Vehicles

Guanghua Cao, Xingke Wang, Limei Yan, Yin Jia

School of Electrical Engineering and Information, Northeast Petroleum University, Daqing, China

## Abstract

Power distribution is critical for the dynamic dual receiver coil wireless charging system of electric vehicles. The power distribution method of the existing wireless power transmission technology mainly distributes the power to the load according to the requirements of different resonant frequencies. However, the existing methods have the problems of low accuracy and low power consumption, so it is difficult to implement in practice. This paper presents a new power distribution method, which can dynamically and accurately distribute power to loads. This method can improve the control speed of the receiving circuit without additional circuit on the receiving side, and realize constant power output and efficiency optimization at the same time when there is no communication connection with the transmitter. Therefore, it is easy to realize in the wireless charging system of electric vehicle with dual receiver coil. The experimental results show that the load-side output power of the dynamic radio energy transmission system can be kept constant when moving, and the maximum efficiency of the output system reaches 91.38%. The experimental results prove the effectiveness of the proposed control method.

## Keywords

Electric Vehicle Dynamic Radio Energy Transmission; Double Receiver Coil; Mutual Inductance Estimation.

## 1. Introduction

Wireless Power Transfer (WPT) technology uses the principle of magnetic field coupling to complete the transmission and supply of electric energy without directly connecting the Power supply side and the load side wires. In the whole process of transmission, it is convenient and safe, and can be charged with the use, which can solve many problems of traditional wire power supply[1].

The commonly used WPT technology is divided into static and Dynamic modes. The Dynamic Wireless Power Transfer (DWPT) technology can ensure the electric Power supply of electric vehicles when they are running, and get rid of the constraints of the traditional wire Power supply pair. Avoid the awkward situation that the car cannot be used during static charging, and solve the problem that electric cars carry heavy batteries[2].

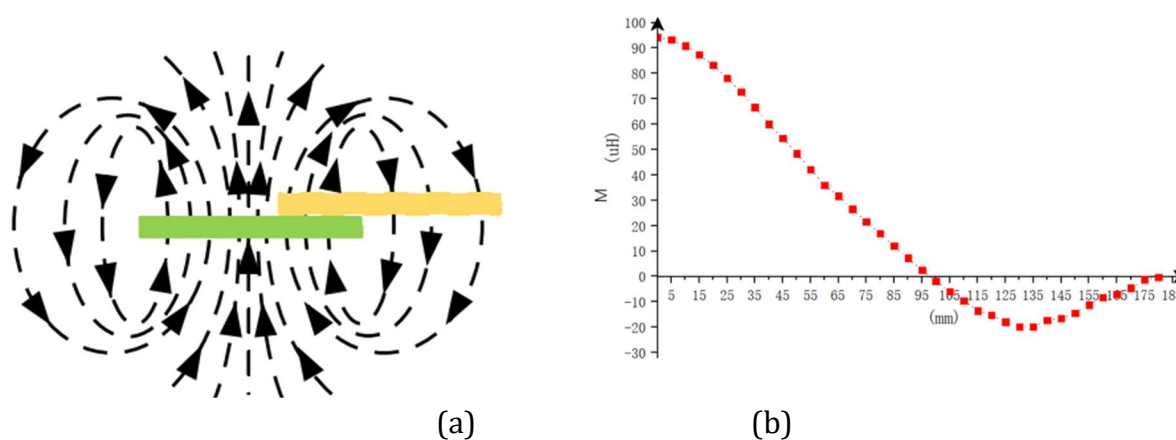
## 2. Coil Structure

### 2.1. Common Coil Structure

Unipolar and bipolar coils are common structures in the coupling mechanism of radio energy transmission devices. Unipolar coil is D - type structure. Bipolar coil is made up of two unipolar coils with the same parameters but opposite directions, so it is also called DD coil. BP coil type

structure with double coil structure, which is composed of two type D coil, but unlike the DD coil, superposition of the two basic part of coil, and according to two different coil overlap distance BP coil to realize the mutual inductance between two basic coil is greater than zero and mutual inductance, mutual inductance is less than zero three states[3].

In order to increase the transmission efficiency of the device without increasing too much cost, the BP coil composed of two unipolar coils is used as the receiving coil of the secondary side in this paper[4]. Under the condition of constant power output and high efficiency of the system, mutual inductance between the two coils forming the secondary side is zero: Under the condition of self-inductance of secondary coil and mutual inductance of primary coil, the appropriate stacking distance is selected to cancel mutual inductance of two monopole coils in BP coil.



**Figure 1.** BP coil decoupling diagram and decoupling curve

As shown in Figure 1. (a), in BP coil, as the superposition distance of the two basic coils changes in a certain direction, their mutual inductance becomes zero at a certain distance, that is, mutual decoupling is realized. When the two coils are decoupled, the magnetic flux in and out of each coil reaches a dynamic balance, and the mutual inductance is zero. The decoupling curve is shown in Figure 1.

## 2.2. Guide Power Supply Mode

At present, there are mainly two distribution modes of primary side-coil, which are single rail power supply and multi-rail cascade power supply[5]. The two power supply modes are shown in Figure 1.2. As shown in Figure 2 (a), the characteristics of the single-guide power supply mode are as follows: the guide length is long, the structure is simple, the guide has a wide charged range and is practical, but the equivalent internal resistance of the guide is large; As shown in Figure 1.2 (b), the multi-guide power supply mode is characterized by cascade of multiple short guides, which can realize segmented power supply with less energy loss. From the perspective of maintaining system stability, security, energy saving and emission reduction, the second power supply mode is more consistent with the practical application[5]. Therefore, the design of the primary side coil adopts the power supply mode of multi-rail cascade, combined with the size of the coil, spacing and loosely coupled transformer air gap and other parameters design, so as to achieve the purpose of stable and efficient power transmission of the transmission device[6].

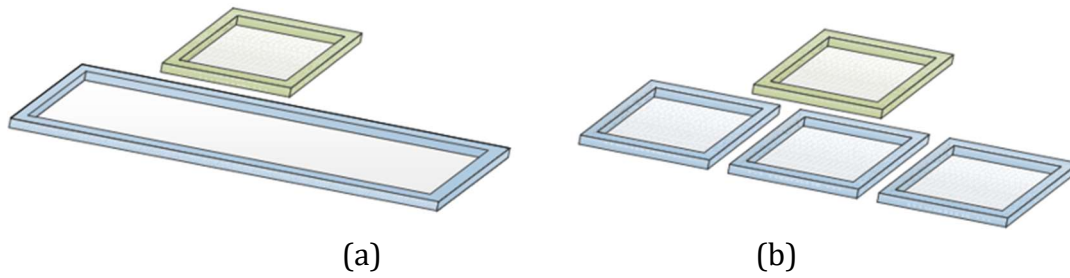


Figure 2. Two power supply modes of guide rail

**2.3. System Coupling Mechanism**

The loosely-coupled transformer is the most important mechanism in the radio energy transmission device, which can affect the power transmission characteristics and efficiency characteristics of the whole device. The structure of loosely coupled transformer mainly includes transmitting coil on the primary side, receiving coil on the secondary side and ferrite core. The BP coil structure is used in the secondary side of the coupling mechanism. At the same time, the decoupling between the two basic coils is needed to achieve the same function and reduce the material cost. The coil on the primary side is arranged in DD type, which has less magnetic leakage than the d-type coil and higher coupling coefficient with the secondary side coil.

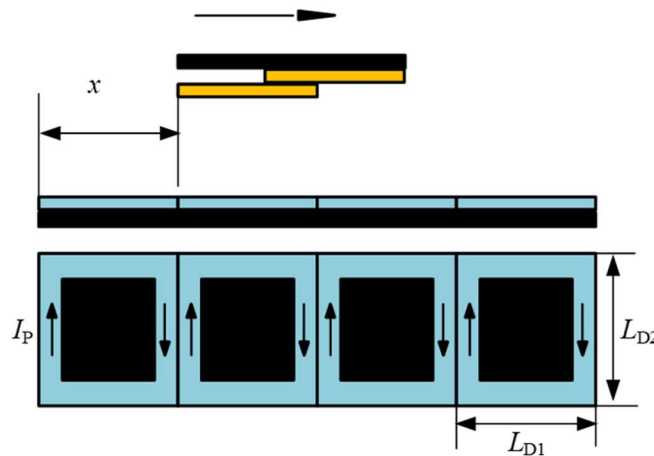


Figure 3. Schematic diagram of coil structure

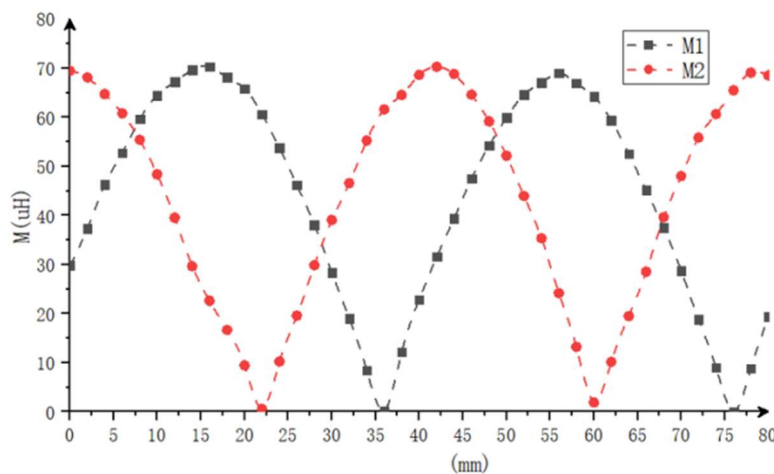
In this design, the motion diagram of single launch and double pick coupling mechanism of WPT device is shown in 1.3. Let the mutual inductance between coupling mechanisms be and. The primary multi-coil cascade power supply track is composed of unipolar D-type coils arranged in different directions to provide a stable coupled magnetic field for the moving BP coil. The specific parameters of loosely coupled transformer are shown in Table 1-1. In the coupling mechanism adopted in this paper, when the secondary side coil moves in a certain direction, the mutual inductance curve between the coil and the primary side power supply track follows sinusoidal distribution, which can be approximately described as[7]:

$$M_i = M_{A_0} [\sin(2\pi/l_{D1})] \tag{1}$$

**Table 1.** Loosely coupled transformer parameters

circuit parameters	value	circuit parameters	value
$L_p$	182.4 $\mu H$	$L_{s2}$	153.9 $\mu H$
$R_p$	0.93 $\Omega$	$R_{s2}$	0.89 $\Omega$
$L_{s1}$	156.2 $\mu H$	$R_{s1}$	0.91 $\Omega$

In Formula (1), is the maximum mutual inductance when d-type coil and a basic coil are aligned in space, is the side length of primary side-coil, and is the moving distance of BP coil. Figure4 shows the change curve of primary side mutual inductance measured and drawn by Maxwell simulation software. In order to better obtain the curve, the displacement of BP coil moves 80cm along the Y-axis ( $0 \sim 2^{l_{D1}}$ ).



**Figure 4.** Variation curve of mutual inductance

### 3. Power Distribution Analysis of Dynamic Radio Energy Transmission System

#### 3.1. Circuit Topology Analysis of Dynamic Radio Energy Transmission System based on S-S Compensation

The circuit topology of the radio energy transmission device designed in this paper is shown in Figure 2.1. The s-S compensation topology is selected at the same time for the primary side and secondary side, which can reduce the mutual inductance of the secondary side coil when it moves and the influence of load change on the primary side coil, and provide magnetic field when the mechanism carries out power transmission. Where,  $U_d$  is the equivalent DC voltage source at the input end;  $L_p, C_p$  is the coil inductance and series compensation capacitance of the primary side, and  $L_{s1}, L_{s2}, C_{s1}, C_{s2}$  is the equivalent inductance and series compensation capacitance of the two basic coils of BP coil respectively. And are mutual inductance between coupling mechanisms.

When the device starts to work, the compensation capacitors of the primary side and the secondary side realize resonance with the coil inductance, that is, the working frequency of the primary side and the secondary side meets (2). The power of the AC power supply to the secondary side through the coupling mechanism can be described in (2) and (3).

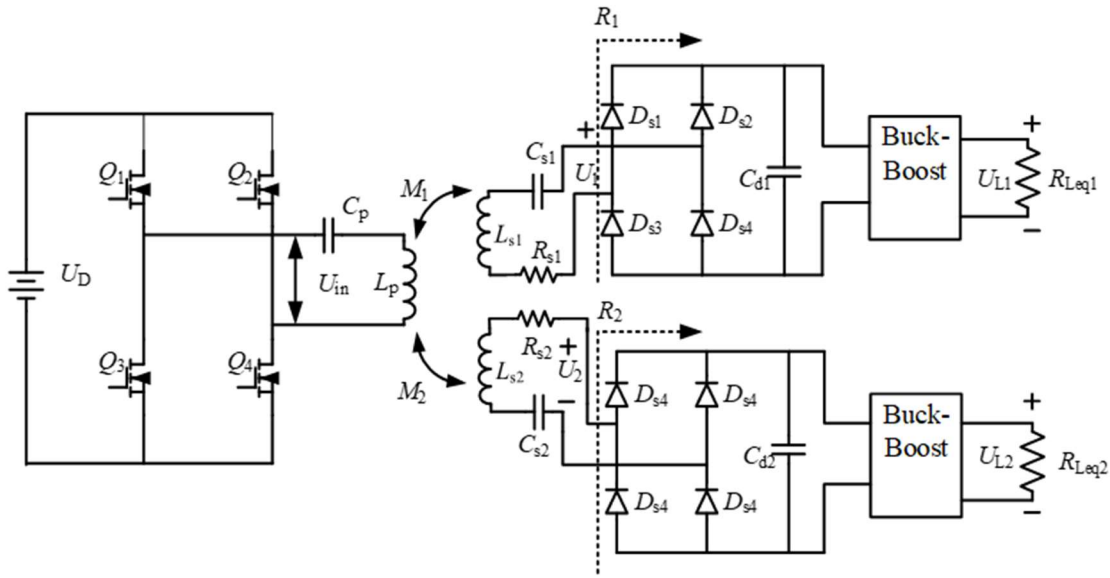


Figure 5. Overall topology of dynamic radio energy transmission structure system

$$2\pi f = \omega_p = \omega_s = \omega_0 = \frac{1}{\sqrt{L_p C_p}} = \frac{1}{\sqrt{L_s C_s}} \tag{2}$$

$$P_1 = \frac{U_{in}^2 \omega^2 M_1^2 R_1 (R_2 + R_s)^2}{\{R_p (R_1 + R_s)(R_2 + R_s) + [M_2^2 (R_1 + R_s) + M_1^2 (R_2 + R_s)] \omega^2\}^2} \tag{3}$$

$$P_2 = \frac{U_{in}^2 \omega^2 M_2^2 R_2 (R_1 + R_s)^2}{\{R_p (R_1 + R_s)(R_2 + R_s) + [M_2^2 (R_1 + R_s) + M_1^2 (R_2 + R_s)] \omega^2\}^2} \tag{4}$$

$$P_t = \frac{U_{in}^2 \omega^2 [M_2^2 R_2 (R_1 + R_s)^2 + M_1^2 R_1 (R_2 + R_s)^2]}{\{R_p (R_1 + R_s)(R_2 + R_s) + [M_2^2 (R_1 + R_s) + M_1^2 (R_2 + R_s)] \omega^2\}^2} \tag{5}$$

Therefore, the output power of the whole device is the superposition of the received power of two equivalent loads, namely  $P_t = P_1 + P_2$ , whose expression is shown in (5).

#### 4. Simulation Experiment

In this section, MATLAB and Simplorer are used for joint simulation. The simulation motion model of the device is established in ANSYS Maxwell, and the feasibility of the proposed mutual inductance estimation and power distribution method is verified in the joint simulation of MATLAB and Simplorer. In order to reduce the difference between the simulation results and the calculation results, the diode and MOSFET are set as ideal devices in the simulation model. In order to verify the power distribution control method of mutual inductance estimation, the circuit modeling and experimental simulation of the 3kW power transmission device mentioned in the design objective are carried out in this section. Table 4-1 lists the simulation parameters.

**Table 2.** Circuit parameters of the simulation model

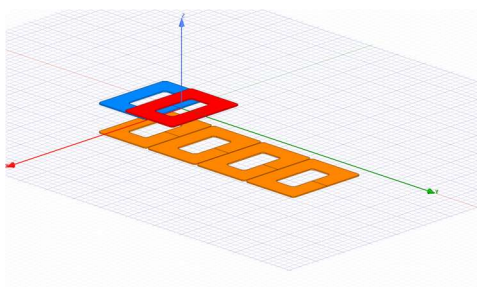
circuit parameters	value	circuit parameters	value
$L_p$	182.4 $\mu H$	$U_{in}$	220v
$R_p$	0.093 $\Omega$	$f_1$	85kHz
$C_p$	51.54 $\mu F$	$f_2$	100kHz
$L_{s1}$	156.2 $\mu H$	$R_{eq1}$	20 $\Omega$
$R_{s1}$	0.09 $\Omega$	$R_{eq2}$	20 $\Omega$
$C_{s1}$	51.91 $\mu F$	$d_1$	0.5
$L_{s2}$	153.9 $\mu H$	$d_2$	0.5
$R_{s2}$	0.09 $\Omega$	$C_{s2}$	51.25 $\mu F$

In order to verify the mutual inductance estimation method, ANSYS Maxwell software was first used to model the coupling mechanism and measure the mutual inductance between the primary side coil and the secondary side coil. The measured values are shown in Table 2. Then, the mutual inductance of the primary and secondary sides was estimated, and the difference between the measured results and the estimated results was less than 10%, which may be caused by the error caused by replacing solid winding with wire disk winding when modeling the coupling mechanism in Maxwell simulation. The estimated mutual inductance coefficients are shown in Table 2, and the calculation results are also listed in Table2.

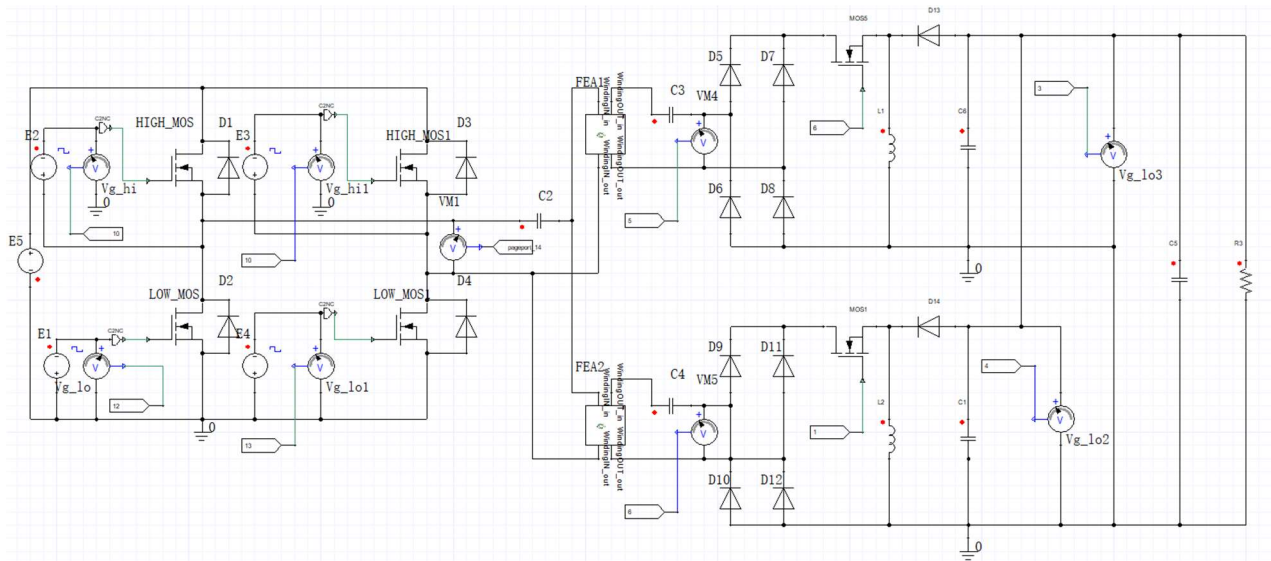
According to the above design and analysis of the new compensation network, the dynamic radio energy transmission model is built with ANSYS Maxwell, as shown in Figure 3.

**Table 3.** Calculation and simulation results of mutual inductance estimation

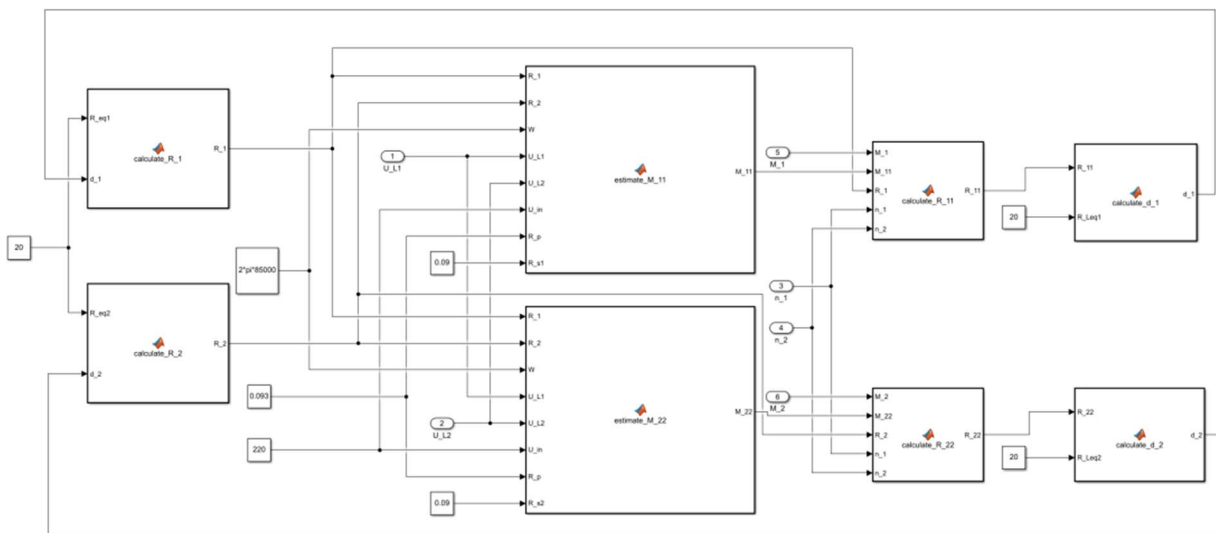
class number		estimated value	simulation value
1	$M_1$	68.88	68.1
	$M_2$	41.96	41.02
2	$M_1$	52.98	51.92
	$M_2$	48.65	48.11
3	$M_1$	41.22	42.1
	$M_2$	60.21	60.33



**Figure 6.** Coil motion model



**Figure 7.** External circuit model of dynamic radio energy transmission



**Figure 8.** Control circuit

### 5. Conclusion

This paper presents a new power distribution method for electric vehicle dynamic dual pickup wireless charging system. Compared with the existing power distribution methods, the proposed method fully considers the mutual inductance variation caused by electric vehicle motion. The optimal equivalent load is derived from a constant output condition and is used to distribute power according to load demand. In addition, the method can simultaneously achieve a constant total output power.

### Acknowledgments

This paper is supported by the higher education teaching reform project of Heilongjiang Province ( No.SJGY20210111).

## References

- [1] Optimal load ratio control for dual-receiver dynamic wireless power transfer maintaining stable output voltage[J].
- [2] Qin Liyuan. Research on Anti-Offset Characteristics and Parameter Design of Coupling Mechanism of ELECTRIC Vehicle Mc-wpt System [D], 2019.
- [3] Li Yong, MAI Ruikun, MA Linsen, et al. An Inductive Power Transmission System with Double Primary Coil and Its Power Distribution Method [J]. Proceedings of the CSEE, 2015, 35(17): 4454-4460.
- [4] Yongcan Huang, Chunhua Liu, Yujing Zhou, et al. Power Allocation for Dynamic Dual-Pickup Wireless Charging System of Electric Vehicle [J]. Ieee Transactions on Magnetics, 2019, 55(7): 1-6.
- [5] YE Xing. Research on Dynamic Radio Energy Transmission System for Electric Vehicle [D], 2020.
- [6] HUANG Xueliang, TAN Linlin, Chen Zhong, et al. Transactions of China Electrotechnical Society, 2013, 28(V.28): 1-11. (in Chinese).