Suitable for the Design of Electric Vehicle Charger LLC Half-Bridge Converter

Bowen Hou, Guangzhui Wei, and Hailong Ma

Abstract The development of new energy vehicles is the only way for China to move from a large automobile country to an automobile power, and it is a strategic measure to address climate change and promote green development. Based on the electric vehicle charger, the design of the half-bridge LLC resonant circuit changer is carried out to improve the charging device of new energy electric vehicles, and the resonant parameter design and resonant frequency gain system design of the half-bridge LLC half-bridge converter of the electric vehicle charger LLC are studied by analyzing the working principle and working characteristics of the half-bridge LLC resonant circuit. Through MATLAB for half-bridge LLC resonant circuit and debugging, observe the waveform and data to obtain the simulation model can effectively ensure the stability of the output, in the full load and heavy load output voltage fluctuation is within the range of change, thus verifying the feasibility of the design of the electric vehicle charger LLC half-bridge resonant converter, therefore, the LLC resonant converter can improve the conversion efficiency of the DC-DC converter, so that the charging efficiency is greatly accelerated, so as to achieve fast charging. It is efficient and fast to apply to the needs of high-power power supplies, thereby promoting the development of new energy vehicles.

Keywords DC-DC converter · EV chargers · Half-bridge LLC resonant converter · MATLAB simulation

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1 Introduction

With the continuous consumption of global non-renewable energy and the intensification of environmental pollution problems, the status of electric vehicles that are considered clean and new energy has been continuously improved, and the development of new energy electric vehicles has become the focus of social attention. The development of new energy vehicles is the only way for China to move from a major automobile country to an automobile power, and it is a strategic measure to address climate change and promote green development. However, in the process of promoting the development of new energy vehicles, the charging efficiency of new energy electric vehicles has been questioned, so on the basis of the research status and technical difficulties of high-power on-board chargers of electric vehicles, the research on the resonant converter of the post-stage LLC to improve the conversion efficiency of the post-stage DC-DC converter, so that the charging efficiency is greatly accelerated, so as to achieve fast charging is particularly important. In this paper, a simple and reliable design method is used to study the post-stage LLC resonant converter in depth, and the reliability and stability of this design method are proved through theoretical and simulation observation records [1].

2 LLC Half-Bridge Working Principle and Characteristic Analysis

In this paper, the half-bridge LLC resonant topology is selected, because the excitation source inverter circuit of the LLC resonant converter can also use the full-bridge structure or half-bridge structure, but in the case of the same gain obtained, the half-bridge structure uses fewer components, and the number of turns on the primary side of the transformer is less than half of the full-bridge circuit, which can effectively reduce the weight of the charger and is cost-effective [2]. As shown in Fig. 1, with the dead time ignored, the half-bridge structure consists of switch tubes S1 and S2, and the switch top tube S1 and switch down tube S2 alternately complement each other on and off the drive signal through the half-bridge topology with a fixed duty cycle of 50% [3]. The resonant cavity consists of two resonant inductive elements, namely the excitation inductor Lm and the resonant inductor Lr, which are composed of a resonant capacitor Cr, where Lm is usually the transformer excitation inductor, and the resonant capacitor Cr also plays the role of DC isolation. After the resonant Lm and the load are connected in parallel with Lr and Cr, through the frequency control of the switch tube driving signal, the switching tube working frequency is slightly higher than the resonant frequency, then the resonance produces a current signal similar to a sine wave, and its current phase is slightly lagging behind the voltage phase of the resonant cavity input, so that the entire cavity is inductive, so that ZVS

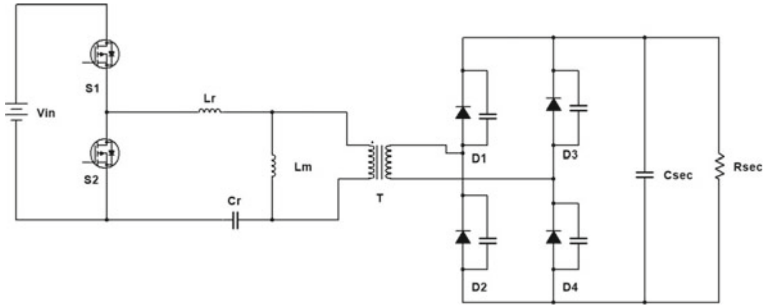

Fig. 1 Schematic diagram of the half-bridge LLC resonant main circuit

can be realized. The secondary side of the transformer is composed of rectifier diodes D1, D2, D3, and D4 to form a full-wave rectifier circuit, the capacitor Csec is the output filter capacitor, and then, we form direct current in the filter part to power the electric vehicle charger [4].

3 Suitable for EV Charger LLC Half-Bridge Converter Parameter Design

The design of EV charger LLC half-bridge converter parameters is the most critical step to improve the conversion efficiency of the post-stage DC-DC converter. Therefore, it is particularly important to design a suitable order of LLC half-bridge resonant transformation parameters and to comply with various rules [5].

The LLC resonant converter operates at two resonant frequencies, namely the series resonant frequency generated by the resonant capacitor C_r and the resonant inductor L_r, and the series–parallel resonance frequency generated by the resonant capacitor C_r, the resonant inductor L_r, and the excitation inductor L_m.

Series resonant frequency generated by resonant capacitor C_r and resonant inductor L_r:

$$f_r = \frac{1}{2\pi\sqrt{L_r C_r}} \tag{1}$$

Series and parallel resonant frequency generated by resonant capacitor C_r, resonant inductor L_r, and excitation inductor L_m:

$$f_m = \frac{1}{2\pi\sqrt{(L_m + L_r)C_r}} \tag{2}$$

3.1 Determine the Transformer Ratio

When designing a half-bridge LLC resonant converter, we first need to determine the input voltage required for our design in this article and the input voltage (V) and set the output voltage (V) for output voltage setting according to the theory of the LLC resonant converter:

$$V_{\text{input}} = 390;\ V_{\text{inputmin}} = 365;\ V_{\text{inputmax}} = 405;\ V_{\text{output}} = 55V$$

The selection of a suitable core model is not only based on theoretical calculations to determine the turns ratio of the transformer, but also the original calculation without considering the resonant gain adjustment, series–parallel resonance frequency F_r.

Turns ratio of transformers:

$$n = \frac{V_{\text{input}}}{2V_{\text{output}}} = 3.7 \tag{3}$$

There into V_{input} is the input voltage, and V_{output} is the output voltage.

3.2 Determine the Maximum and Minimum Gain

First, we first determine the voltage rating of the rectifier diode tube voltage drop and the voltage drop on the secondary side line, because the voltage rating of the diode tube voltage drop and the voltage drop on the secondary side line is an important factor in determining the maximum and minimum gain [6].

Diode tube voltage drop:

$$V_D = 0.7V \tag{4}$$

The rated voltage drop on the secondary line:

$$V_{\text{loss}} = 1.05V \tag{5}$$

Calculate the minimum gain:

$$H_{g\min} = \frac{n(V_{\text{outmin}} + V_D)}{\left(\frac{V_{\text{inputmax}}}{2}\right)} = 1.019 \tag{6}$$

Calculate the maximum gain:

$$H_{g\max} = \frac{n(V_{\text{outmin}} + V_D + V_{\text{loss}})}{\left(\frac{V_{\text{inputmin}}}{2}\right)} = 1.152 \tag{7}$$

The highest gain values are:

$$H_{g\max} = 1.2 \tag{8}$$

3.3 Select the Appropriate *Γ* and Q Values and Plot the Gain Curve of the LLC Half-Bridge Converter

Characteristic impedance:

$$Z_0 = \sqrt{\frac{L_r}{C_r}} = 2\pi f_r L_r = \frac{1}{2\pi f_r C_r} \tag{9}$$

Factor of merit:

$$Q = \frac{Z_0}{R_{ac}} = \frac{Z_0}{n^2 R_e} = \frac{\pi^2 Z_0 P_0}{8n^2 V_0^2} \tag{10}$$

Ratio of inductance:

$$L_n = \frac{L_m}{L_r} \tag{11}$$

Normalization frequency:

$$f_n = \frac{f_s}{f_r} \tag{12}$$

Define γ and Q values:

$$\gamma = 3.5,\ Q = 0.27 \tag{13}$$

In an LLC half-bridge converter, the converter gain is mainly determined by the switching frequency, and the LLC gain function is calculated:

$$H(\gamma, Q, f_n) = \frac{1}{\sqrt{\left[1 + \frac{1}{\gamma}\left(1 - \frac{1}{f_n^2}\right)\right]^2 + \left[Q\left(f_n - \frac{1}{f_n}\right)\right]^2}} \tag{14}$$

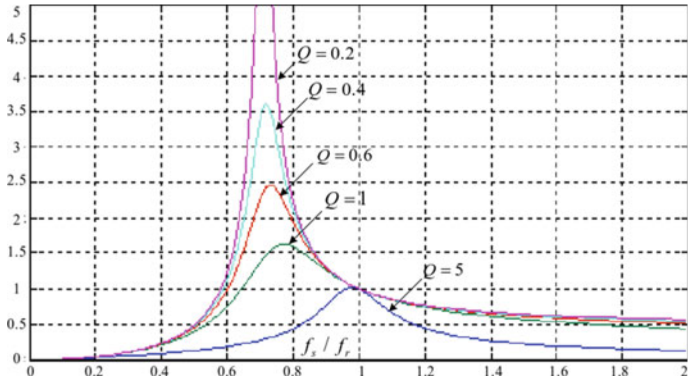

Fig. 2 DC gain curves for different quality factors

Cuse $Q = 0$, that is, the DC voltage gain of the converter in the no-load state is (Fig. 2):

$$M_{\mathrm{OL}}(f_n, \lambda) = \frac{1}{1 + \lambda - \frac{\lambda}{f_n^2}} \tag{15}$$

3.4 *Determine the Equivalent Resistance and Calculate the Resonance Parameters*

Equivalent load calculation (rated output power rated output voltage): When the output voltage is 55 V and the output current is 11.5 A, then:

$$R_L = \frac{V_{\mathrm{output}}}{I_o} = 4.78\ \Omega \tag{16}$$

$$R_{L\min} = \frac{V_{\mathrm{output}}}{1.1 I_o} = 4.34\ \Omega \tag{17}$$

Equivalent internal resistance:

$$R_e = \frac{8n^2}{\pi^2} R_L = 53.09\ \Omega \tag{18}$$

$$R_{e\min} = \frac{8n^2}{\pi^2} R_{L\min} = 48.20\ \Omega \tag{19}$$

Calculate the resonant capacitance:

$$C_r = \frac{1}{2\pi Q\pi R_e} = 1.12 \times 10^{-7} F \quad (20)$$

Calculate the resonant inductance:

$$L_r = \frac{1}{(2\pi f_r)^2 C_r} = 2.26 \times 10^{-5} H \quad (21)$$

Calculate the excitation inductance:

$$L_m = \gamma L_r = 7.91 \times 10^{-5} H \quad (22)$$

The MOSFET tube is selected as the switching transistor, in order to make the on-resistance small enough, its maximum peak current rating should be 5 ~ 10 times of the peak current of the above equation, which can reduce the on-voltage drop and loss [7].

3.5 *Design Resonance Parameters*

In summary, the design requirements for the parameter design of the LLC half-bridge converter suitable for electric vehicle chargers are shown in the following Table 1.

By designing the parameters of the LLC half-bridge converter suitable for electric vehicle chargers, we then use the principle of LLC resonant converter and related formulas to calculate the transformer turn ratio, gain range, resonant frequency range,

Table 1 Design indicators and some device parameters of the electric vehicle charger LLC half-bridge converter

Input DC Voltage range	V_{input}	365 ~ 405 V
Rated input DC voltage	V_{rated}	390 V
Rated output voltage	V_{out}	55 V
Rated output current	I_{out}	11.5 A
Rated power	P	600 W
Expect efficiency	H	97%
Duty cycle	DT	0.5
Rectifier diodes On-voltage drop	DV	0.7 V

Table 2 Circuit device parameters suitable for EV charger LLC half-bridge converter design

Transformer Turns ratio	N1:N2	3.7:1
Gain range	M min ~ max	0.533 ~ 1.191
Resonant frequency range	Fr min ~ max	80 ~ 130 kHz
Inductance ratio	Ln	3.5
Resonant capacitors	Cr	112nF
Resonant inductance	Lr	22.6μH
Excitation inductance	Lm	7.91μH

inductance ratio, resonant capacitance, resonant inductance, and inspirational inductance. The specific main circuit device parameters of the LLC half-bridge converter design are shown in the following table, that is, the main circuit device parameters of the LLC half-bridge converter design in Table 2 [8].

4 Resonant Gain System Design

After the input 390 V DC is step-down and resonant converted, the output is obtained after rectification and filtering on the secondary side of the transformer to obtain a DC current with an output of about 55 V. Because the characteristics of the LLC circuit are low-frequency filtering, energy is transferred through the fundamental image load, and resonant conversion is required in this process, so we need to design a resonant frequency to control the half-bridge LLC switch, so that the output voltage is more stable and reliable, and the resonant frequency gain system is shown in Fig. 3.

According to the characteristics of the impedance of the resonant element in the resonant network with frequency, the constant voltage output of the resonant converter can be realized, and the control and adjustment of the voltage gain can be realized by adjusting the size of the voltage injected into the resonant network by adjusting the switching frequency injected by the switching network. The system simulation is carried out on the basis of the block diagram of the resonant frequency gain system of the half-bridge LLC in the figure above. The simulation diagram of the resonant frequency gain system of the half-bridge LLC is shown in Fig. 4.

5 MATLAB Simulation and Results Analysis

In order to show the working process of the half-bridge LLC converter more clearly, the Simulink module in MATLAB is used to build a model of the half-bridge LLC resonant converter and simulate it, and replace the load with resistance, and apply the oscilloscope to detect the voltage and current waveforms of various components. The simulation is shown in the figure below, and Fig. 5 is a simulation design for the

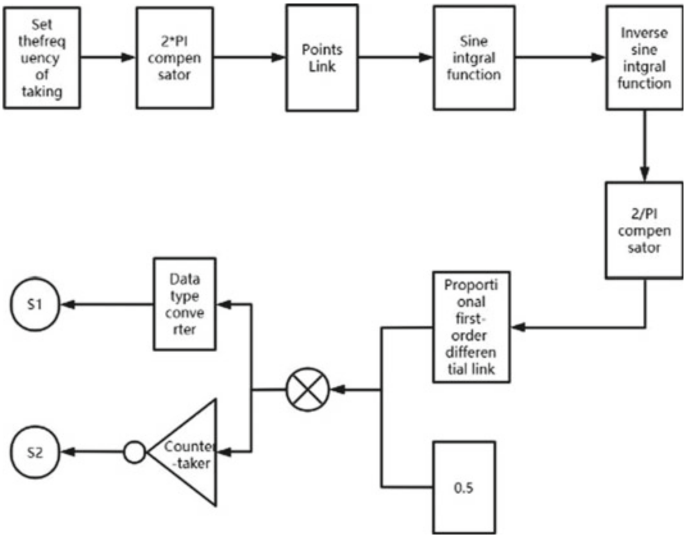

Fig. 3 Resonant frequency gain system diagram of half-bridge LLC

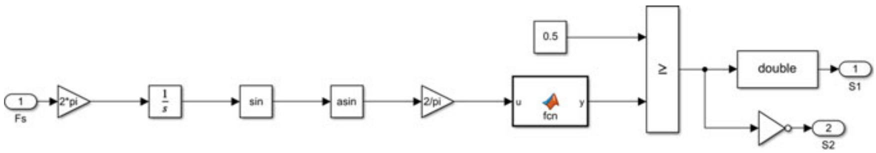

Fig. 4 Simulation diagram of resonant frequency benefit system of half-bridge LLC

LLC half-bridge converter suitable for electric vehicle chargers. The figure consists of the main circuit section, the lower left resonant frequency system section, and the right oscilloscope [9].

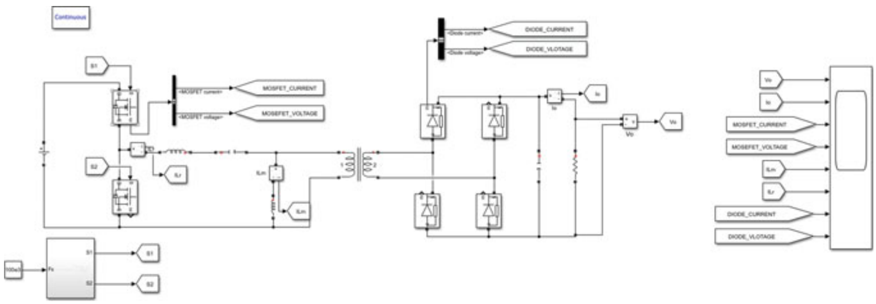

Fig. 5 Simulation design diagram of LLC half-bridge converter suitable for electric vehicle charger

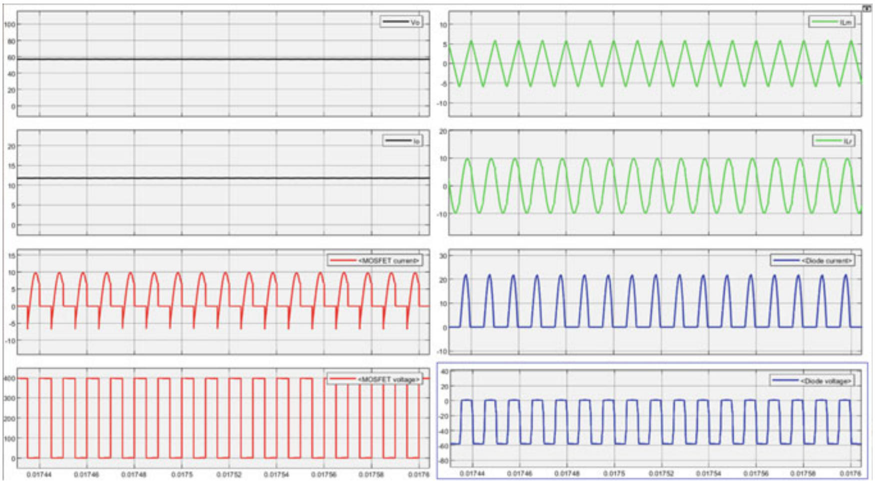

Fig. 6 Waveform diagram of various components suitable for simulation of electric vehicle charger LLC half-bridge converter

The two figures in the lower left corner of Fig. 6 are the current and voltage waveforms of the MOSFET in the LLC half-bridge converter; the two figures in the upper right corner are the current waveform diagram of the excitation inductor Lm and the resonant inductor Lr; the two figures in the lower right corner are the current and voltage waveforms of the rectifier diode [10].

Figures 7 and 8 show 390 V AC input, 55 V output voltage, and 11.5 A output current waveforms. From the above figure, it can be concluded that the output voltage and current are relatively stable, and the output data meets the requirements of theoretical calculation.

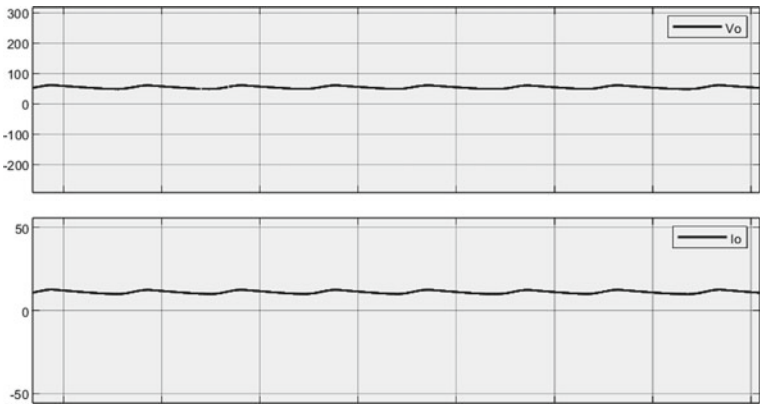

Fig. 7 Output voltage and current waveform diagram

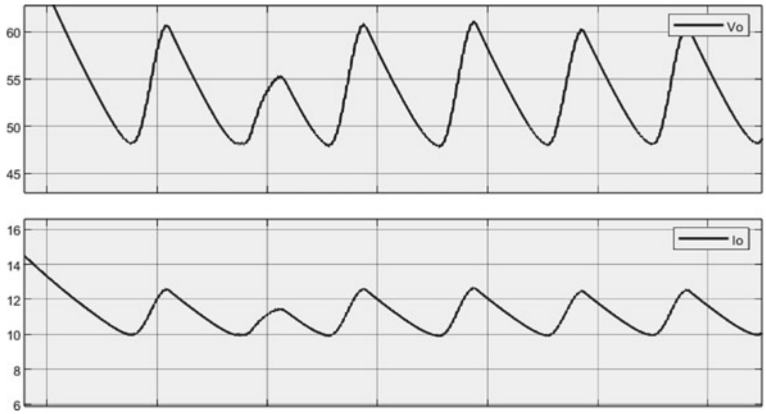

Fig. 8 Output voltage and current waveform diagram

6 MATLAB Simulation and Conclusions

This simulation design is to optimize the post-stage DC/DC circuit part of the electric vehicle charger, design the half-bridge LLC resonant circuit changer, analyze the working principle and working characteristics of the half-bridge LLC resonant circuit, study the resonant parameter design of the electric vehicle charger LLC half-bridge converter, conduct half-bridge LLC resonant circuit and debugging through MATLAB, and observe the waveform and data to obtain the simulation model can effectively ensure the stability of the output. The output voltage fluctuation is within the range of full load and no load, which verifies the feasibility of the resonant parameter design of the electric vehicle charger LLC half-bridge converter, so this design can improve the conversion efficiency of the DC-DC converter, greatly accelerate the charging efficiency, and realize fast charging. Meet the needs of efficient, fast, and high-power power supplies.

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