

A Novel LLC Resonant Converter Circuit-Input Parallel Output Series Subside Resonant LLC Resonant Converter

Ting Yu^{1*}, Xikun Chen¹ and Dongjing Wu¹

¹Electrical engineering, Shanghai University, Shanghai, 201100, China

*Corresponding author's e-mail: 1175709163@qq.com

Abstract. At present, LLC resonant converters are mostly used in step-down situations. The reason why LLC resonant converters are not used in high step-up situations is that parasitic parameters caused by high turn-to-turn ratio of transformers affect the circuit and the large current stress of switching devices and resonant components on the input side. In this paper, a new type of LLC resonant converter circuit, i.e. input parallel output series subside resonant LLC resonant converter, is designed. It can not only reduce the current stress borne by the switching devices on the input side and the resonant components, but also reduce the turn-to-turn ratio of the transformer under the same output voltage. Therefore, it can be used in boost occasion to output high voltage. In this paper, a new type of circuit is used in high boost situation, and the final output is stable 2KV high voltage.

1. Introduction

Resonant converter has been widely used because of its high efficiency, high power density, small electromagnetic interference and wide input voltage range. In particular, LLC resonant converter can realize zero voltage switching of power switch and zero current switching of rectifier diode in full load range. At present, the research of LLC resonant converter mainly focuses on voltage stabilization and voltage reduction [1-3]. The parasitic parameters of transformer affect the circuit, which leads to the instability and uncontrollability of the circuit, as well as the large current stress on the switching devices and harmonic components on the input side, which results in the high requirement and large volume of the device, so it is not suitable for high boost voltage situations.

In this paper, a new type of LLC resonant converter circuit, multi-module input parallel output series subside resonant LLC resonant converter, is designed. The current stress of the resonant element is reduced by using the second-side resonance. The current stress of the switching device and the voltage stress of the subside element can be reduced by using the multi-module input parallel output series converter [5]. To increase the output voltage, and the multi-module can greatly reduce the turn-to-turn ratio of the transformer, thereby reducing the parasitic parameters of the transformer on the circuit. In order to verify the feasibility of the circuit, the circuit of LLC converter with multi-module input parallel output series subside resonant is modeled and simulated in MATLAB. The simulation results show that the designed multi-module input parallel output series subside resonant LLC resonant converter can output 2kV stable voltage and has good steady-state performance.

2. Operating Principle of Input-Parallel-Output Series Parallel-Side Resonant LLC Resonant Converter

The input parallel output series subside resonant LLC resonant converter uses secondary side resonant to reduce the current stress of the resonant element. The multi-module input parallel output series



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

converter can reduce the current stress of the switching device and the voltage stress of the secondary side resonant converter. Because of the multi-module, compared with the single-module LLC resonant converter circuit, the multi-module input parallel output series converter can reduce the current stress of the switching device. The turn-to-turn ratio of the transformer can be greatly reduced, and the parasitic parameters of the transformer can be reduced. The model of the new circuit is shown in Fig. 1. In this paper, the two-module system is analyzed.

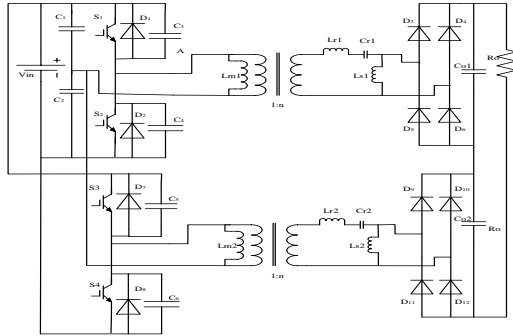


Figure 1. Input-Parallel-Output Series Second-Side Resonant Slot LLC Converter.

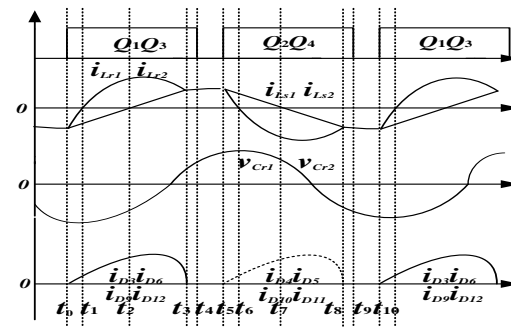


Figure 2. Main working waveforms.

Firstly, the transient process of the circuit is analyzed. The main waveform of the system is shown in Fig. 2, and the switching mode of the system is analyzed.

Switching mode 1 $[t_0-t_1]$, as shown in Figure 3 (a): at t_0 , the switches Q_1 and Q_3 are turned on at zero voltage. At this time, the direction of the resonance current at the side of the secondary side has not changed for the time being, but the current value decreases rapidly. The rapid attenuation of the secondary resonant current will produce a reverse voltage in the secondary winding which is not related to the resonant current reference direction. When the reverse voltage is greater than the sum of the output voltage and the on-off voltage drop of two rectifier diodes, the rectifier diodes D_3 , D_6 , D_9 and D_{12} are on, and the inductors L_{s1} and L_{s2} are clamped in V_o , without participating in resonance, and the inductor current begins to increase linearly in reverse direction.

Switching mode 2 $[t_1-t_2]$, as shown in Fig. 3 (b): changes in the direction of i_{Lr1} and i_{Lr2} of the secondary side resonance current at t_1 , while the direction of i_{Ls1} and i_{Ls2} of the excitation current remains unchanged for the time being. Both of them provide the load current i_p . Secondary rectifier diodes D_3 , D_6 , D_9 and D_{12} are on, inductors L_{s1} and L_{s2} are clamped in V_o , and inductor current continues to increase linearly in reverse direction.

Switching mode 3 $[t_2-t_3]$, as shown in Fig. 3 (c): the direction of excitation current changes at t_2 . The difference between resonance current i_{Lr1} , i_{Lr2} and excitation current i_{Ls1} , i_{Ls2} is equal to load current i_{p1} and i_{p2} . At t_3 , although the V_{AB} is still greater than 0, the resonant current is not enough to support the rising rate of excitation current. i_{p1} and i_{p2} are equal to 0. At this time, the current of D_3 , D_6 , D_9 and D_{12} is naturally zero-crossing, the diode achieves zero current switching (ZCS).

Switching mode 4 $[t_3-t_4]$, as shown in Fig. 3 (d): during t_3-t_4 period, the resonant currents i_{Lr1} and i_{Lr2} are equal to the excitation currents i_{Ls1} and i_{Ls2} . Excitation inductors L_{s1} , L_{s2} , resonant inductors L_{r1} , L_{r2} , resonant capacitors C_{r1} , C_{r2} participate in LLC resonance, diode D_3 , D_6 , D_9 , D_{12} reverse bias cut-off. Because the switches Q_1 and Q_3 are turned off at t_4 , the diodes D_4 , D_5 , D_{10} and D_{11} are also cut off during t_3-t_4 . Therefore, in t_3-t_4 time, the energy required to load R_{Ld} is supplied by capacitor C_f , and the converter depends on capacitor C_f to maintain the output voltage unchanged.

Switching mode 5 $[t_4-t_5]$, as shown in Fig. 3 (e): at t_4 , the switch Q_1 and Q_3 are turned off, and Q_2 and Q_4 are still turned off, and the circuit enters dead time. Rectifier diodes D_3 , D_6 , D_9 and D_{12} are cut off by reverse bias. The output is isolated by transformer, and the output capacitor C_f supplies power to the load. Because the inductances i_{Ls1} and i_{Ls2} have large inductance values and the duration of mode 5 is very short, it can be approximately considered that the resonant inductance current remains

unchanged in the t_4 - t_5 period, i.e. $i_{Lr}=i_{Ls}=i_m$. At the same time, the current continues through the parasitic capacitance loop of the switch, where the charge on the parasitic capacitance C_2 of the switch Q_2 transfers to the parasitic capacitance C_1 of the switch Q_1 , and the charge on the C_4 transfers to C_3 . When the charge transfer on C_2 and C_4 is completed, the voltage at both ends of C_2 and C_4 is approximately 0, so zero voltage switching (ZVS) of the switch can be realized when the high level of the next PWM driving cycle comes.

In a cycle, t_5 - t_{10} is similar to t_0 - t_5 , which is not specifically described here.

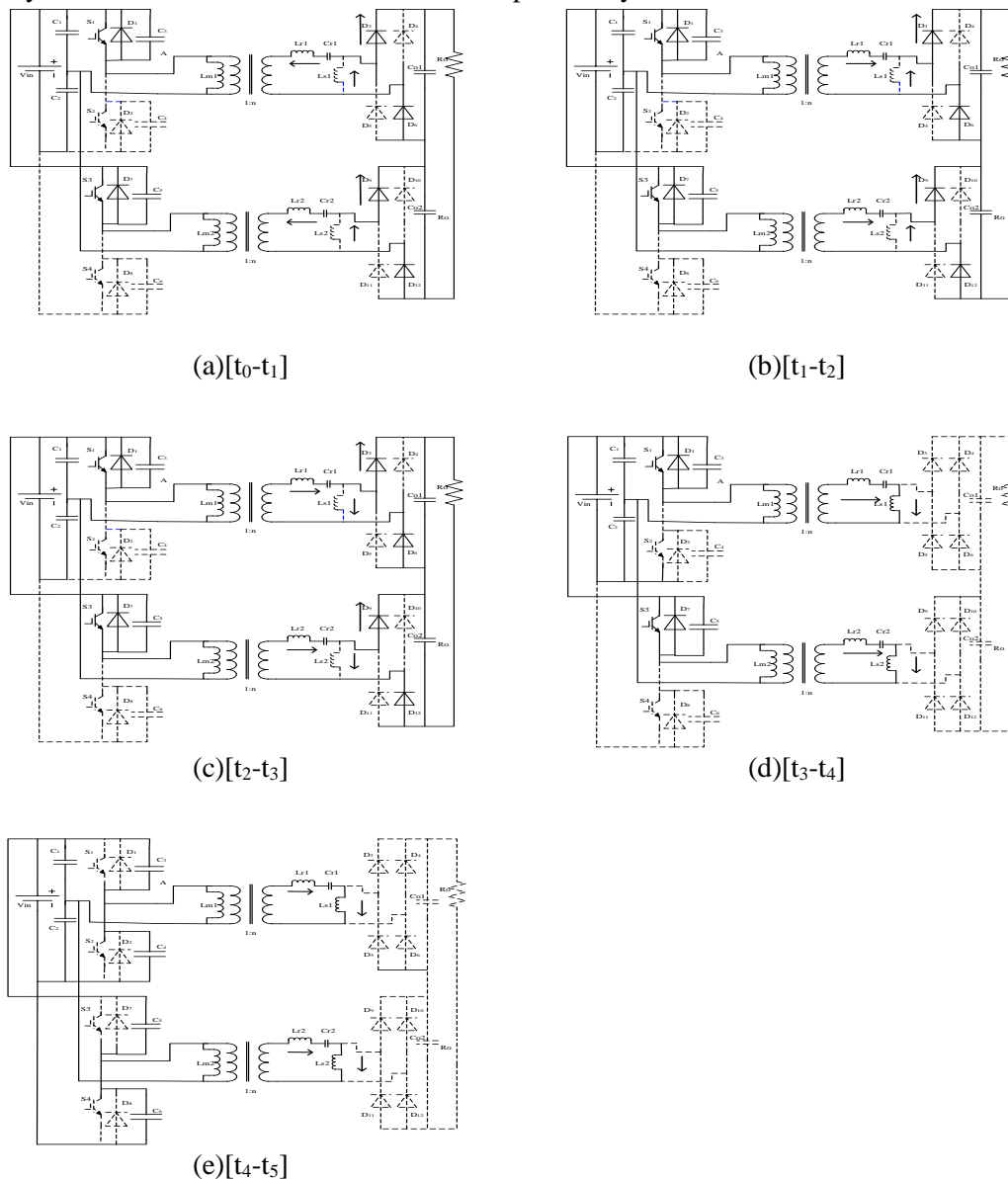


Figure 3. Working waveforms of various modes.

3. Control strategy for stable operation of the system

Generally, there are two control strategies, i. e. control of input current sharing and control of output voltage sharing, to make the output voltage balanced. Because this paper needs to design a stable high voltage output circuit, so we choose to control the output voltage equalization. The output voltage equalization control block diagram of the system is shown in Fig. 5 below. The sampling voltage of

the module is input to the voltage regulator together with the given value of the output voltage. The output voltage of one module compares with half of the output voltage of the input voltage equalizer. The output of the voltage equalizer and the output of the voltage electric regulator act as the given signal of the frequency regulator to adjust the frequency of the switch.

When the system has reached a stable state, the voltage of module 1 is disturbed and lowered. That is $V_{o1} < V_o/2$. The output signal of the closed-loop equalizing voltage is increased by V_{cf_ea} and decreased by $V_{o_ea} - V_{cf_ea}$. Through the voltage controlled oscillator, the switching frequency of module 1 decreases by V_{o1} and increases by $V_{o_ea} + V_{cf_ea}$. Through the voltage controlled oscillator, the switching frequency of module 2 increases, thus the switching frequency of module 2 increases. The output voltage of module 2 is reduced by V_{o2} . Similarly, when $V_{o1} > V_o/2$, the output voltage can be equalized.

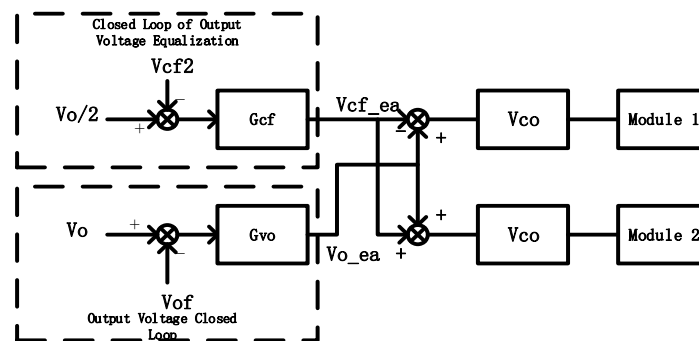


Figure 4. Voltage equalization control block diagram.

4. System simulation verification

4.1. The simulation results of building a single module model in Matlab/Simulink

Fig. 5 (a) is the output voltage waveform under fixed load. The output voltage is stable at about 980V. Fig. 5 (b) is the second side resonant current and excitation current.

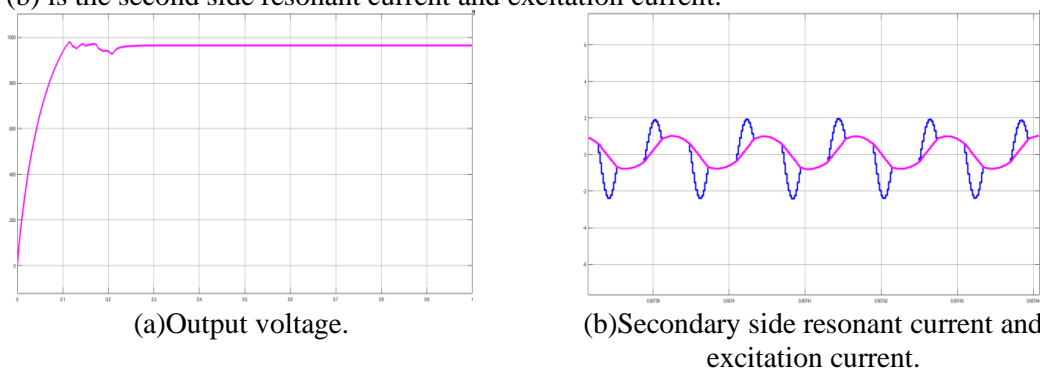


Figure 5. Simulation waveform under fixed load.

4.2. The simulation results of building multi-module model in Matlab/Simulink

The output voltage sharing control strategy is adopted for the converter. The simulation results are shown in the following figure. Fig. 7 (a) shows that the total output voltage of the module is stable at 2020 V. Fig. 7 (b) shows that the output capacitance voltage of the two modules is stable at 1010 V.

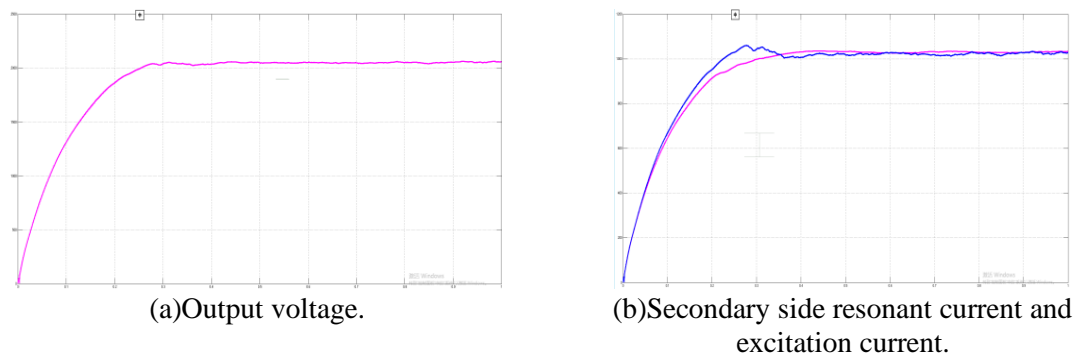


Figure 6. Multi-module simulation waveform.

5. Conclusion

In this paper, a new LLC resonant converter - input parallel output series subside resonant LLC resonant converter is designed, its working principle is analyzed, voltage sharing strategy for stable operation is formulated, and a reasonable voltage equalization scheme is selected. The converter model is built and simulated in MATLAB/Simulink. The system can output stable voltage of 2KV, which verifies that the designed circuit can meet the design requirements.

References

- [1] Haojun Lu. (2017)Control and Simulation of LLC resonant converter [D]. Harbin University of Technology.
- [2] Zejing Wang, Ying Wang, Chunying Gong. (2015)LLC resonant DC transformer with high step-down ratio [J]. Journal of Electrical Technology.30 (14): 193-200.
- [3] Zhendao Wang, Yakui Wang, Ke Zhang, Xu Wu. (2012)Parameter Model and Design of LLC Half-Bridge Resonant Converter [J]. Journal of Electrical Technology.27 (12): 51-55.
- [4] Rahman A N, Chiu H J, Hsieh Y C. (2018) Design of wide input voltage range high step-up DC-DC converter based on secondary-side resonant tank full bridge LLC. In: IEEE 2018 3rd International Conference on Intelligent Green Building and Smart Grid. Taiwan.1-6.
- [5] Tao Zhang, Xinbo Ruan. (2005)A method of equalizing voltage and current for input-series-output shunt full-bridge converters [J].(24): 47-50.