Research and Design on IGBT Induction Heating Power Supply

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Abstract

This paper introduces a new method, using PLL and fixed angle control, to track the converter's frequency automatically. After analyzing the work state of parallel inverter, a new control method using closed-loop rectifier control of voltage and current. The commonly-happening faults in the IGBT Medium Frequency Induction Heating Power Supply is analyzed, and the corresponding protective measures and protection circuits are designed. 100kw / 8 kHz Parallel induction heating power is developed, and the designed control method is verified to be scientific and effective.

Key words: induction heating; IGBT; phase lock; overvoltage protection

1. Introduction

Induction heating technology having the advantage which traditional methods don't have, such as high heating efficiency, high speed, controllable and easy to realize automation, is an advanced heating technology, and thus it has a wide range of application in the national economy and social life.

Parallel medium frequency induction heating equipment (1~10kHz) has the advantages such as [0]low requirement on capacity of the power devices, easy to be paralleled to expand capacity, high adaptability to load and so on, so an increasing number of applications is received in induction heating power supply. Emerged in the early 80s, the entire control of power electronic semiconductor devices IGBT, with its high-speed, high input impedance, easy to drive, low on-state voltage drop and other outstanding features, has now a wide range of applications over the IF and VHF fields, and let the induction heating technology has a new leap [1] [2] .The research on the induction heating power supply has been deepening in China. With the object of 100 kW / 8 kHz shunt induction heating power supply, the key technologies of the development of medium frequency induction heating power supply will be discussed as followed.

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2.1 The Main Circuit Topology

With the development of power electronics and power semiconductor device, the topology of the parallel induction heating power supply has been developed continuously and has become a fixed AC / DC / AC transformation form. The basic structure is shown in Figure 1.

The main system of parallel induction heating system includes rectifier, filter reactor, inverter and load. The input three-phase AC goes through the thyristor rectifier three-phase fully-controlled bridge, and then supply power to the inverter bridge in DC after filtered by large reactor, the switching devices of the inverter bridge alternately turn on and turn off according to certain laws, the output is square wave current of a certain frequency, and sin load voltage is formed. That completes an AC / DC / AC transformation providing the required current and frequency for the load. Selecting fully-controlled IGBT as the switching device, and 4 IGBT devices constitute an inverter. If the output power is larger, you can use multiple parallel inverter bridge, each bridge is 100kW, and the size of the output power determines the number of parallel inverters.

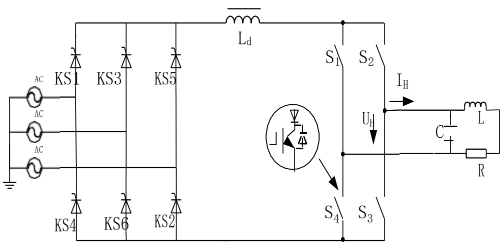

Figure 1. Topology of parallel induction heating power supply

2.2 Parallel Inverter Working Conditions

Parallel inverter has three kinds of working conditions, the load resonant frequency is:

$$f_0 \approx \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

1) When f $<f_0$, the load works in inductive state. At this time the phase of the load current leads the phase of the voltage. IGBT is forced to be turned off in high-current mode when in conversion, so the two ends of IGBT will form peak voltage, which may cause device damaged;

2) When f = f_0, the load works in resonance condition. This is an ideal working condition. As the circuit has stray parameters, it is difficult to achieve this working state when the accuracy of the PLL and the load change;

3) When f> f_0, the load works in capacitive state, At this time the load current phase takes advance of the voltage phase, the convert process will cause current spikes in the upcoming opening of the power devices , but the limiting action of the filter reactor in the DC side ensures the safety of the power devices. Therefore, capacitive working condition is an ideal working condition, which is also reliable in the actual operation [3].

3. Rectifier control

The rectifier uses the program of three-phase fully controlled rectifier, and the controller uses dual-loop of current, voltage strategy. The diagram of control schematic is shown in Fig.2. The control core of rectifier side uses MCS-51 Series MCU, with peripheral circuits constitutes rectifier trigger control system. The fixed power control and protection are central control sections of the device. The single chip processor control and thyristor conversion technology which are coordinate with two closed loop regulator are adopted into them.

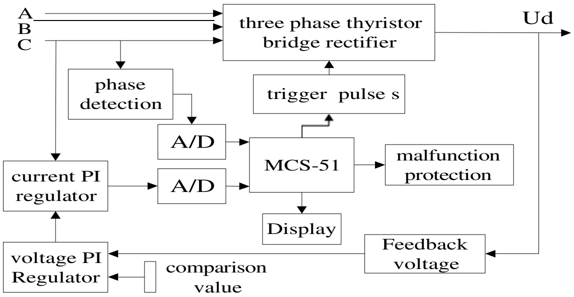

Figure 2. Block diagram of rectifier side of the control mechanism

The level of the average rectifier output DC voltage can be controlled when the size of the delay angle α of the fully controlled thyristor rectifier bridge is changed, which can control the size of the equipment output power. As the PI regulator is static error of the regulator, therefore given equals feedback in the static time, when the load of the equipment changes, the double loop PI adjuster uses the sampling current and sampling voltage as feedback signal, to regulate the size of voltage and current using closed loop, which will make sure the output value of current and voltage does not exceed the limit set value of current and voltage on the equipment, so as to achieve precise effects of limiting current and voltage.

When the value of the operating current exceeds the related value, because of the equipment overload, the trigger delay angle α of the thyristor in the rectifier bridge rise for the effect of the feedback of the current, the average the DC voltage reduce and the operating current is limited on the desired value of maximum of the operating current, and the function of current limiting is reached. In the same manner, in the course of voltage regulating, the output voltage is tested, and the PI regulator moderates the size of α automatically, thereby the output voltage is hold stable. The max output voltage will change according to the feedback value of the rated voltage, and the function of voltage limiting is reached.

4. The control of the inverter

The main functions of the inverter control are to implement the automatic trace of the frequency of the load, the start of the inverter, the supplement of solid trigger impulse for inverter power device and the control of the output voltage of the rectifier bridge to ensure the safety of the device when failure happens inside or outside of the device.

The core technology of the inverter control is phase lock. This paper adopts the method of fixed value phase lock control, which is the load current advances the voltage an angle, so as to let the device work at the mood of minor capacity consistently [4]. The phase locked control module is shown in Fig.3. In this module, the phase lock loop is made up of exclusive XOR phase detector, low-pass filter, PI controller, Voltage Controlled Oscillator and divider and so on.

For the reason that there is no output on the load end before start, i.e. there is no signal and the inverter IGBT can’t get pulse, so the additional start control circuit is necessary. For this reason, separate excitation to self-excitation module is designed. When started, the system works in the mood of separate excitation. When the load voltage has reached a certain value, the mood turns to self-excitation. This method calls for the frequency of separate excitation is near to and higher slightly than the one of the load vibration frequency. Otherwise, the start will be failed. This mode of start is the best method for the inverter, which has the self turn-off device as the switch of the inverter bridge [5].

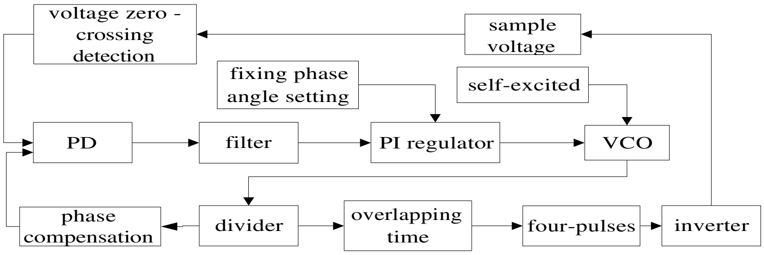

Figure 3. Block diagram of angle control of Inverter side

First of all, the load side voltage is obtained by voltage transformer, which will enter the phase detector through zero detect circuit. Phase detector uses XOR gate to phase, requiring that the two input signals are 50% duty cycle square wave. When the two signals are locked, the phase difference is 90°. So the other side input of phase detector can be is obtained from the divider output signal after phase compensation. The output of phase detector represents a certain phase relationship of the level signal, after compared filtering by low-pass filter with setting the phase locking value can get the phase error, and then get phase lock through a PI regulator. No-deviating regulation is ensured by the integrator, and the already-set phase will be positioned accurately. The output level of PI regulator goes into the VCO to control the inverter frequency.

As the current of the filter reactor is continuous, in order to get reliable circulation, both the upper and lower legs of the inverter should be opened first and then be turned off. the IGBT drive pulses have sufficient overlapping time in conversion. Therefore, the form part of the overlapping time is designed in this paper. Overlapping Time is adjustable, which can be regulated slightly depending on the working state.

5. The desigh of power source protection

5.1 The Overvoltage and Overcurrent Protection of the Inverter

In the inverter bridge, the bridge can work in different conditions for the reason that IGBT is a fully-controlled device. In capacity mode, the sequent FRD will burden reverse voltage at once after conversion; while in inductive mode, the IGBT will turn off at once. For the existence of lead wire loop inductor, the IGBT will burden a spike pulse. So the improved phase trace technology is adopted. That is to modulate the power source and let it work in capacity mode, and restraint it through detecting the reverse voltage imposed on the two terminals of the diode. Through this method, the reverse voltage of the series diode is controlled effectively, and the reliability of the power source is improved. In addition, the snobbery circuit shown in fig.4 can be adopted to absorb the spike pulse of the IGBT and diode in order to protect the device [6].

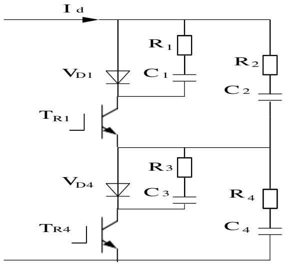

Figure 4. Absorption buffer circuit

The overvoltage protection circuit can be shown in fig.5. When overvoltage occurs in the inverter, trigger pulse signal is supplied to change the IGBT from rectification to inversion. Tp of the thyristor is put into operation. So the loop to give off power for filtering inductor is provided by thyristor, and the voltage rise rate of the inverter input port is hampered. The input of the inverter is clamped to a low level, and the IGBT is protected from overvoltage.

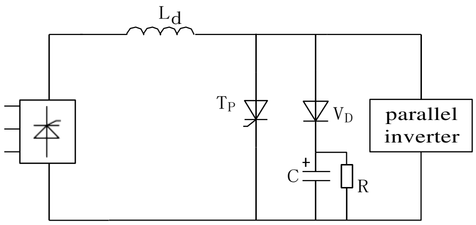

Figure 5. Over-voltage protection

When overcurrent occurs:

1) All of the IGBT are put into operation, and the two bridges can share the short circuit in a very short time;

2) Tp should be triggered at once when overcurrent occurs. For the reason that the voltage drop after Tp put into operation is much lower than the voltage drop when IGBT bridge is put into operation. The current of the IGBT transfers to Tp at once because of shunt current, therefore there is no overshoot for the current of the short-circuit IGBT. At the same time, signal is sent to the rectifier and the rectifier changes from rectification mode to inversion mode. The power source should be turned off after the power has been released.

5.2 Integrated Protection

In order to raise the reliability of the protection, the phase lock protection circuit is designed. This is an integrated protection. The phase lock protection block diagram is shown in fig.6. When abnormal conditions occur for the load, for example, the output is open, the output is short or the sensor is short, there will be large change for the phase difference between the load voltage and the load current. This circuit can be blend with the phase lock control circuit. When the phase difference of the load voltage and load current change quickly, the output voltage of the phase discriminator changes quickly with it, and when it exceeds the rated value of the protection, a signal will be supplied to let the protection circuit work.

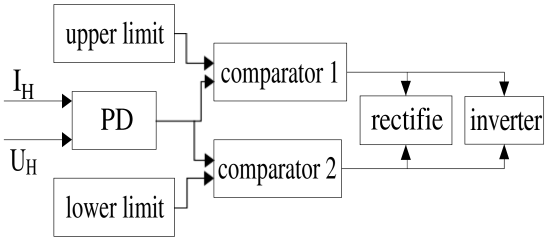

Figure 6. Block diagram of phase-locked protect

4. Experiments and conclusion

According to the theory and plenty of experiments, a 100kW/8kHz of medium frequency induction heating power supply is produced. Specifications are: input voltage 380V, output power 100kW, resonant frequency of slot road 8 kHz, when the prototype running in no-load condition, the measured set of data is shown in Table 1. Fig.7 is overlapping time of IGBT drive pulse waveform.

TABLE Ⅰ. Experimental data

DC voltage /V	*DC current/A*	*Peak voltage/V*
110	15	210
220	27	390
320	38	510
400	50	600

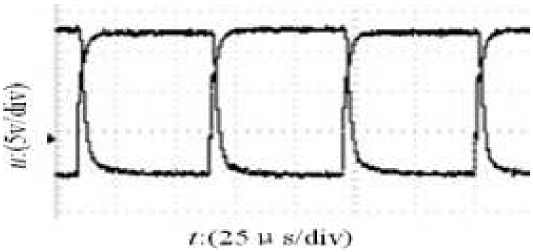

Figure 7. Waveform of overlap time driving pulse

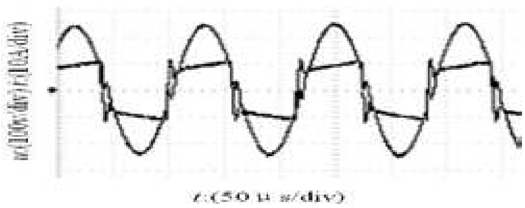

Figure 8. Output voltage and current waveforms of the inverter

The output voltage and output current waveforms of the inverter are shown in fig.8, the voltage waveform is sin wave and the current waveform is square wave. The device will work at minor capacitor mode after it has completed the change from separate excitation to self-excitation. The principle of operation designed in this paper is proved correct according to the experience data and the waveforms, especially the phase lock control of the inverter, which can let the device work at minor capacitor mode with fixed angle.

The successful design of this circuit has sharply raised the automatic operating level of the device. It can make the live editing stuff convenient and the operating stuff and save much human and material resources, meanwhile, it can drop the occurrence of accidents. The design principle and circuit structure introduced in this paper can be applied to design induction heating power sources which have other frequencies and different power values.

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