A Hydride Bridge LLC Converter

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Abstract

A circuit topology of hydrid bridge LLC resonant converter of double output was proposed. It keeps features like excellent soft switching, high efficiency, low EMI and wide range of input voltage which traditional LLC resonant converters have. The number of MOSFETs is reduced to four ones, thus the power density of the whole converter is improved. Simplified control method is adopted to keep converter operate.And first harmonic approximation(FHA) is used to model the circuit. Then the principle of steady-state operation is analyzed, and the complete circuit parameter design is deduced. Finally, the topology is experimentally verified by circuit simulation with PSIM .

Keywords

Hydride bridge; LLC; double output; double voltage.

1. Introduction

In recent years, high-voltage and high-power DC-DC converters have been widely used in electrical traction, DC microgrid system, HVDC transmission and other engineering fields. However, due to the material characteristics and the level of power devices manufacturing process currently, it is still difficult to achieve perfect balance of high voltage, high switching frequency, low power loss and low EMI in high voltage and high power DC-DC converters. Therefore, it is one of the hot topics in the field of DC-DC power transformation to innovate the topology level of the converter and find the industrial applications that meet high input voltage, high switching frequency and high power density and high reliability. With the development of power electronics technology, the power density and conversion efficiency of DC-DC converters are becoming more and more demanding. At present, LLC resonant converters have attracted wide attention in the engineering field. The utility model has the advantages of strong no-load working ability, wide working voltage range, and the realization of power rate transistor ZVS and rectifier diode ZCS [9] in the full load range. The converter topology proposed in reference [1] realizes the soft switching of power devices by resonant mode. However, the unbalanced circuit results in the inconsistent clamping voltage between the lead arm power tube and the lagging arm power transistor, which affects the system performance. Reference [10-14] adopts diode clamped three-level LLC resonant topology. More active switching devices are used, the control is complex, which is not conducive to increasing power density and reducing cost. In reference [15], an interleaving parallel LLC resonant converter topology is proposed, which adopts the structure of IPOS(Input Parallel Output Series). The input and output terminals in series realize the reduction of the current stress of the input power transistor and the reduction of the voltage ripple at the output terminal. But there are still eight power transistors. It is unfavorable to the compact structure and resource saving of the whole machine. Based on the analysis of basic LLC resonant converters, a LLC resonant converter with double outputs using compound switching networks is derived in this paper. The principle of the circuit is analyzed, and the simulation of the circuit is carried out in the end.

2. Topology derivation

The basic LLC resonant converter is shown as fig.1(a). From input terminal to output terminal, the converter can be divided into four parts: switch network, resonant network, isolated transformer, rectifier and filter network. For the voltage and current change in a sinusoidal fashion, it can be easy to achieve soft-switching when the electric parameters go to zero naturally.

Since the asymmetry of half bridge LLC topology, an interleaved half bridge LLC converter can be built by two basic half bridge LLC converter with interleaved control method. Thus a full bridge switch network can be consist of the four MOSFETs. Therefore another resonant tank can be added into the full bridge switch network.

The parameters of first and second resonant tanks can set the same. By a multiple winds transformer, the first and second resonant tanks can be coupled as one output. And another transformer can be used for the third resonant tank. Q1~Q4 are MOSFETs of switch network. Cr1~Cr3 are resonant capacitors. Lr1~Lr3 are resonant inductors. Lm1~Lm3 are magnetization inductors of first and second transformers. VD1, VD2, VD3, VD4 are recitifier diodes. Co1 and Co2 are output capacitors. Ta and Tb are the first and second transformer with center-tapped transformers, Ta is with double winds in primary side.

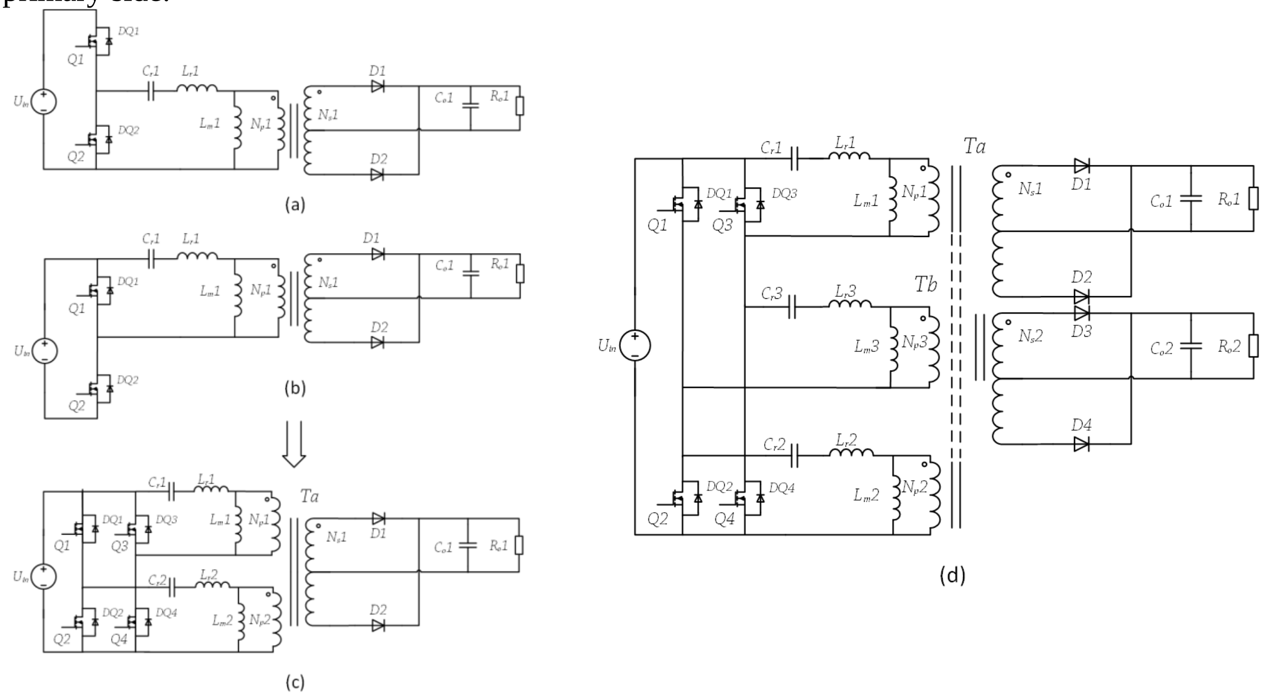

Fig.1 Derivation of topology

3. Operation principle

A whole switch period can be divded into eight states. Half-bridge LLC (HBLLC) parts and full-bridge LLC (FBLLC) parts are analysed seperatly.

3.1 Double HBLLC parts

Mode1 (t0~t1): Before t0, all the switches are turned off. And Dds1,Dds4 conducts at t0. The drain-source voltages of S1 and S2 go to zero, and that provides the conditions for ZVS of MOSFETS. The voltage of Lm are clamped to output voltage, polarity of transformer is upper positive and lower negative. The resonant frequency is fr1.

Mode2 (t1~t2): At t1, the gate drive signals of Q1 and Q2 are high level, and ZVS can be achieved. The current of Lr equal zero, which tend to increase from negative to positive.

Mode3 (t2~t3): The resonant current iLr equals magnetizing current iLm. Besides, Lm participates in resonance, the resonant frequency becomes fr2. And the energy is no longer transmitted from primary side to secondary sides meanwhile the output capacitors supply for load. The rectifier diodes are cut-off naturally with ZVS, thus the reverse recovery loss is eliminated.

Mode4 (t3~t4): At t3, S1~S4 turned off . Cds1and Cds4 are charged with resonant current while Cds2 and Cds3 are discharged. The magnetizing current is greater than resonant current. In this mode, the polarity of transformer get reversed, and D2 turns on.

The above analysis is based on first half period, and operation principle the second half period is similar to the first one, therefore unnecessary repeat is left out.

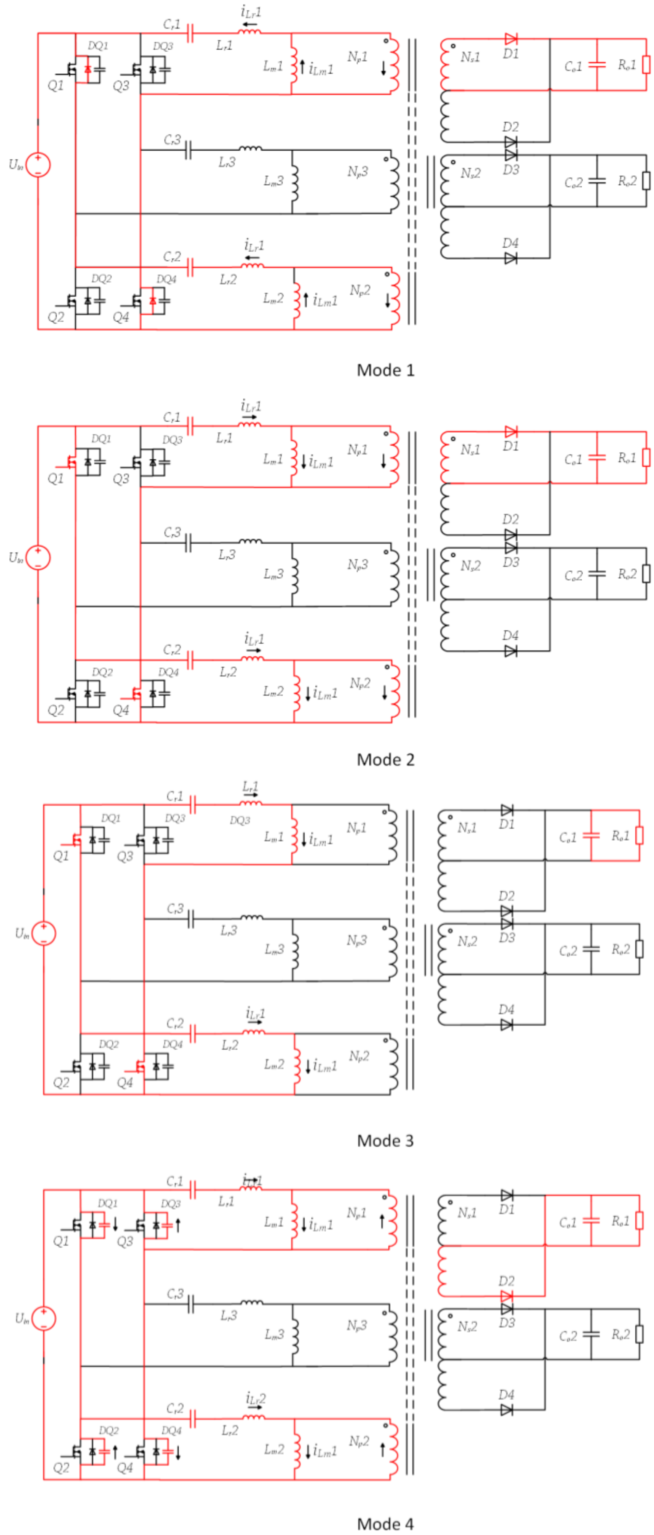

Fig.2 Modes of half-bridge LLC resonant parts

3.2 FBLLC parts

Mode1 (t0~t1): Before t0, all the switches are turned off. And Dds1,Dds4 conducts at t0. The drain-source voltages of S1 and S2 go to zero, and that provides the conditions for ZVS of MOSFETS. The voltage of Lm are clamped to output voltage, polarity of transformer is upper positive and lower negative. The resonant frequency is fr1.

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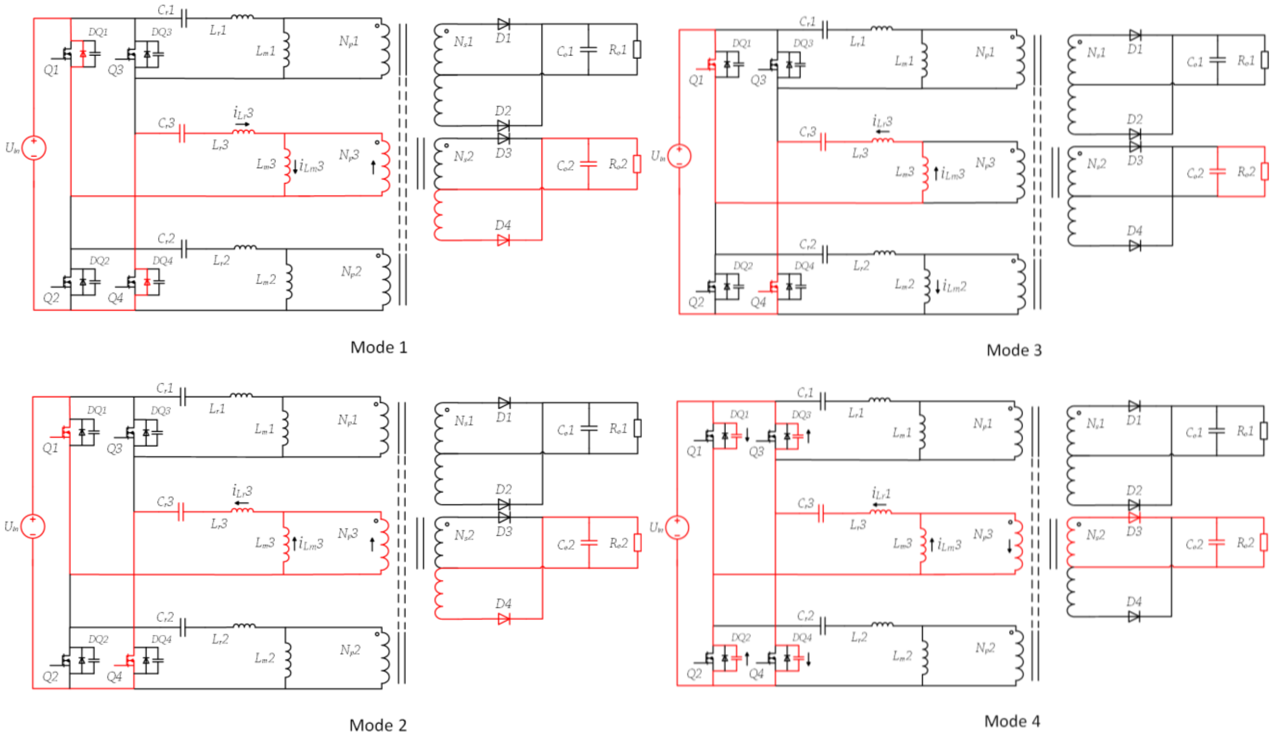

Fig.3 Modes of full-bridge LLC resonant parts

4. Steady-state anlysis of proposed converter

Before analysis, the following assumptions are made for convenience.

(1) All the devices are ideal, and the capacitors of switches are all equal.

(2) The output capacitors are large enough. And the output voltage can viewed as constant.

(3)The parameter can be ignored.

When the converter is working in steady condition, the input DC voltage is chopped by switch network, and the square-wave voltage work with resonant tank which is composed of two inductors and a capacitor. There exists two resonant states. When the energy transfers from the primary side to the secondary side of transformers, the magnetizing inductors Lm1 and Lm2 are clamped, resonance occurs between Lr1, Lr2 and Cr1, Cr2, with the resonance frequency fr1. When there is no energy transferred to the secondary side, the load will be supplied by discharging the output capacitor Co1, Co2 and resonance will occur in Lr; Cr; Lm1 and Lm2, the second resonant frequency is fr2.

$$f_{r1} = \frac{1}{2\pi\sqrt{L_r C_r}} \tag{1}$$

$$f_{r2} = \frac{1}{2\pi\sqrt{(L_r + L_m)C_r}} \tag{2}$$

When the switching frequency of the power transistor is in the range of (fr1,fr2), the load characteristic of the switching network is inductive, which is beneficial to the realization of the ZVSs of the power MOSFETs. Using the fundamental approximation analysis method , an AC equivalent model as shown in fig.3 is established by the method of fundamental harmonic approximation(FHA). The AC equivalent load Rac is converted from secondary of center-tapped transformer.

$$R_{ac} = n^2 \frac{8}{\pi^2} R_L \tag{3}$$

The equivalent impedance of resonant tank

$$Z_{in} = j\omega L_r + \frac{1}{j\omega C_r} + \frac{j\omega L_m \cdot n^2 \frac{8}{\pi^2} R_L}{j\omega L_m + n^2 \frac{8}{\pi^2} R_L} \tag{4}$$

The effective value of input fundamental voltage wave

$$E_{in} = \frac{\sqrt{2}}{\pi} V_{in} \tag{5}$$

The effective value of output fundamental voltage wave

$$E_o = n \frac{2\sqrt{2}}{\pi} V_o \tag{6}$$

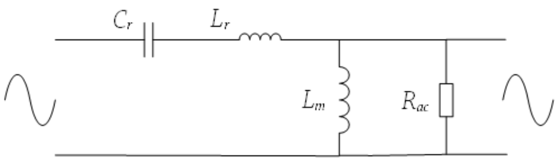

Fig.4 Diagram of half bridge structure working principle

The following definition are made.

Inductance ratio, $k = \frac{L_m}{L_r}$

normalized frequency, $f_n = \frac{f_s}{f_r}$

characteristic impedance, $Z_o = \sqrt{\frac{L_r}{C_r}}$

quality factor, $f_n = \frac{\sqrt{\frac{L_r}{C_r}}}{R_{ac}}$

And n is the transformation ration.

The AC gain,

$$G_{ac} = \frac{E_o}{E_{in}}$$

$$= \frac{1}{1 + \frac{1}{k}\left(1 - \frac{f_r^{\,2}}{f_s}\right) + j\left(\frac{f_s}{f_r} - 1\right)\frac{\pi^2}{8n^2} \cdot \frac{1}{2\pi f_s R_L C_s}} \tag{8}$$

The DC gain,

$$G_{dc} = \frac{V_o}{V_{in}} = \frac{1}{2n}\frac{E_o}{E_{in}} = \frac{1}{2n}\left|G_{ac}\right| \tag{9}$$

$$G_{dc} = \frac{1}{2n}\frac{1}{\sqrt{\left(1 + k - \frac{f_r^{\,2}}{kf_s^{\,2}}\right)^2 + \left(\frac{f_s}{f_r} - \frac{f_r}{f_s}\right)^2 Q^2}} \tag{10}$$

5. Simulation results and analysis

The power electronics simulation software PSIM is used to verify the theory analyzed. And the following parameters are .

Tab.1 parameters of circuit

parameter	value
Input voltage	380V
Switch frequency	60kHz
Resonant capacitor	8.35nF
Magnetizing inductance	4.21mH
Load	60Ω
Output voltage	116V/58V

It can be seen from figure 1 that the current waveform lags behind the voltage waveform, indicating that the power transistor can turn on zero voltage. Figure 2 shows the zero-current switch of the rectifier diode. Figure 3 shows the relationship between the resonant inductance current and the excitation inductance current of the half-bridge and full-bridge resonators, which is consistent with the previous analysis. Figure 4 shows two output voltages. The output voltage of the full bridge topology is twice the output voltage of the half bridge topology. Figure 5 shows the case of two output currents under the same load, and the output current of the full bridge topology is also twice the output current of the half-bridge topology.

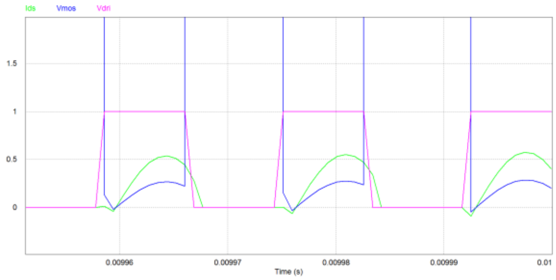

Fig.5 Waveforms of MOSFETs with ZVS

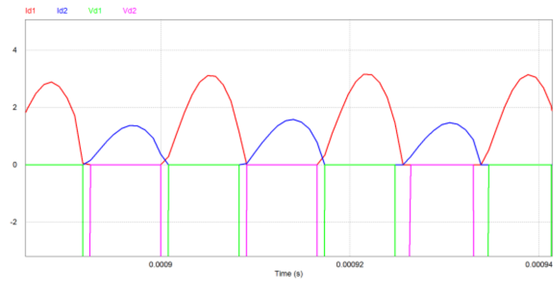

Fig.6 Waveforms of rectifier diodes with ZCS

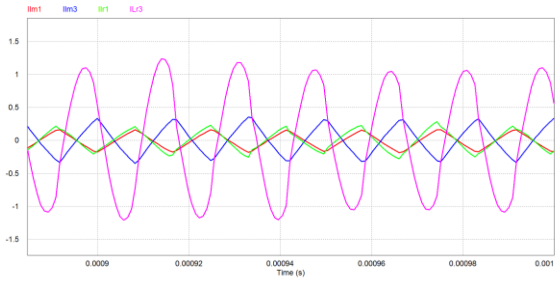

Fig.7 Current of Lr and Lm

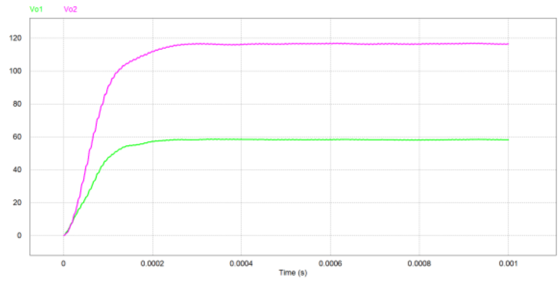

Fig.8 Diagram of output voltage

6. Conclusion

In this paper, a hydride bridge LLC resonant converter is proposed by using the multiplexing and simplified control of active devices to deduce the basic LLC topology. Through the design and simulation of the circuit parameters, it is found that the topology of the converter has the following characteristics: 1: 1 makes use of the asymmetry of half-bridge switching network, turns asymmetry into symmetry by interleaving and parallel connection, makes the circuit work more balanced, .2 and half-bridge. The full bridge topology and the simplified control strategy realize the double voltage doubling output, the ZVS of the power transistor and the ZCS of the diode. It provides a new idea for double output power conversion.

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