Research on Grid Connected Inverter Based on Parallel Resonance

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Abstract. In order to solve the problem of large switching loss, large voltage peak and poor stability in DC-DC transform high frequency isolation inverter, a new inverter circuit topology, which is combined with parallel resonant and traditional DC-DC converter, is proposed. The inverter can realize the zero voltage opening of the high frequency power device, the soft turn off of the body diode and the rectifier diode, so as to eliminate the switch peak of the power device and reduce the loss of the inverter. The working process of the circuit and the soft switching principle of various switch devices are introduced in detail, and the resonant equivalent model of the circuit, the influence of the resonance parameters on the gain and the soft switch are established, and the design principle of the resonant parameters is given. In order to eliminate the low harmonics introduced by dead zone, dead time compensation is added to the control system to improve the quality of inverter current. Finally, an experimental prototype is built, and the correctness of the circuit topology and control strategy is verified by experiments.

1. Introduction

As a clean renewable energy, solar energy is being paid more and more attention. As an important conversion component between the solar energy and the grid, the performance of the grid inverter not only affects the life of the photovoltaic system, but also plays an important role in the safe, stable and efficient operation of the whole system [1, 2]. Applied to different power levels, grid connected inverters can choose different circuit topology. The performance of topology has an important impact on the efficiency, reliability and cost of the whole system [3].

Many papers introduce resonant DC-DC converters to achieve soft switching of power switches and reduce switching losses. The circuit proposed by [4] is simple and can realize soft switching, but additional resonant network is needed. Literature [5] compares the characteristics of non-resonant mode DC-DC converter, and proposes a LC resonant DC-DC converter with isolation. By using phase shift control to realize zero voltage switching of power devices, the efficiency of the system is improved. The circuit characteristics of LCC resonant converter are analyzed in detail in document [6], and the design principles of resonant parameters are given. However, the resonant converter proposed in the above literature is only used for DC constant voltage output, and the post stage connection inverter bridge is needed to complete the inverter grid connection.

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This paper combines the high frequency chain inverter and the harmonic converter, uses the circuit topology of the parallel resonant converter and the control idea of the high frequency chain inverter. A high frequency chain inverter based on LC resonance is proposed. The parameter design method of the resonant element is given, which can realize the soft switch of the high frequency power device and improve the efficiency.

2. key parameter design

2.1. Resonant equivalent model

The basic wave analysis method is used to analyze the circuit. The following assumption is made as: neglecting the influence of high harmonic in the resonant network; the parasitic parameters of the transformer are equivalent to the LC resonant network; the switch devices and diodes are all ideal devices; the output filter inductance is large and the output current within a carrier cycle is almost invariable.

First define the quality factor of the resonant network

$$Q=\frac{\omega_r L}{R_{ac}} \tag{1}$$

$$R_{ac}=\pi^2 R_L \Big/ (8n)^2 \tag{2}$$

In the formula, the frequency of the resonant angle is $\omega_r = 1\Big/\sqrt{L_r C_p}$ the ratio of working angle frequency to resonance angle frequency is $\omega_n = \omega_0 / \omega_{ac}$ and current base value $I_b = V_{in} / R_{ac}$ is defined.

The inverter output is equivalent to pure resistive load because of inverter power factor operation. The AC load to the primary side of the transformer is R_{ac} , and the expression is

In a carrier cycle, the output voltage u_{ab} of the inverter bridge is decomposed by Fourier transform. The fundamental wave v_{ab1} is expressed as:

$$v_{ab1}=\frac{4V_{in}}{\pi}\sin\left(\frac{\pi}{2}m\left|\sin(\omega_0 t)\right|\right)\sin(\omega_r t) \tag{3}$$

The input voltage of the resonant network is represented by a sinusoidal voltage source, and the steady-state model of the whole circuit is simplified to the equivalent circuit shown in Fig. 1.

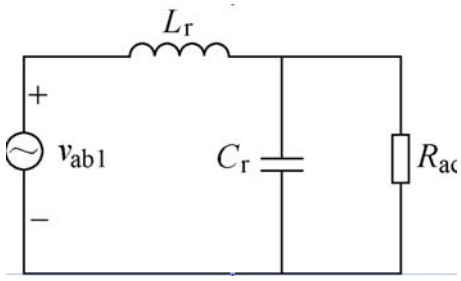


Figure 1. The equivalent circuit of LC resonance

The input current I_{in} and the current base value I_b ratio of the resonant tank are J.

$$J = \frac{Q^2 + jQ\omega_n}{1-\omega_n{}^2 + jQ\omega_n} \tag{4}$$

$$Z = \frac{R_{ac}}{1+\omega^2{}_n Q^{-2}} + jR_{ac}\left(Q\omega_n - \frac{Q\omega_n}{\omega_n^2+Q^2}\right) \tag{5}$$

The formula (4) shows that the magnitude of the resonant inductor current is related to Q . ω_n In addition to the AC load. The value of J directly reflects the current flowing through the switch tube, that is, the switching loss.

The input impedance of the equivalent circuit is Z:

The impedance angle αof the resonant circuit

$$\alpha = \arctan\left[\frac{\omega_n}{Q}\left(\omega_n^2 + Q^2 - 1\right)\right] \tag{6}$$

$$G_{(\omega_n,Q)} = \frac{V_0}{V_{in}} = \frac{1}{\sqrt{\omega_n^2 Q^2 + (1-\omega_n^2)^2}} \tag{7}$$

The gain of the inverter consists of three parts, namely, the inverter gain, the gain of the resonant circuit and the gain of the transformer. The formula for calculating the gain of the resonant circuit is

The formula (7) shows that the load variation will result in the gain variation of the resonant circuit. The whole inverter control is a dynamic adjustment process, and the gain change will seriously affect the stable output of the inverter.

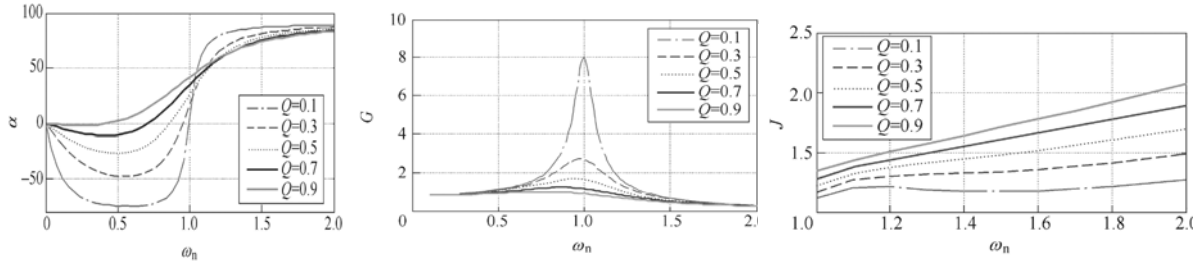
2.2. Resonant parameter design

The 2.1 section analyzes three kinds of soft switching states of the lagged bridge arm due to the variation of phase shift angle θ in a sinusoidal period. For MOSFET switching loss, it is necessary to maximize zero voltage switching to reduce losses. As shown in Fig. 5, the relationship between the phase shifting angle θ and the impedance angle B is achieved when the zero voltage switching is realized.

$$\alpha \geq 0.5\theta \tag{8}$$

As shown in Figure 2, in order to design the optimum resonant parameters, the efficiency of the zero voltage opening of the lag bridge arm is high. It is necessary to consider the following aspects: the size of the impedance angle α will affect the efficiency of the zero voltage opening; the size of the resonant current will directly affect the loss of the switch tube; the gain of the resonant circuit will determine the stability of the system. Therefore, the smaller the quality factor and the larger the impedance angle, the more beneficial to zero voltage switching. The larger the resonant loop gain and the smaller the resonant current, the lower the loss. The greater the impedance angle of ω_n, the higher the efficiency of the zero voltage opening; the smaller the gain of the resonant circuit, the lower the sensitivity of the circuit to the load, the higher the stability of the system, and the smaller the resonant current. However, the Omega n cannot be too small, and its gain is close to zero at very small hour, which results in a high turn ratio of the transformer, and increases the volume and parasitic parameters of the transformer. As shown in Fig. 2, the quality factor has little effect on gain when Q>0. In consideration of the above consideration, when the resonance parameters are designed, the gain of the resonant circuit is required and the harmonic

current is smaller and the impedance angle is large enough to be based on the above original. The values of Q and ω_n are selected and the resonant parameters are designed.



(a) the relation between impedance angle α and Q and ω (b) the relationship between gain G and Q and ω (c) current ratio J and Q and ω system

Figure 2. Parallel resonant characteristic curve

2.3. Filter parameters design

The resonant frequency of the filter determines its performance, and the resonant frequency is:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{9}$$

$$10 f_g < f_r < f_{har} \tag{10}$$

$$L_s = \frac{V_{o\max}(nV_{in} - V_{0\max})T}{n\Delta i V_{in}} \tag{11}$$

Fourier analysis of the output voltage waveform V_{cd} after rectification is carried out, and the lowest harmonic is 100 kHz centered distribution. In order to make the filter have better performance, only the fundamental wave signal is retained but the resonant wave of the filter will be caused by filtering, and the resonant frequency of the filter satisfies the relationship.

In the formula, f_g is the fundamental frequency and f_{har} is the lowest sub harmonic frequency.

The value of the resonant frequency, inductance and capacitance must be calculated separately. The size of the filter is mainly determined by the inductance, and the size of the inductor affects the output current ripple. Inductance calculation formula

In the formula, $V_{o\max}$ is the amplitude of AC voltage, T is the switching period and Δi is ripple current.

The parameters in type (10) take the parameters of the inverter's rated working time, the ripple coefficient is 5%, and the inductance L_s determines, then the capacitance value C_s is determined by the formula (11).

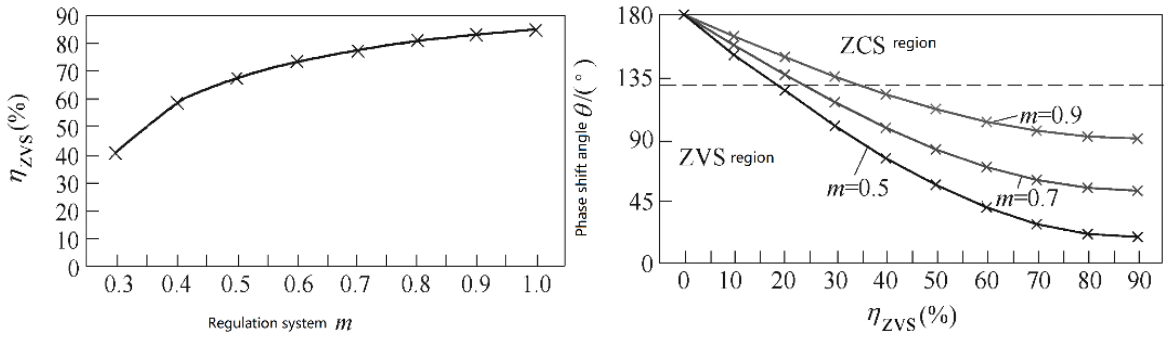
3. experimental results

In order to verify the correctness of the scheme, an experimental prototype was produced. In the hardware circuit, the S1 to S4 model is IRFP486, the VD1 to VD4 model is ISL9R30120G2, and the S5 ~ S8 model is SPW55N80C3. The main parameters of the experiment are shown in Table. 1

Table 1. The parameters of prototype.

parameter	numerical value
DC voltage	150
Power grid voltage	220
output power	1200
Turn ratio of transformer	2.8
switching frequency	50
Resonant inductor	26
Resonant capacitance	0.6
Filter inductor	2
Filter capacitor	120

The resonant inductor in Table. 1 contains 4 H leakage inductance of the transformer. According to the parameters of the table. 1, the prototype is designed to carry out the experiment. The figure 3a is the efficiency of the zero voltage opening of the bridge arm after the different adjustment system. 3b is the efficiency change of the soft switch in the 1/4 sinusoidal period under the rated output power. It can be concluded that in the resonant state, the range of zero voltage switching is related to the modulation system. The larger the modulation is, the larger the range of zero voltage switching is. The amplitude of sine wave is easy to realize ZVS. It is very difficult to realize ZVS near zero crossing point.

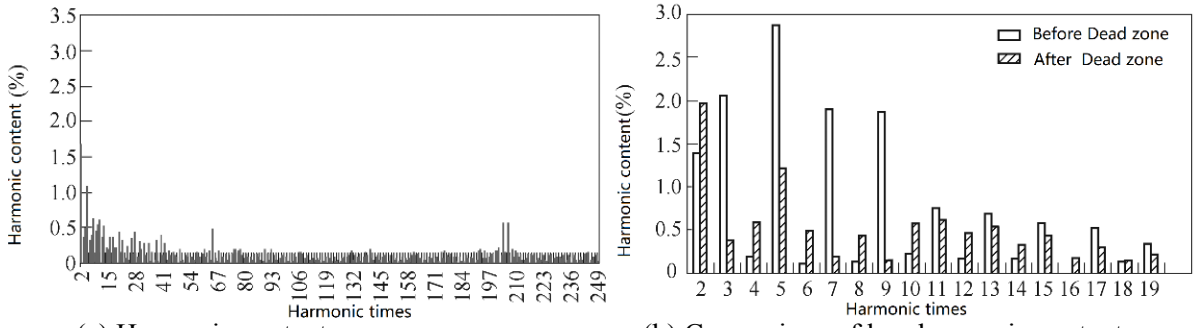


(a) ZVS efficiency under Different modulation systems

(b) soft switching efficiency under rated output power

Figure 3. Soft switch diagram of the lag leg

Fourier analysis of grid connected current shows that the harmonic content is 3.5%, which meets the requirements of grid connection. The harmonic content is low, and the low harmonic content is shown in Figure 4a. In order to verify the effect of dead zone compensation, the experiment is carried out before and after the dead zone compensation, and the harmonic analysis of the current is carried out. The figure 4b is the comparison of the low harmonic content before and after the dead zone compensation. It is shown that after adding dead zone compensation, the low harmonic content is obviously reduced, and the quality of grid connection is improved. But it still contains a small amount of 3 and 5 times harmonics.



(a) Harmonic content (b) Comparison of low harmonic content

Figure 4. Harmonic analysis of grid current

Figure 5 is the measured efficiency curve. Under the grid state of the inverter, 8 power points are tested in the experiment. The output power of the diagram is measured by the given reference value of the different current. When testing the efficiency of the traditional DC-DC converter, the auxiliary resonant circuit is removed, and the switch tube works in a hard switching state. Taking into account the actual read error, each measurement point is added to the same number for several times to obtain its average value. It can be seen from the diagram that the efficiency of the inverter in this paper is 93.4% when the power of the grid is 1 200W. Compared with the traditional DC-DC converter, the efficiency of the inverter is raised by 3.8% to achieve the purpose of saving energy.

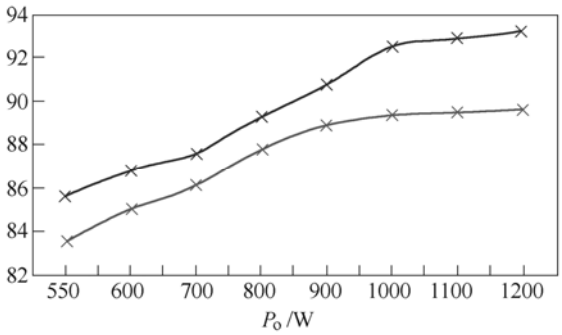


Figure 5. Efficiency curve

4. Conclusion

A high frequency isolated grid connected inverter based on parallel resonance is proposed in this paper. The working principle of the resonant circuit, the resonant characteristic, and the principle of parameter design and the control strategy of the system are analyzed in detail.

The resonant unit absorbs the parasitic parameters of the transformer, reduces the loss of the transformer and eliminates the voltage spike caused by leakage inductance. It realizes the zero voltage opening of the high frequency power device and the soft recovery block of the body diode. The two side rectifier diode of the transformer is softened and the system loss is reduced, compared with the traditional isolation type. The inverter has further improved the efficiency of the system.

The experimental results of the prototype fully show that the soft switch in the system is in accordance with the theoretical analysis. Under rated power, the quality of the grid is high, the harmonic content is 3.5%, and the efficiency of the rated power is up to 93.4%.

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