

Review Of Control Methods of Dual-Output Half-Bridge LLC Resonant Converter

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Abstract: Dual-output half-bridge LLC resonant converters are widely used in data centres, aerospace, portable electronic devices, new energy vehicles and other fields due to their superior performance of high frequency, high efficiency and high power density. This paper analyses the topology and operating principle of the dual output LLC resonant converter; introduces the traditional control methods and the new control methods in recent years. For each control method, its principle, characteristics, advantages and disadvantages are described. Finally, the future research direction and development trend of dual-output half-bridge LLC resonant converter are outlooked.

Keywords: Dual-output half-bridge LLC resonant converter; Control strategy.

1. Introduction

In many applications, outputs of different voltage levels need to be provided simultaneously, such as power adapters, server power supplies, etc. The dual-output half-bridge LLC resonant converter can meet this multi-output requirement, simplify the system structure, and reduce cost and volume[1]. The dual-output half-bridge LLC resonant converter can provide multiple output voltages in the same size, thereby increasing the power density of the system. At the same time, the use of resonant topology can improve conversion efficiency and reduce energy loss. The design of the dual-output half-bridge LLC resonant converter has strong flexibility and can adapt to a variety of application scenarios and voltage requirements. Through reasonable design, independent control and regulation of different output voltages can be achieved. By using the LLC resonant topology, the dual-output half-bridge LLC resonant converter can achieve better electromagnetic compatibility (EMC) and electromagnetic interference (EMI) suppression, improving the stability and reliability of the system[2]. As the functions of electronic devices continue to increase and diversify, the requirements for power systems are becoming higher and higher. As an efficient and flexible power conversion solution, the dual-output half-bridge LLC resonant converter has broad application prospects, especially in the fields of new energy, smart homes, electric vehicle chargers, and data centers. In summary, the dual-output half-bridge LLC resonant converter has important research significance and application value in meeting multiple output requirements, improving power density and efficiency, and improving system stability and reliability[3].

Determine the design and optimization methods of the dual-output half-bridge LLC resonant converter to meet multiple output requirements, including the selection of output voltage, the design of circuit topology, etc. By optimizing the design and control strategy, the power density and conversion efficiency of the dual-output half-bridge LLC resonant converter can be improved to meet the growing power density and energy efficiency requirements. Analyze the stability and reliability of the dual-output half-bridge LLC resonant converter under different operating conditions, and design effective control algorithms and protection mechanisms to ensure safe and reliable operation of the system. Study the needs of

dual-output half-bridge LLC resonant converters in specific application fields (such as electric vehicle chargers, smart homes, data centers, etc.), and optimize the design to meet the special requirements in this field[4-8].

Study the circuit topology of dual-output half-bridge LLC resonant converter, including different design schemes such as parallel output and series output, and perform design optimization. Analyze the control strategy of dual-output half-bridge LLC resonant converter, including traditional control methods and advanced control methods, and conduct performance evaluation and comparison. Study the selection and performance characteristics of the power devices required for the dual-output half-bridge LLC resonant converter, including switching tubes, inductors, capacitors, etc., and analyze their impact on system performance. Study the selection and performance characteristics of the power devices required for the dual-output half-bridge LLC resonant converter, including switching tubes, inductors, capacitors, etc., and analyze their impact on system performance. Study the selection and performance characteristics of the power devices required for the dual-output half-bridge LLC resonant converter, including switching tubes, inductors, capacitors, etc., and analyze their impact on system performance. By clarifying the purpose and scope of the research, the development of research work can be effectively guided, ensuring that the research results can achieve the expected goals and have practical application and promotion value[9-11].

This article analyzes the topology and working principle of the dual-output half-bridge LLC resonant converter; introduces the traditional control method of the dual-output half-bridge LLC resonant converter and the new control methods in recent years; for each control method, its principles and characteristics are described and pros and cons. Finally, the future research direction and development trend of dual-output half-bridge LLC resonant converter are prospected.

2. Overview of Dual Output Half-Bridge LLC Resonant Converter

2.1. Basic principles and working principles

Fig.1-1 is the schematic diagram of a dual-output half-bridge LLC resonant converter. The topology structure of the dual-output half-bridge LLC resonant converter mainly includes a DC voltage source, a half-bridge switching network, a resonant tank,

an ideal transformer, a rectifier circuit, a filter circuit and an output load; among them, V_{in} is the DC voltage source, Q_1 and Q_2 are Switching tube, C_{oss1} and C_{oss2} are switching tube parasitic capacitances, L_r is resonant inductance, C_r is resonant capacitance, L_m is excitation inductance, the transformation ratio of transformer T is $N_1:N_2:N_3$, $D_1\sim D_4$ are the rectifier diodes of output branch 1, $D_5\sim D_8$ are the rectifier diodes of output branch 2, C_1 and C_2 are the output filter capacitors of output branches 1 and 2 respectively, r_{c1} and r_{c2} are the equivalent resistances of the filter capacitors of the two output branches respectively, R_1 and R_2 are respectively are the load resistances of output branches 1 and 2; V_{o1} and V_{o2} are the output voltages of output branches 1 and 2 respectively, v_{ab} is the switching network output voltage, v_{Cr} is the resonant capacitor voltage, i_{Lr} is the resonant inductor current, and i_{Lm} is the excitation inductor current, i_p is the primary current of the transformer.

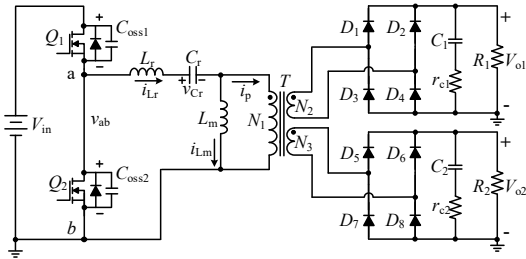


Figure 1-1. Dual output half-bridge LLC resonant converter schematic diagram

Fig.1-2 shows the key waveform diagram of the dual-output half-bridge LLC resonant converter. To simplify the analysis, it is assumed that: 1) Except for the switching tubes Q_1 and Q_2 and the secondary-side output capacitors C_1 and C_2 , the remaining components in the circuit are ideal components; 2) The frequency of the disturbance signal is much smaller than the switching frequency. As can be seen from Fig. 2, within a switching cycle ($t_0\sim t_8$), the dual-output half-bridge LLC resonant converter has eight operating modes.

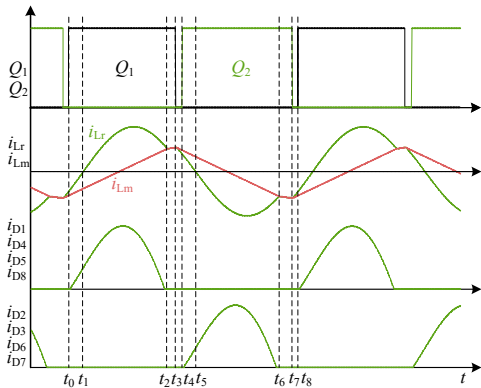


Figure 1-2. Key waveform diagram of dual output half-bridge LLC resonant converter

Mode 1 ($t_0\sim t_1$): At time t_0 , Q_2 is turned off, and the circuit enters the mode 1 stage. The current flowing through the resonant inductor L_r is negative. At this time, the body diode of Q_1 is turned on, creating a state for the ZVS turn-on of Q_1 conditions. At this stage, energy is fed back to the input V_{in} . When the body diode of Q_1 is turned on, i_{Lr} begins to gradually increase, the polarity of the primary winding of the transformer becomes up positive and down negative, and the polarity of the two secondary windings of the transformer is also up positive and down negative. The rectifier diodes D_1, D_4, D_5 and D_8 are turned on. The voltage on L_m is clamped by the output voltage. Therefore, only L_r and C_r participate in resonance, and L_m is charged at a

constant voltage during this process. The equivalent circuit is shown in Fig.1-3.

Mode 2 ($t_1\sim t_2$): When the current flowing through the resonant inductor i_{Lr} changes from negative to positive, it enters mode 2. Q_1 has already input the gate drive signal in mode 1, so Q_1 is forward-conducting at time t_1 . At this time, the rectifier diodes D_1, D_4, D_5 and D_8 are turned on, the voltage on the primary side of the transformer is clamped, and L_m is charged linearly. Does not participate in resonance. In this mode, the entire circuit is equivalent to the series resonant circuit energy of the resonant inductor L_r and the resonant capacitor C_r being transferred from the input end to the output end. At time t_2 , the current flowing through L_r is equal to the current flowing through L_m , and mode 2 ends. At this time, the current flowing through the rectifier diodes D_1, D_4, D_5 and D_8 becomes zero. The equivalent circuit is shown in Fig.1-4.

Mode 3 ($t_2\sim t_3$): At time t_2 , the current i_{Lr} flowing through the resonant inductor L_r is equal to the current i_{Lm} flowing through the excitation inductor L_m . The rectifier diodes $D_1\sim D_8$ are reversely blocked, the output is isolated by the transformer, and the excitation inductor L_m begins to participate. Resonance, connected in series with L_r and C_r to form a series resonant circuit. Output capacitors C_1 and C_2 continue to power the output. Q_1 turns off at time t_3 , and the mode 3 working state ends. The equivalent circuit is shown in Fig.1-5.

Mode 4 ($t_3\sim t_4$): Starting from time t_3 , Q_1 and Q_2 are turned off and enter the dead time. The resonant current i_{Lr} charges the parasitic capacitance C_{oss1} of Q_1 and discharges the parasitic capacitance C_{oss2} of Q_2 . At this time, i_{Lm} is greater than i_{Lr} . The difference between the two flows through the primary side of the transformer, and the rectifier diodes D_2, D_3, D_6 and D_7 begin to conduct. At time t_4 , the discharge of C_{oss2} ends, the body diode of Q_2 is turned on, and the mode 4 working state ends at this time. The equivalent circuit is shown in Fig.1-6.

The next four working modes ($t_4\sim t_8$) are symmetrical to the above four working modes respectively, and will not be described again here.

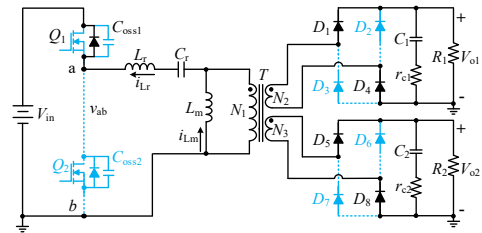


Figure 1-3. Mode 1 ($t_0\sim t_1$)

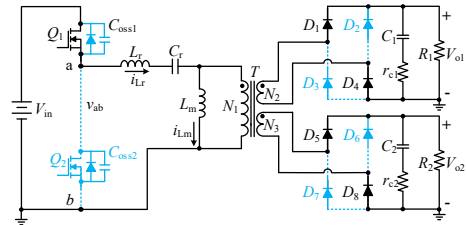


Figure 1-4. Mode 2 ($t_1\sim t_2$)

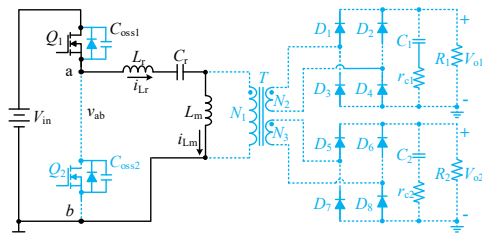


Figure 1-5. Mode 3 ($t_2\sim t_3$)

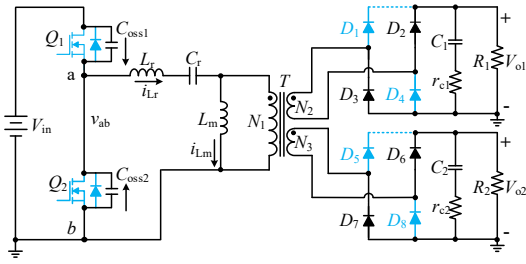


Figure 1-6. Mode 4 (t_3-t_4)

2.2. Circuit topology

The circuit topology of dual-output half-bridge LLC resonant converter can be divided into dual-output half-bridge LLC resonant converter and dual-output full-bridge LLC resonant converter according to the primary side division of the transformer. The structure of the dual-output half-bridge LLC resonant converter includes two switching tubes and a resonant inductor, forming a half-bridge topology. It is relatively simple in structure, suitable for low and medium power applications, and has high power density and efficiency. The structure of the dual-output full-bridge LLC resonant converter includes four switching tubes and two resonant inductors, forming a full-bridge topology. It enables large power conversions and high efficiencies and is typically used in medium to high power applications.

The circuit topology of the dual-output half-bridge LLC resonant converter can be divided into half-wave rectification, half-bridge rectification and full-wave rectification according to the secondary side of the transformer. Half-wave rectification usually consists of a rectifier tube; in half-wave rectification, only the positive half-cycle signal is retained, and the negative half-cycle signal is cut off. This rectification method is relatively simple, but the output DC voltage waveform will have large pulsations. In the field of power electronics, half-wave rectification is often used in some low-power and low-cost application scenarios. Half-bridge rectifier is a common rectifier circuit commonly used to convert alternating current to direct current. In half-bridge rectification, through the work of two rectifier tubes, only the signal of the positive half cycle is retained, while the signal of the negative half cycle is truncated. This rectification method is relatively simple and low-cost, and is suitable for some low-power application scenarios. In the field of power electronics, half-bridge rectifier is often used in some devices that require smaller power output, such as some small power adapters. Full-wave rectification is a rectifier circuit commonly used to convert alternating current to direct current. In full-wave rectification, through the work of four rectifier tubes, both positive and negative half-cycle signals are retained, thereby achieving complete rectification of the input AC signal. Compared with half-wave rectification, this rectification method has a more stable DC output and reduces the pulsation of the output waveform. Full-wave rectification is usually used in applications that require more stable DC output, such as power adapters, electronic equipment, etc.

3. Control Method Classification

3.1. Traditional control methods

There are two main traditional control methods for dual-output half-bridge LLC resonant converters: PWM (Pulse Width Modulation) control and PFM (Pulse Frequency Modulation) control.

a PWM control

Pulse Width Modulation (PWM) control is a commonly used power electronic control method, often used to adjust the

conduction time of switching devices (such as MOSFET, IGBT, etc.) in the circuit to adjust the output voltage or current [12].

By changing the duty cycle of the dual-output half-bridge LLC resonant converter, increasing or decreasing the voltage gain, and adjusting the output voltage, the switching frequency of the dual-output half-bridge LLC resonant converter remains unchanged under this control strategy. The gain range of duty cycle adjustment is small. When the duty cycle is small, the control signal of the dual-output half-bridge LLC resonant converter will be lost, which is not conducive to the conduction of the switch tube ZVS. Pulse width control is divided into symmetrical control and asymmetrical control. The symmetrical control switch tube drive signal is shown in Fig.2-1(a). The dual-output half-bridge LLC resonant converter switch tubes are complementary and conductive, and the duty cycle is the same. Symmetrical control When the switch tube dead time is not easy to determine, it is difficult to achieve ZVS conduction. The asymmetric control switching tube driving signal is shown in Fig. 2-1(b). The switching tubes of the dual-output half-bridge LLC resonant converter are complementary and conductive with different duty cycles, which can achieve ZVS conduction. During asymmetric control, the converter's The working mode is asymmetrical and the transformer utilization rate is low.

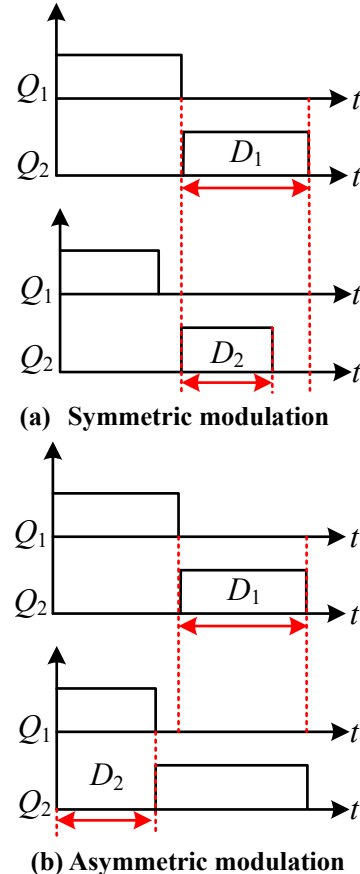


Figure 2-1. PWM control dual output half-bridge LLC resonant converter switch tube drive signal

b PFM control

Pulse Frequency Modulation (PFM), also known as voltage-type frequency conversion control, has a constant duty cycle of 50%. The disadvantage is that the voltage gain adjustable range is small and the frequency modulation range is narrow. When the system is in a low-gain state, the resonant frequency of the dual-output half-bridge LLC resonant converter is smaller than the switching frequency, and the diode cannot achieve ZCS turn-off [13]. Fig. 1-4 is the schematic diagram of the voltage-type variable frequency control dual-output half-bridge LLC resonant

converter. It can be seen from the Fig. that the output voltage v_{o1} of the sampling branch 1 is compared with the reference voltage v_{ref} , and the switching frequency is changed through the voltage-controlled oscillator V_{co} , and the driving circuit DC controls the on and off of switching tubes Q1 and Q2, thereby regulating the output voltage of the dual-output half-bridge LLC resonant converter. Its working principle is shown in Fig.2-2.

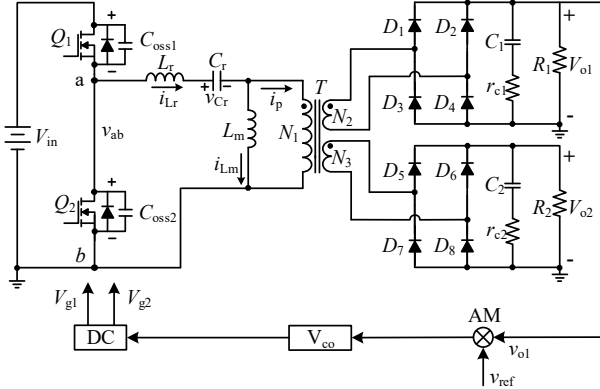


Figure 2-2. Schematic diagram of voltage-type frequency conversion controlled dual-output half-bridge LLC resonant converter

The pulse-controlled dual-output half-bridge LLC resonant converter will adjust the operating frequency and thus the output voltage only when the output voltage changes. Therefore, its load transient response is slow and there is a high voltage overshoot during adjustment.

3.2. Other control methods

a Average current type pulse frequency control

The essence of average current type pulse frequency control [14] is also variable frequency control. In order to improve the load transient response speed of the dual-output half-bridge LLC resonant converter, a current loop is introduced to sample the inductance of the resonant cavity of the dual-output half-bridge LLC resonant converter. Current, because the inductor current phase leads the output voltage, when the inductor current changes, the converter adjusts the output voltage by changing the switching frequency. Therefore, compared to the voltage-type pulse frequency control, the average current-type pulse frequency control dual-output half-bridge LLC resonant converter has a faster load transient response than the voltage-type pulse frequency control dual-output half-bridge LLC resonant converter. Its working principle is shown in Fig. 2-3.

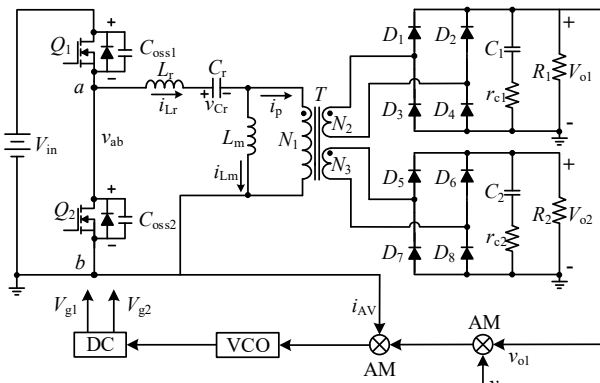


Figure 2-3. Average current mode controlled dual output half-bridge LLC resonant converter schematic diagram

The average current type control dual output half-bridge LLC resonant converter control circuit consists of a current inner loop

and a voltage outer loop. The current inner loop samples the resonant network inductor current through the average current sampling circuit to obtain i_{AV} , and generates current compensation through the error amplifier AM. signal; similarly, the voltage outer loop samples the output voltage signal, and generates a voltage compensation signal through the error amplifier AM. The current compensation signal and voltage compensation signal are used as inputs of the voltage controlled oscillator VCO, and are output through the drive circuit DC to the dual output half-bridge LLC converter. Control the pulse signal and adjust the output voltage.

b Dual frequency control

Dual-frequency control [15] (Bi-Frequency Control, BFC) controls the dual-output half-bridge LLC resonant converter through two sets of pulse signals of different frequencies. Since the dual-frequency control strategy control loop does not require a compensation circuit, it has fast response to changing load transients and lower voltage overshoot. The disadvantage is that under the dual-frequency control strategy, the output voltage of the dual-output half-bridge LLC resonant converter will produce low-frequency oscillation, which will increase the output voltage ripple. Its working principle is shown in Fig. 2-4.

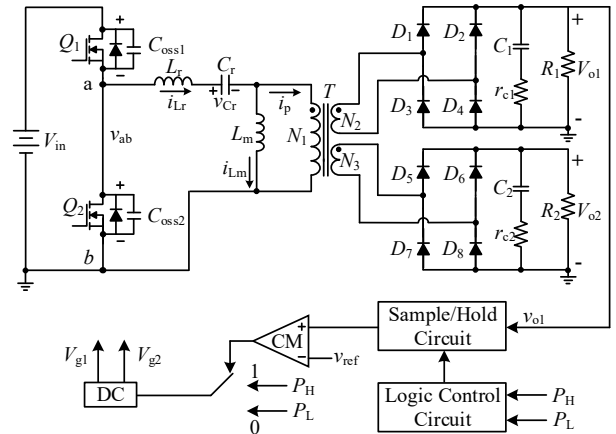


Figure 2-4. Dual-frequency controlled dual-output half-bridge LLC resonant converter

The dual-frequency control dual-output half-bridge LLC resonant converter control circuit includes an output voltage sampling and holding circuit (Sample/Hold Circuit), a logic control circuit (Logic Control Circuit), a comparator (CM), and a drive circuit (DC). The dual-frequency controlled dual-output half-bridge LLC resonant converter achieves output voltage regulation through two sets of control pulses PH and PL with a duty cycle of 50% and frequencies of f_H and f_L . The output voltage sampling circuit samples the output voltage v_o and compares it with the voltage reference value v_{ref} . When $v_{o1} > v_{ref}$, the logic control circuit connects the control pulse signal PH with the frequency f_H to the control circuit to reduce the output voltage. In the same way, when $v_{o1} < v_{ref}$, the logic control circuit connects the control pulse signal PL with frequency f_L to the control circuit to increase the output voltage.

In addition to the above control strategies, there are quite a few control strategies in the literature that can be applied to the dual-output half-bridge LLC resonant converter. The Burst control method is proposed in the literature [16], which changes the output current of the half-bridge LLC resonant converter switching network. Transformed into a discontinuous state, the effective value of the input voltage of the resonant network is reduced, and the low-voltage output of the converter can be achieved at light load. The disadvantage is that the output voltage ripple is large [17]. Literature [18] proposed a hysteresis band dead zone adjustment control strategy, which improves the

converter control efficiency by adjusting the LLC resonant converter dead time, thereby improving its load transient response speed. However, the resonant converter circuit design is complex. Literature [19] proposed a partially isolated single-input dual-output half-bridge LLC resonant converter, using PWM control method to adjust the output voltage. This topology can achieve high power density and low cost by integrating magnetic components. The disadvantage is that the switch The ZVS range of the tube is narrow, which affects the converter efficiency. Literature [20] proposes a dual-output half-bridge LLC resonant converter with synchronous rectifier control for the cross-influence problem existing in practical applications of the dual-output half-bridge LLC resonant converter. The main output is controlled by pulse frequency, and the auxiliary output Synchronous rectifier control is used to achieve strict two-channel output voltage regulation and suppress the cross-effect between the output branches of the dual-output half-bridge LLC resonant converter. Literature [21] uses a single transformer to control the dual output port circuit of the LLC resonant converter, and adjusts the duty cycle of the switching tube through a control chip to achieve accurate output of the two voltages. This circuit can be used in vehicle charging systems. Disadvantages It is difficult to implement mathematical modeling and the implementation method is complicated. Literature [22] uses an auxiliary switch and pulse width modulation integrated circuit to achieve strict output voltage control of a dual-output half-bridge LLC resonant converter. The analysis process of this method is complicated. Literature [23] combines fuzzy PI control and frequency conversion-phase-shift control hybrid strategy to solve the problem of traditional dual-output half-bridge LLC resonant converter that requires a wide output voltage range for on-board charging, and improves its dynamic response performance. But the voltage overshoot is higher. Literature [24] uses the Bang-Bang charging control method and uses the voltage level of the resonant capacitor of the resonant cavity to control the on and off of the switching tube. This control strategy can improve the dynamic performance of the dual-output half-bridge LLC resonant converter. The voltage The overshoot is low, but the experimental design of this control strategy is complex. Literature [25, 26] proposed two different control methods to accurately control the voltage of the two output branches of the dual-output half-bridge LLC resonant converter. The disadvantages are that the control circuit design is complex and the system transient response is slow.

4. Outlook

Future research on dual-output half-bridge LLC resonant converters will focus on multiple aspects: first, improving efficiency and power density, which includes optimizing topology, control strategies, and magnetolectric component design to achieve more efficient energy conversion and more compactness system size; secondly, optimize the control strategy and explore new hybrid control strategies and intelligent control algorithms to improve the performance and stability of the system under different operating conditions; in addition, the dual-output half-bridge LLC resonant converter will be expanded to more application fields, such as electric vehicle charging systems, renewable energy systems and power supply systems, to meet the needs of different fields; on the other hand, research will be dedicated to achieving integrated and modular design to improve product installation and maintenance and management convenience, and reduce system costs; finally, combined with the development of new materials and new technologies, such as silicon carbide devices and gallium nitride devices, explore their application in dual-output half-bridge LLC resonant converters, thereby promoting the system Performance and reliability improvements.

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