Parameters Design of Series Resonant Inverter Circuit

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Abstract

This paper analyzes the main circuit structure of series resonant inverter, and designs the components parameters of the main circuit. That provides a theoretical method for the design of series resonant inverter.

Keywords: inverter series; the main circuit parameters; induction heating power supply

1. Introduction

Resonant inverter is a key component of solid state induction heating power supply. Its development level has closely related with the development and application of induction heating power supply and induction heating technology. The block diagram of solid state induction heating power supply is shown in Figure 1:

Figure 1. Block diagram of solid state induction heating power supply

There are two main forms of resonant inverter: voltage source type series resonant inverter and current source parallel resonant inverter, the distinction of induction heating power is from the point of the inverter they used.

IGBT parameters, RC snubber circuit and its related parameters of series resonant inverter are mainly calculated and designed in this paper.
2. The Operation Principle of Series Resonant Inverter

Main circuit topology of series resonant inverter is shown in Figure 2.

![Figure 2: Schematic of series resonant inverter](image)

Series resonant inverter generally works in the emotional state of quasi-resonant, which need to set the dead time when inverter converts. The output voltage is a rectangular wave, output current is sinusoidal, and the load frequency is the series resonant characteristics, so it should not be no-load.

3. Parameters Design of IGBT

The reliability of induction heating power supply depends on the properties of components, so how to choose components is very important. Most of the IGBT modules work under the DC bus voltage, so the general IGBT voltage (600V, 1200V, 1700V) corresponds to the common power grid voltage. Therefore, roughly selecting the voltage according to network voltage $U_N$ (if it is controlled rectifier bridge, the control angle is $0^\circ$) or the ideal no-load DC voltage $U_{di}$ is the first step of the selection. And then the maximum allowable voltage of the module in the case of the maximum voltage appearing is checked whether exceeded or not, i.e.

- The grid rated voltage plus the fluctuations spread is static input voltage as maximum, for example, 15%\[^{[1]}\]
- The grid dynamic over-voltage is the voltage that is not absorbed by the absorption circuit of power filter, the DC bus capacitor or DC voltage.
- Turn-off over Voltage $U_d + \Delta U$, which
  \[ \Delta U = L_{\phi} \cdot I_{\text{max}} / t_f, \]
  Where $L_{\phi}$ is the parasitic inductance of converter circuit; $I_{\text{max}}$ is the maximum possible current collector or turn-off current; $t_f$ is the fall time of collector or the gate current.

In practical application process, if the load impedance varies greatly, loop voltage, current is large, and its volatility is very intense, therefore when IGBT is selected, the following two aspects should be noted:

a) Pressure side: It must be able to withstand the maximum no-load voltage of power supply, taking into account the transient spikes of grid voltage, voltage spikes caused by voltage fluctuations, switching current and other side effects, and have some margin, so the pressure value of IGBT we choose should be about more than double the peak voltage added to both ends at the steady-state \[^{[1]}\].

b) Rated current: It must be able to withstand the maximum rated current of the power, at the same time the IGBT collector peak current must be within the safe operating area of IGBT switch, and can withstand overload to a certain extent, so the selected rated current of IGBT should be about 1.5 times of the maximum current value.
4. Element Parameters Design of RC Snubber Circuit

As other power semiconductor devices IGBT has lower overloads capacities, RC snubber circuit is needed in order to inhibit of the transient overvoltage generated in the process of switching. RC snubber circuit in parallel at both ends of IGBT has the role of the following aspects: inhibiting of over-voltage, reducing switching losses, limiting the rate of the voltage rise, eliminating the electromagnetic interference and so on.

Buffer circuit of resonant inverter has various forms, and the summarized five connections are shown in Figure 3:

![Figure 3. Five kinds of buffer circuit](image)

The buffer circuit in Figure 3a is the most simple circuit, when IGBT works, capacitor $C_s$ at both ends of the DC bus which is cross-connected close to IGBT can absorb the energy at both ends of $L_s$, so that the emitter IGBT set inhibition on transient voltage spikes between collector pole and emitter pole of IGBT can be inhibited, this method is suitable for protecting devices under 50A or used in conjunction with other protection methods [3].

The circuit showed in Figure 3b is used for protecting devices under 200A, the circuit has a good effect in inhibiting the transient voltage when IGBT is turned off, inhibition of transient voltage is less effective when IGBT works, and the existence of Rs is to eliminate oscillation.
Figure 3c and d show that it is the most effective for the buffer circuit to inhibit the transient voltage when IGBT is switching, it is also helpful to reduce the IGBT turn-off losses and eliminate parasitic oscillation. But when IGBT is opening, the discharge of capacitor Cs will increase opening losses of IGBT, especially in resistor Rs which has a large loss, the circuit can be used in high current, low voltage system and the chopper \cite{3}.

The circuit in Figure 3e can be used for protecting devices over 300A, which has a lower buffer element power loss, a good performance in reducing the IGBT turn-off loss, an advantage of the opening of IGBT and no spurious oscillation and so on.

Take the third RC snubber circuit for example, the device parameters are usually determined with a method by the combination of calculation and test, the parameters are preliminary fixed as follows:

a) **Buffer capacitor**

We can see from the law of conservation of energy, the energy absorbed by the buffer capacitor $C_s$ and the energy stored in the lead inductance $L_s$ are equal. Therefore

$$L_s I_{\text{Coff}}^2 / 2 = C_s (U_{\text{CEP}} - U_d)^2 / 2$$

(1)

In the equation: $L_s$ is the lead inductance, $I_{\text{Coff}}$ is the shutdown current. $U_{\text{CEP}}$ is the peak voltage between the collector and emitter of IGBT, in order to protect IGBT from damage, which is generally limited to 80% of rated voltage IGBT.

By Equation (1), the equation of calculating the capacitance of the buffer is derived:

$$C_s = \frac{L_s I_{\text{Coff}}^2}{(U_{\text{CEP}} - U_d)^2}$$

The voltage undertaken by $C_s$ is equal to the voltage spikes $U_{\text{CEP}}$, generally 1.5 to 2 times of the voltage reserve should be considered.

b) **Absorption resistance**

The larger the external capacitor, the more load current transferred from the power tube, i.e., the more turn-off losses are transferred from the power tube, and the working conditions of the power tube are improved. To ensure the over-voltage of the snubber capacitor discharged before the IGBT is turned off, the absorption resistor $R_s$ should be met:

$$R_s \leq \frac{1}{(2 \sim 6) C_s f}$$

In the inequation, $f$ is frequency of switching device. Meanwhile, in order to prevent the oscillation caused by $C_s$ discharging, $R_s$ should be met:

$$R_s > 2\sqrt{L_s C_s}$$

So generally it is calculated by the following equation:

$$2\sqrt{L_s C_s} < R_s \leq \frac{1}{(2 \sim 6) C_s f}$$

c) **The calculation of the parameters of anti-parallel diode**

A variety of factors need to be considered for the proper design of anti-parallel diode. Some of them are related with their own technology, others are related with application. The power supply works in near resonant emotional state, so from Figure 2, the output current expression of the inverter is:

$$I_H = \frac{4U_d}{\pi RL} \sin(\omega t - \varphi)$$

The approximate expression of average current flowing through the anti-parallel diode during
Since the opening process of IGBT depends on the reverse recovery process of the anti-parallel diode, fast recovery diode is generally used.

5. Design of Other Parameters

5.1 Filter Input Capacitance

Single-phase 220V/50Hz power supply is commonly used by low and medium power as an input, pulsating DC voltage $U_{dc}$ can be get through the power rectified $D_f \sim D_{f4}$ rectifier bridges, the input filter capacitor $C_d$ is used to reduce the pulse to get a smooth DC voltage, the selection of $C_d$ filter capacitor is critical, because

- If the filter capacitance $C_d$ is too small, the pulse of DC voltage $U_{dc}$ will be larger, causing the output voltage fluctuation, while the minimum value $U_{dc\,\text{min}}$ of DC voltage $U_{dc}$ is smaller, leading to the switch current increasing [4].
- If the filter $C_d$ is too large, that will lead to input power factor lower, EMI increasing, the loss of the input rectifier and filter capacitor caused by excessive input current (RMS) increases; at the same time capacitance increases, the cost will also increase [4].

Generally it based on empirical algorithms: when the minimum input is AC, the pulse value $U_{pp}$ of DC voltage after the rectifier filtering is 20% to 25% of the minimum input AC voltage peak value. If input AC voltage ranging from $U_{\text{min}} \sim U_{\text{max}}$, and the frequency ranging from $f_{\text{min}} \sim f_{\text{max}}$ are known, the following steps are used to calculate the capacity of $C_d$:

- Voltage RMS: $U_{\text{min}} \sim U_{\text{max}}$;
- Peak voltage: $\sqrt{2} U_{\text{min}} \sim \sqrt{2} U_{\text{max}}$;
- The maximum pulse rectifier filtered DC voltage:
  \[ U_{pp} = \sqrt{2} U_{\text{min}} \times (20\% \sim 25\%) \]
- Rectified filtered DC voltage:
  \[ U_{dc} = (\sqrt{2} U_{\text{min}} - U_{pp}) \sim \sqrt{2} U_{\text{max}} \]

While input power $P_{in} = P_{out} / \eta$; Where $P_{out}$ is the output power, $\eta$ is power conversion efficiency; to ensure the minimum DC voltage to meet the requirements, the energy $W_{in}$ which $C_d$ can provide each cycle is about

\[ W_{in} = \frac{P_{in}}{A \times f_{\text{min}}} \]

The energy provided by input filter capacitor each half cycle is:

\[ \frac{W_{in}}{2} = \frac{1}{2} C_d \left( (\sqrt{2} U_{\text{min}})^2 - (\sqrt{2} U_{\text{min}} - U_{pp})^2 \right) \]

Capacity and maximum value of the rectified DC voltage $\sqrt{2} U_{\text{max}}$ are calculated according to the equation, the appropriate electrolytic capacitors are selected with the reference.

5.2 Resonant Capacitor

The output voltage of the inverter is
The output current of the inverter is

\[ I_H = \frac{P_H}{U_{ab} \cos 10^\circ} \]

Resonant capacitor and the voltage across the two ends of the sensor are \( Q \) times of the output voltage. \( Q \) is the quality factor of the circuit, which can be empirically selected according to the different uses of the device. Generally when it is used for high-frequency quenching, \( Q \) takes 10 to 20. Therefore, the voltage across the resonant capacitor is

\[ U_C = QU \]

Therefore, the impedance is

\[ X_C = \frac{U_C}{I_H}, \quad C = \frac{1}{\omega X_C}, \quad Q_C = I_H^2 X_C \]

Therefore, the resonant capacitor must be selected according to the above parameters, the resonant frequency can be regulated through exchanging the number of parallel capacitors.

Conclusion

The main circuit of series resonant inverter is studied in this paper, and on this basis, its parameters were carried out by theoretical analysis after analyzing the main structure, which has a very important significance for the inverter parameter selection and optimization design.

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