A Novelty Half-bridge Inverter Control System Design and Control Regulation

Yu YANG¹, Jie-ke NI² and Zhen WANG³

¹Department of Mechanical Engineering, Guangdong Songshan Polytechnic College, Shaoguan Guangdong 512126, China
²Department of Mechanical and Electronic Engineering, Guilin University of Electronic Technology, Gangxi Guilin 541000, China
³Department of Communication and Information Engineering, Xi'an University of Science and Technology, Xi'an 710054, China

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Abstract. A novelty method of pulse frequency power modulation and pulse width power modulation strategy are proposed for solving the problem of the skin effect of the load in the inductance heating mainly. A series half-bridge and inductance surface hardening is described. In the paper, established modeling for a series of half-bridge inverter circuit. An inductance heating system circuit is built through Simulink software to verify the feasibility of the complex power adjustment rules. After the circuit testing, results show that the composite power adjustment strategy can effectively achieved the control of constant power output and the load frequency tracking. Our strategy can improve the ability of adaptability and the overall performance with a certain feasibility and effectiveness.

Introduction

Inductance Heated and Surface Quenched is a method was applied widely. Its course is described such as metal heat treatment method that produces a certain inductance current on the surface of the work piece, rapidly heats the surface of the part and then rapidly quenches it [1].

Electric energy realizes the conversion of energy with electromagnetic inductance through inductance heating the inductance coil of main loop. For the advantages of high temperature control precision, less oxidation, less carbon consumption, no pollution and easy to realize uniform heating and small temperature difference between the core table and so on [2] and it has been widely used in industry. The key technology of inductance heating surface quenching is whether the system can output constant power [3]. Therefore, Designed an intelligent controller mode for inductance heating inverter and letting constant and stabilization output is very important. The adjusting power mode used in industry is divided into three kinds, such as pulse frequency modulation method; pulse density modulation method and pulse width modulation method [4]. Aiming at deficiency of the traditional mode of power regulation, a compound power regulation strategy based on pulse frequency modulation and pulse width modulation is described in this paper.

The mode for the inductance heating constant power control system is designed and built on the MATLAB/Simulink platform, through the analysis of the working state of the inductance heating half bridge system. In addition, based on the experimental results, the feasibility of the inductance heating compound power adjustment strategy is verified by prototype.

Analysis on the Overall Power Adjustment Strategy of Intelligent Controller

General Description

Inductance heating surface hardening inverter control system can be divided into two major parts, such as power conversion and power adjust control circuit.
The first partial content have inductance heating device to obtain normal frequency AC; rectifier circuit rectifier; conditioning the DC sent to the resonant inverter, The reverse that variable power electronics is made of electronic switches, and generated alternating current for the supplied work piece or load in the article [5, 6].

The second section is adjusting Power control, it is made of feedback loop, protection circuit, drive circuit and other components, inductance heating surface hardening inverter control mode is to adjust the pulse width and pulse frequency combined with the power mode, as shown in Figure 1.

Adjusting the pulse width is one of the strategies of the inductance heating surface quenching closed-loop control system. The advantages are mainly to make the inductance heating closed-loop system simple and easy to control. The pulse frequency regulation is the inductance heating surface quenching closed-loop control system inverter frequency tracking. The purpose of the main strategy is to heat the closed loop system load tank to join the firmware, the system can be in a resonant state, the power factor close to 1 in the article [7].

Inductance Heating Surface Quenching closed loop control system inverting side modulation strategy and its closing loop control system, The combination of inverter frequency tracking strategy to achieve the half-bridge inverter soft switch, thereby reducing the switching losses.

![Figure 1. Diagram of inductance heating surface hardening closed-loop system.](image)

**Phase-locked Loop Principle**

The phase-locked loop is an electronic circuit that tracks the closed-loop frequency and phase. Its function is to lock the phase of the output signal or to track the phase change of the input signal. The phase-locked loop is consist of a phase detector (PD), a loop filter (LPF) and voltage-controlled oscillator (VCO) three parts in the circuit [8].

The phase detector outputs a DC pulse voltage by comparing the frequency difference between the output signal and the reference signal. The loop filter is mainly used to filter out the high frequency components in the signal. In paper, Where the time constant \( \tau = RC \). Voltage-controlled oscillator to achieve voltage and frequency changes, which \( K \) is a sensitivity coefficient, \( u(t) \) is output voltage of the loop filter, \( \omega_o \) is the center frequency of the voltage-controlled oscillator.

**PI Power Control Principle**

PI is a linear controller; this controller is the set value \( r(t) \) and the output value \( c(t) \) of the composition of the deviation, named \( e(t) \):

\[
e(t) = r(t) - c(t)
\]

the control formula of the conventional PI is:

\[
u(t) = K_p[e(t) + \frac{1}{T_i}\int_0^t e(t)dt]
\]

In the formula, \( u(t) \) to control the output variable, \( K_p \) the scale factor, \( T_i \) is the integral time coefficient.

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Intelligent Controller Overall Modeling

In the process of inductance heating, the physical parameters of the load firmware will change with the temperature rise, the resulting in the load tank can not be in a resonant state, and thus make the main circuit in the hard switching state, loss increases, power factor is low, can not constant power output. The author in this paper, proposed the pulse frequency modulation and pulse width modulation of the complex power adjustment strategy is to keep the load tank has been in a resonant state, and through the PI power control to adjust the duty cycle of the gate pulse, the output power is constant. Figure 2 for the Simulink / MATLAB environment to build a complex power strategy system model. In addition to the inductance heating main topology circuit, the model includes several parts such as phase-locked loop module, PI module and gate drive module.

![Figure 2. Overall structure of compound control.](image)

![Figure 3. Frequency phase-locking control of PLL.](image)

Phase-locked Loop Modeling

Firstly, the reference input signal and the feedback signal are inputted to the XOR gate, the amplitude is adjusted into the low-pass filter to reduce the harmonic pollution, and completed the control of the frequency. To achieve the conversion between voltage and frequency, the processed signal into the voltage-controlled oscillator.

Finally, this way will achieve the phase-tracking tracking. Modeling parameters sampling time $T_s=\frac{1}{1\times10^6}$, $K_s=1, K_r=16384$ etc. The process of setting the phase-locked loop frequency lock-in control, shown as in Figure 3.

PI Power Control Modeling

The output and the amount of deviation of the deviation and deviation are taken as the input of the PI power calculation, and the output of the inverter is the same as the IGBT gate pulse. In order to make the system dynamic response rate, overshoot smaller, the adjustment time shorter, this paper took $K_s=0.05$; $K_r=0.004$, its model and simulation are shown in Figure 4.

![Figure 4. Simulation of PI power.](image)

![Figure 5. Simulation of driving pulse.](image)

Gate Drive Modeling Design

The function of the drive module is to combine output signal of the phase locked loop frequency with the PI control output signal, Figure 5 shows the IGBT gate drive pulse signal and the time control the IGBT turn on and turn off.

Experiment and Analysis

After the analysis of the strategy of heating resonator system, and simulation study using the Simulink / MATLAB plate form, the result shown that the feasibility of the composite power adjustment strategy and output constant power.
Simulation parameters is below: Input power $U_i = 380 \pm 10\%$, output power $P_o = 90kW$, resonant capacitor $C = 0.13 \times 10^{-6}F$, resonant inductor $L = 980 \times 10^{-9}H$, equivalent resistance $R = 2.02\Omega$.

Firstly, verify the feasibility of the pulse frequency modulation strategy, taking the reference power of 90kW, output gate drive pulse duty cycle of 50%, switching frequency were taken as 1kHz and 2kHz. The power output as shown in Figure 6 (a) (b), the simulation results show that the frequency of 1kHz and 2kHz corresponding to the output power of 89.5kW and 80kW, achieve the purpose of pulse frequency power adjustment.

Secondly, the pulse width modulation strategy is verified, take the reference power $P_{\text{ref}} = 90kW$, the switching frequency $f_s = kHz$, the output gate drive pulse duty cycle $D$ were taken as 30% and 50%, the power output as shown in Figure 7 (a) (b), the simulation results show that the duty Than the D for 30% and 50% of the corresponding output power of 82kW and 89.8kW, achieve the purpose of pulse width modulation.

For the inductance heating device which based on master topology of the series half bridge, the independent simulation results of the two kinds of strategies about the pulse width and pulse frequency that indicated power adjustment strategy is feasible, and explained that this paper proposed composite power control strategy for series inductance heating surface quenching for half bridge can be realized. Through the simulation analysis of the feasibility of the compound power regulation strategy, this paper takes the FPGA as the main controller and makes the prototype of 1 kHz/50W inductance heating.

Considering the output power is too small, take advantage of the transformer primary coil as the main circuit of resonant inductor, and with the secondary coil connected the Non-inductance resistor, Owing to the limited of paper space, the process of circuit parameter calculation and selection was omitted, the system parameters of the inductance heating power supply as shown in Table 1.

<table>
<thead>
<tr>
<th>Name</th>
<th>Specifications / Model Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGBT</td>
<td>FFR300[A]/1200[V]</td>
</tr>
<tr>
<td>Absorption</td>
<td></td>
</tr>
<tr>
<td>Capacitance</td>
<td>50V/2200[pF]</td>
</tr>
<tr>
<td>Diode</td>
<td>HER508</td>
</tr>
<tr>
<td>Resonant Capacitance</td>
<td>50V/10[uF]</td>
</tr>
<tr>
<td>Resonant Inductance</td>
<td>700[uH]</td>
</tr>
</tbody>
</table>
Experimental evaluation shows that when the secondary coil keep clear of the Non-inductance resistor, the resonant frequency is 1205Hz, and when the secondary coil was connected with the Non-inductance resistor, the resistance varies within a certain range, the voltage across of the Non-inductance resistor approximately sinusoidal signal, This peak changes as shown in Table 2.

<table>
<thead>
<tr>
<th>Resistance ( [/\Omega])</th>
<th>Frequency ( [/\text{Hz}])</th>
<th>Voltage Peak ( [/\text{V}])</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>1141</td>
<td>26.8</td>
</tr>
<tr>
<td>170</td>
<td>1163</td>
<td>27.8</td>
</tr>
<tr>
<td>180</td>
<td>1179</td>
<td>29.0</td>
</tr>
<tr>
<td>190</td>
<td>1149</td>
<td>31.7</td>
</tr>
<tr>
<td>200</td>
<td>1142</td>
<td>29.6</td>
</tr>
<tr>
<td>210</td>
<td>1200</td>
<td>32.0</td>
</tr>
<tr>
<td>220</td>
<td>1190</td>
<td>32.5</td>
</tr>
</tbody>
</table>

From the table data, The prototype model which with the Non-inductance resistor under the condition of the change in frequency fluctuation near the natural frequency, within the fluctuation range of 100Hz, and the tracking of PLL frequency make the system in resonance state, the power factor was high; The resistance value varies between 160-220, and the voltage is also corresponding changed. The power consumed by the Non-inductance resistor is approximately constant.

**Conclusion**

Based on analysis traditional inductance heating series half bridge surface quenching power regulation strategy is simulated and realized. The model of inductance heating system is built by Simulink dynamic simulation software to verify the feasibility of pulse width and pulse frequency regulation strategy in inverter. FPGA is used as a controller, realizing the dynamic adjustment of the inductance heating power. The experimental results show that the application of composite power control strategy realizes the control of constant power output and the track of load current signal, hardening the foundation for further application of the composite power control strategy in the field of inductance heating surface.

**Reference**


