Ultrasonic Power Supply of Oil-Water Separation System

AnHua Wang(✉), DongDong Wan, and HongKai Ding

Electronic and Information Engineering Institute, Heilongjiang University of Science and Technology, Harbin 150022, China
3036361_cn@sina.com

Abstract. With the continuous development of oil field, the recovery and recovery of crude oil are gradually reduced, and the water content ratio of oil field production is higher and higher. The ultrasonic oil-water separation technology can improve this situation. The performance of ultrasonic power supply directly affects the reliability and economic benefit of oil-water separation system, which is an important part of the system. This paper introduces an ultrasonic power supply with high efficiency and strong stability. This power supply mainly adopts inverter technology to realize the continuous regulation of output voltage and working frequency. Matlab simulation experiment shows that the output voltage of H-bridge is positive and negative pulse waveform, and the output current is sine wave; reasonable setting of parameters can ensure that the output voltage amplitude is 0 V–00 V, and the frequency is 15 kHz–35 kHz, which meets the actual production demand. The results show that the ultrasonic power supply designed in this paper has good output characteristics and can provide energy to the transducer efficiently and reliably, which is of great significance to the practical application of the ultrasonic oil-water separation system.

Keywords: Oil water separation · Ultrasonic power · Inverter technology · Positive and negative pulse

1 Introduction

The crude oil extracted from oil wells contains not only a small amount of solid impurities such as silt and rust, but also a large amount of water. These moisture will increase the fuel consumption during heating and smelting. If working in this condition for a long time, it will cause the corrosion of equipment and pipelines and even the blockage of pipelines. This problem can be effectively improved by using ultrasonic technology. Because the common power supply can not provide the high frequency alternating current matching with the ultrasonic transducer, the research on the high-efficiency and reliable ultrasonic special power supply [1–4] has become a key problem.

At present, some achievements have been made in the field of ultrasonic power supply at home and abroad. It has gone through two stages of electronic tube generator and transistor analog generator [5, 6], but the former has been eliminated due to its too many

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shortcomings, and the latter is suitable for low-power occasions (below 200 W), and its cost is low and can be used in a certain range [7]. Transistor switch generator [8] is the current mainstream development direction, which can be used in high-power situations (more than 200 W) and can be easily combined with micro electric processor [9]. The switch generator uses the duty cycle of control signal to control the output voltage, which has low power consumption and high efficiency. Thus, the heat dissipation requirements are reduced so that the volume and weight per unit power are smaller [10].

In this paper, the ultrasonic power supply for oil-water separation is taken as the research object. Combined with the current research trend, the DSP with faster CPU and higher integration is used for control, and the new inverter technology is used to realize the continuous change of output voltage and frequency, improve work efficiency and reduce cost.

2 Overall Plan

The structure of the ultrasonic power system is shown in Fig. 1. The input voltage is 220 V/50 Hz AC. the DC voltage is output through the diode uncontrolled rectifier circuit. The DC voltage is chopped and reduced by the forward converter to obtain a stable DC voltage to the H-bridge transmitter. The H-bridge transmitter outputs voltage square wave and current sine wave. The frequency and amplitude of the output voltage are sent to the DSP by the sampling circuit, and then to the driver circuit after the DSP processing. The driver circuit drives the switch tube according to the DSP signal.

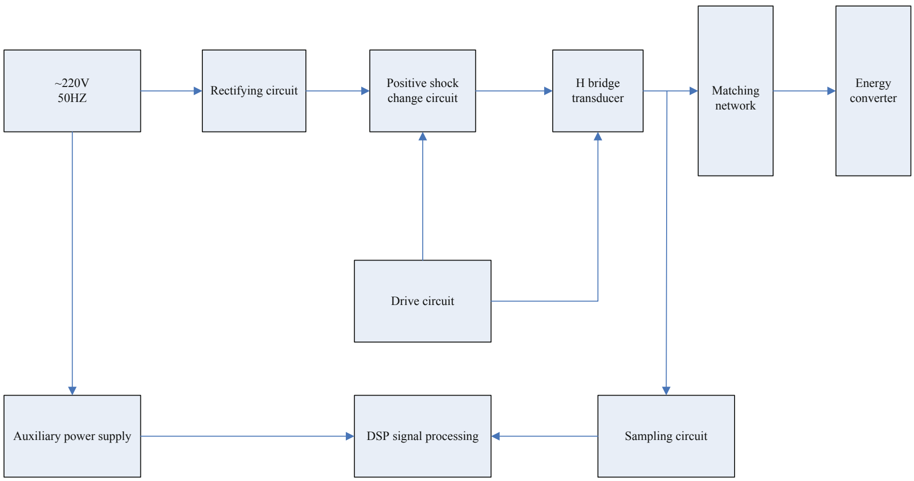

Fig. 1. System diagram of ultrasonic power supply.

3 Hardware Circuit Design

3.1 Main Circuit

The main circuit is as shown in Fig. 2. The input is 220 V 50 Hz AC. the DC voltage is output through a single-phase uncontrolled rectifier circuit. The chopper step-down circuit is a single switch forward circuit, and the forward excitation is output to the single-phase H-bridge transmitter, so as to realize positive and negative pulse voltage and sinusoidal current output.

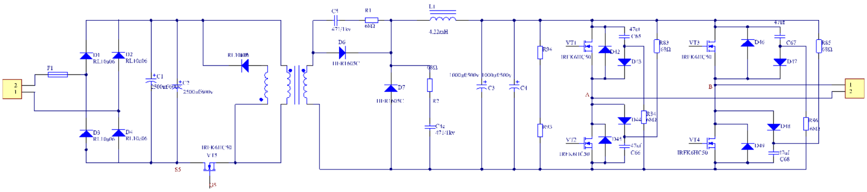

Fig. 2. Schematic diagram of main circuit.

The driving chip of H transmitter is IR2110. IR2110 is highly integrated, with external protection and blocking port, which can be used to drive power tube of - 4–500 V bus voltage system, and can drive two switch tubes of the same bridge arm. And IR2110 can drive power switches with frequency up to 500 kHz [11–14] to meet the system requirements. The driving circuit is mainly composed of bootstrap diode, bootstrap capacitor and other peripheral devices, as shown in Fig. 3.

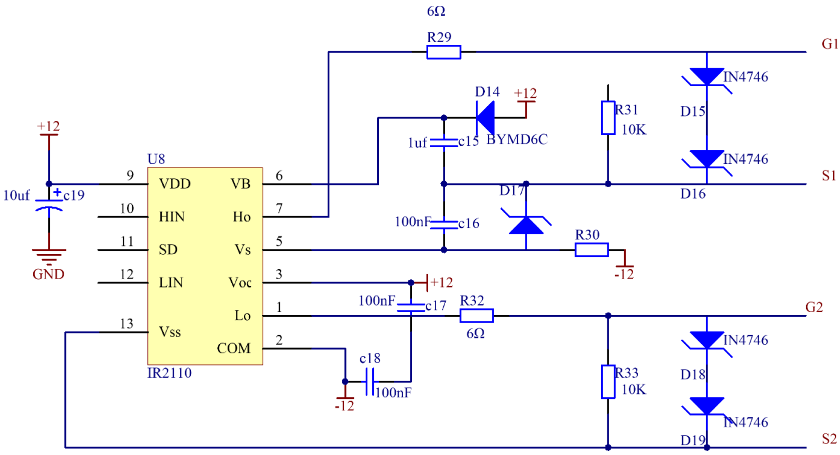

Fig. 3. Drive circuit.

3.2 Auxiliary Power Circuit

Because the digital chip in the control circuit needs positive and negative 12 V voltage and positive 5 V voltage, it needs to design an efficient auxiliary power supply for the control circuit. Flyback converter is selected as the main circuit of the auxiliary power supply, which has the advantages of simple structure, high efficiency and small loss, and is suitable for outputting multi-channel DC [15]. As shown in Fig. 4, the schematic diagram of auxiliary power supply is 220 AC, 36 V AC is obtained through power frequency transformer, and 43 V DC is obtained after diode rectification and capacitance filtering. Finally, the flyback converter is used to obtain positive and negative 12 V voltage, and the switching frequency is 82 kHz.

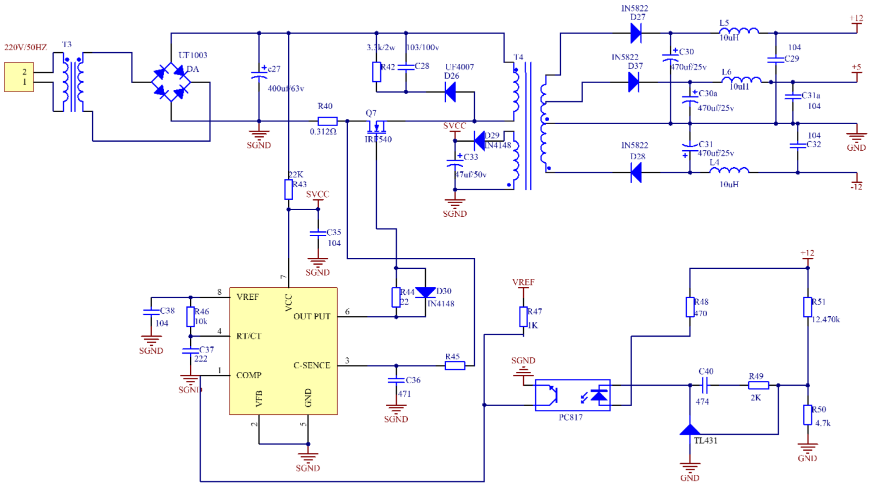

Fig. 4. Auxiliary power supply.

3.3 Detection Circuit

Figure 5 shows the output current detection circuit. The detected current should be fed back to the inverter control circuit for frequency tracking, so it must be selected from the resonance channel. So I choose the current of the channel as the frequency feedback signal. Hall sensor is used to detect the current of the channel. Because the output current of the ultrasonic power supply is sine wave, the detected current should be processed into DC signal and sent to the A / D port of DSP.

The output voltage detection circuit is shown in Fig. 6. By setting the appropriate magnification, adjust the linear proportion relationship between the sampling voltage input and output. Since the working voltage range of DSP is 0 to 3.3 V, the amplitude of the voltage signal entering DSP should be controlled between 0 to 3.3 V. So the limiting circuit is designed to prevent the high amplitude of the voltage signal entering the DSP from burning the chip.

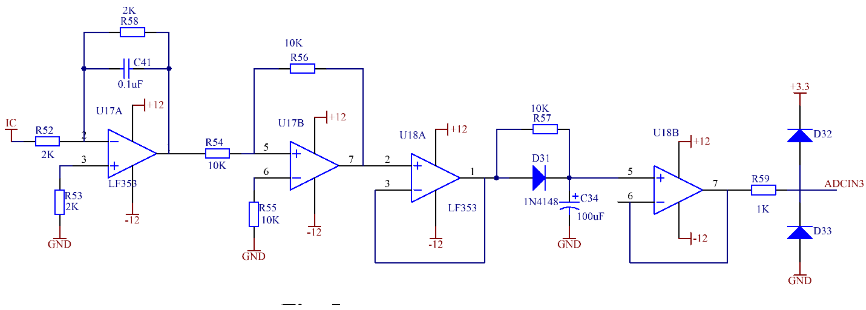

Fig. 5. Current detection circuit.

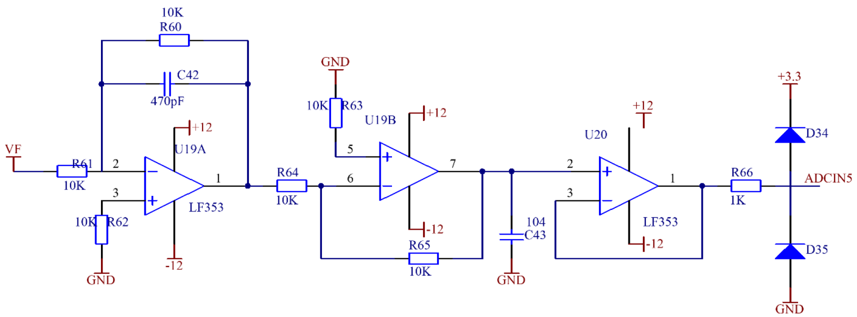

Fig. 6. Voltage detection circuit.

3.4 Protection Circuit

Figure 7 shows the over-current and over-voltage protection circuit. The 5-pin lm319 chip is led out by the current sampling circuit in Fig. 5. If the input voltage of 5-pin is higher than the 4-pin positive phase input voltage of the over-current comparator, the 12 pin of the comparator will output a low level, and the LED D39 is on, indicating the line over-current. Since the 1 pin of the optocoupler pc787 is high level, the LED in the optocoupler will turn on the light, then the 4 and 3 pins of the optocoupler will turn on. The 3-pin optocoupler is connected to the power protection interrupt pin pdpinta of DSP, and the potential of 3-pin changes to low level, which will produce a falling edge, resulting in the effective interruption. DSP immediately blocks PWM drive signal to realize protection. The working principle of over-voltage protection is similar to that of over-current protection.

3.5 Buffer Circuit

Because the switch tube flows a lot of current when it is turned on and bears a lot of impulse voltage when it is turned off, it is necessary to design a buffer circuit to restrain the impulse of current and voltage. The buffer circuit can also improve the reliability of the circuit, reduce the loss of the switch and suppress the electromagnetic interference. The buffer circuit is shown in Fig. 8.

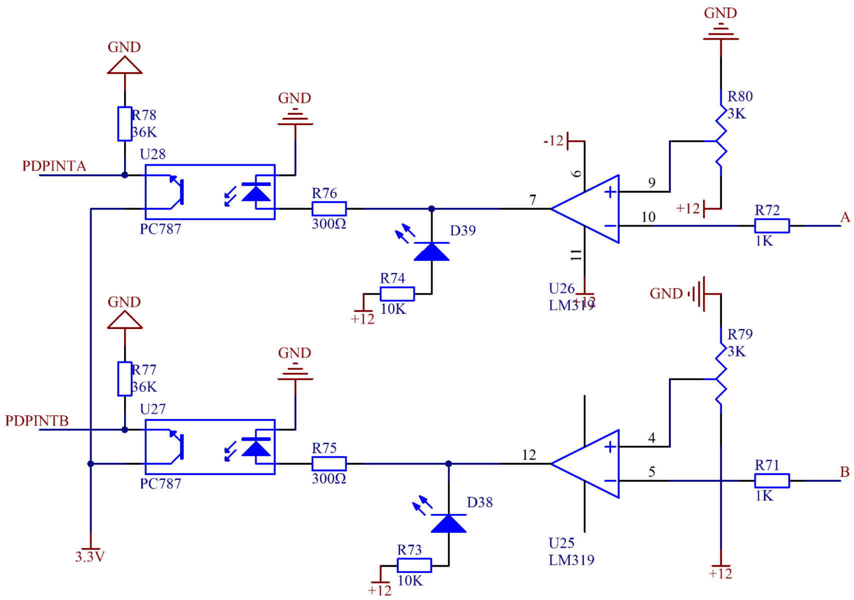

Fig. 7. Protection circuit of over voltage and over current.

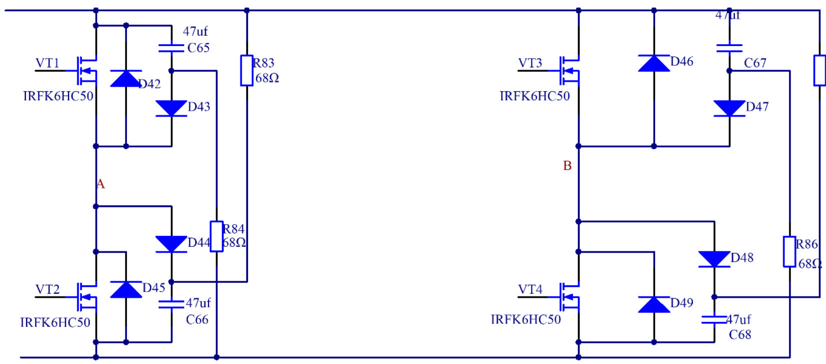

Fig. 8. Buffer circuit.

4 Software Design and Simulation Analysis

4.1 Flow Chart Design of Current and Voltage Sampling Program

TMS320LF2407A chip has integrated a/D A/D conversion module, so the collected voltage signal is directly sent to a/D pin adcin00 of DSP. The timer in the event manager EVA is used to generate 1 cycle ADC conversion trigger signal and read out the conversion value in the ADC interrupt program. In order to improve the accuracy of the sampling value, the average value of the sampling value is taken by setting the sampling times [17, 18]. Figure 9 shows the current and voltage sampling flow chart.

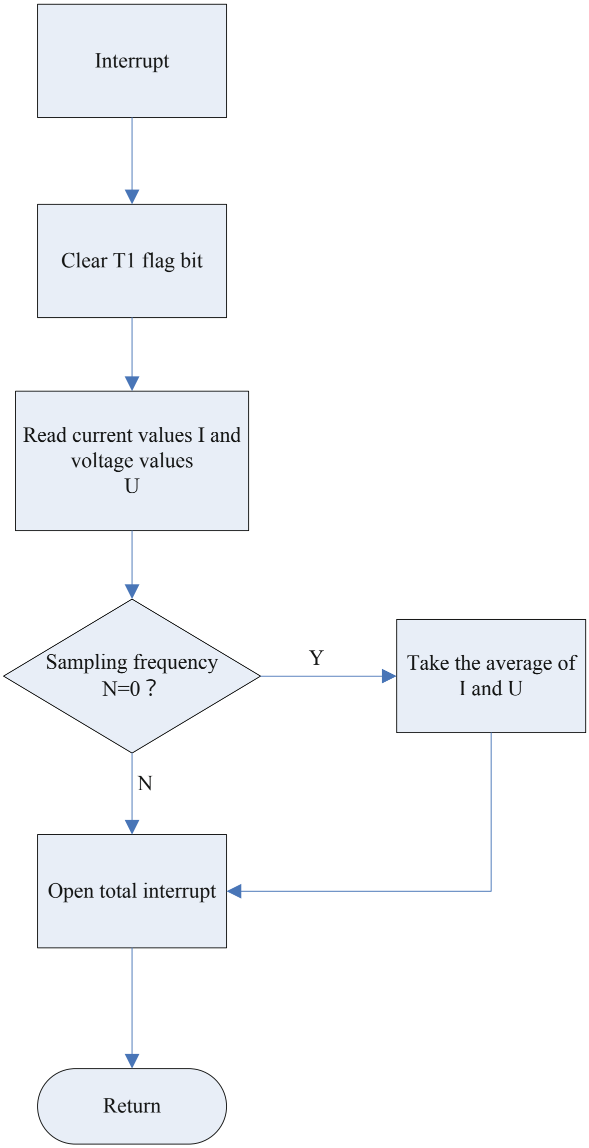

Fig. 9. Flow chart of current detection.

4.2 Flow Chart Design of External Pin Interrupt Program

The external pin interrupt flow is shown in Fig. 10. The external interrupt XINT1 is used to detect whether the waveform output by the optocoupler isolator pc787 is the rising edge or the falling edge. The external interrupt XINT1 pin status is monitored by xint1cr in the DSP chip [19]. When rising edge is detected, iopa6 pin outputs low level, and when rising edge is detected, iopa6 pin outputs high level. The dead time is equal to the delay time plus the program instruction execution time [20, 21].

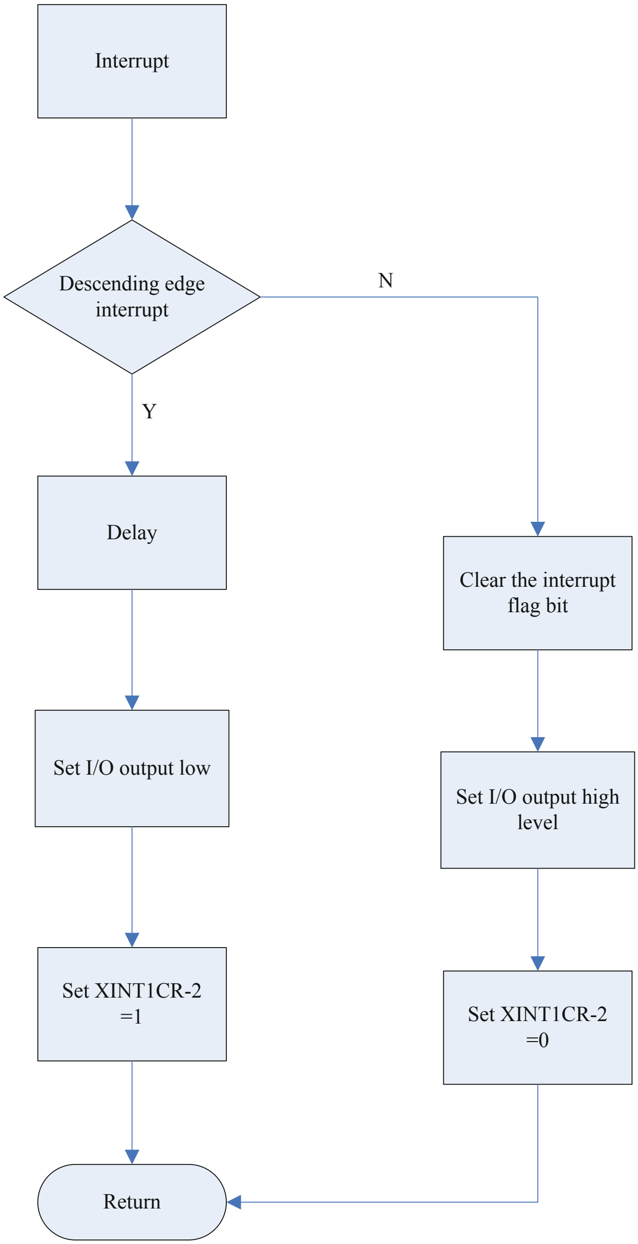

Fig. 10. Flow chart of external pin interrupt.

4.3 Simulation Analysis

The simulation experiment is carried out on the Simulink platform, which is an integrated environment of dynamic system modeling, simulation and comprehensive analysis provided by MATLAB [22, 23]. As shown in Fig. 11, it is the output voltage waveform in the single switch forward open-loop state. The output voltage changes with the input voltage, and the output voltage drops seriously under load. Under the open-loop control, the output voltage tends to be stable after 0.4 s. Since the open-loop control has large defects, the closed-loop control is adopted, and the stable time waveform is shown in Fig. 12. The output stabilization time is 0.0037 s. Compared with the open-loop control, the proportional feedback control greatly improves the control speed. In a certain input range, the output voltage is stable and the load adjustment rate is small.

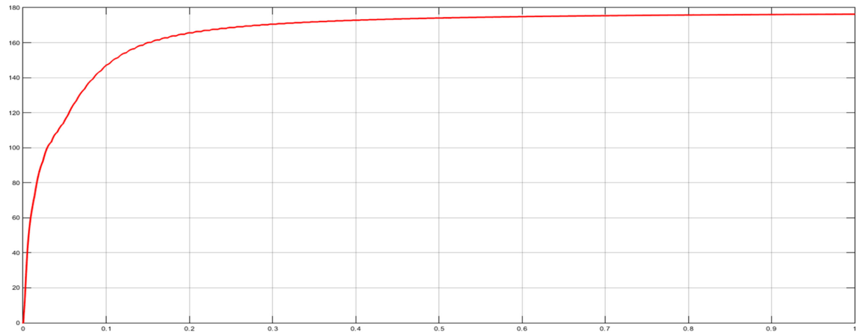

Fig. 11. Output voltage wave of open loop.

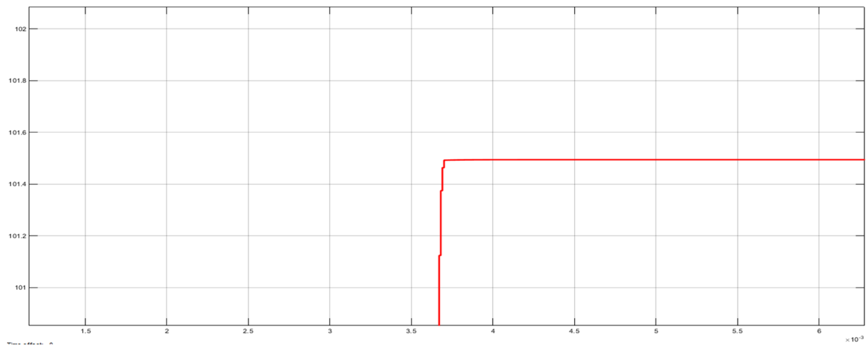

Fig. 12. Output voltage wave of proportional control.

Although the proportional control is better than the open-loop control, but the output has a large error [24, 25], which can not meet the actual requirements, so the proportional integral control is chosen to reduce the steady-state error of the system. The output voltage is as shown in Fig. 13. The steady-state error is 0.3, the stable time is 0.0106 s, and the overshoot is 0.01%.

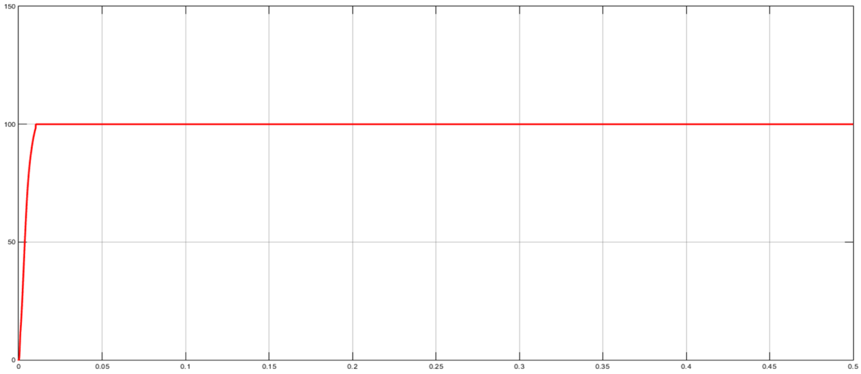

Fig. 13. Output voltage wave of proportional integral control.

The four switches of the H-bridge unit adopt phase-shifting control, and there is a certain dead zone between the pulses to prevent the straight through of the same bridge arm. The driving waveform is shown in Fig. 14.

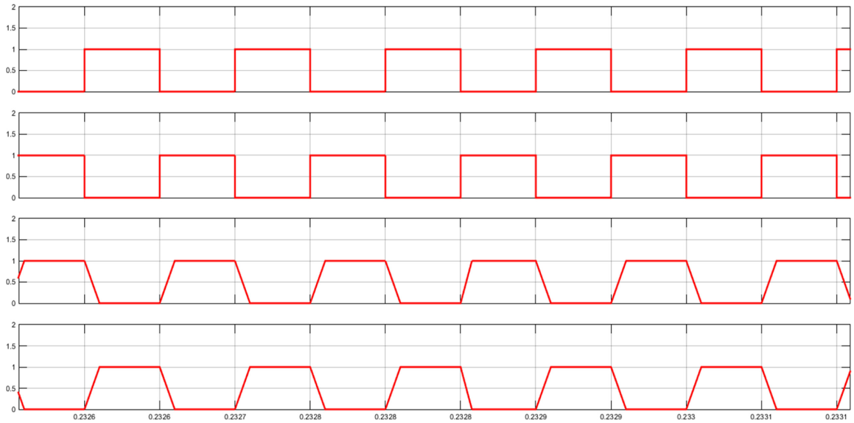

Fig. 14. Wave of drive signal.

The output voltage of H bridge is square wave, the frequency is 20 kHz, and the amplitude is plus or minus 100 square wave. The output voltage meets the actual demand, and its waveform is shown in Fig. 15.

The output matching network is LC resonance [26]. The resonance frequency can be obtained by setting the parameters of inductance and capacitance reasonably. The resonance frequency is set in the controllable range of H-bridge. The output current waveform after resonance matching is shown in Fig. 16, which is similar to sine wave. In the experiment, the capacitance is set as 500 pf, the inductance is set as 1000 μ h, and the resonance frequency is 22.5 kHz.

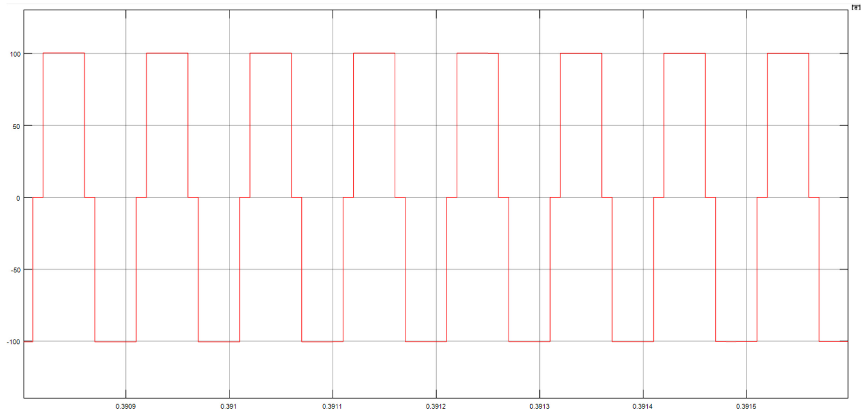

Fig. 15. Output voltage wave of H-bridge.

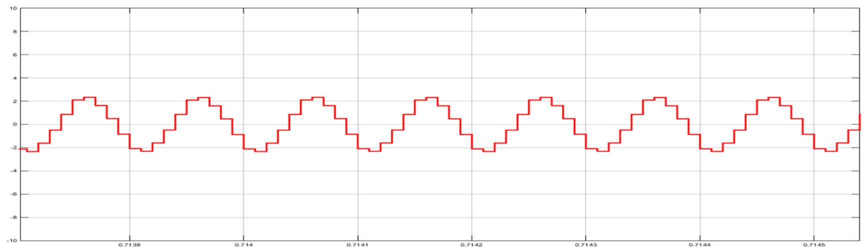

Fig. 16. Output current wave.

5 Conclusion

In this paper, the ultrasonic power supply for oil-water separation device is studied. The main structure of the system is composed of single-phase uncontrolled rectifier circuit, single switch forward circuit and single-phase H-bridge transmitter, and DSP is used as the control chip. By using the typical PID control algorithm, the output voltage and frequency are changed continuously, and the power density of the power supply is greatly improved. Through the MATLAB simulation experiment, it is found that the output voltage and output current waveform are consistent with the expectation after the resonance matching; in the appropriate frequency and amplitude range, it can meet the actual work needs. It is proved that the scheme of ultrasonic power supply proposed in this paper is feasible and has certain reference value for practical application.

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