Design of Digital Control Phase-Shifting Full-Bridge Switching Power Supply

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Abstract. With the development of switching power supply towards miniaturization and high efficiency, digital and soft switching technology has become the research focus of switching power supply. Phase-shifted full-bridge DC/DC converter is commonly used in medium and high power applications due to its advantages of low switching loss, high efficiency and low output current ripple. Based on the existing switching power supply and digital control technology, a digital control phase-shifting full-bridge switching power supply is designed. Its output voltage ranges from 0 to 12 V. The output current ranges from 0 to 50 A. The voltage and current level can be adjusted according to the user's power demand, and the output mode of steady voltage or steady current can be set. The parallel operation of multiple power supply is realized by RS485 communication protocol.

1. Introduction
Switching power supply has experienced the development of circuit topology transformation, control technology and power device. The traditional analog control switching power supply can not meet all the application needs, its shortcomings include high output noise and ripple, low reliability and flexibility, etc[1]. The whole machine system is in urgent need of switching power supply which can realize intelligent functions such as quick and accurate response, monitoring and so on. The digital embedded technology is introduced into the field of power electronic switching power supply, and the digital sampling, operation, control output, system monitoring and human-machine interface function are realized[2]. Soft-switching technology is the core technology to solve the reliability problem of digital control switching power supply. The use of resonance principle to achieve zero voltage and zero current conduction or turn off is the basic characteristics of PWM soft-switching[3]. The main circuit of medium and high-power switching power supply is basically a Full-Bridge Converter (FBC) structure, and its soft-switching has three ways of working accordingly, namely ZVS, ZCS and ZVZCS[4]. This paper designs a digitally controlled phase-shifted full-bridge switching power supply. It plays the characteristics of high precision and high speed of microcontroller. By combining traditional power electronics with modern embedded system, the output precision, intelligence, integration and system stability of switching power supply are improved.

2. Design of system scheme
A microcontroller STM32F103RC is used as the main control unit of the digital control power supply designed in this paper. The main circuit is a full-bridge inverter topology, which adopts phase-shifting
full-bridge control mode, and can realize the function of ZVS/ZCS soft switch. In the design, the touch screen is utilized to display voltage and current, and realize the function of the human-machine interface. An isolated optocoupler called HCPL7840 is utilized to sample the voltage and current. The PWM waveform output by the main control unit is driven by a chip called M57962L to control the opening or closing of the IGBT. Thus realizing the purpose of controlling the output voltage and output current.

The hardware circuits of the whole project include the main control circuit based on STM32, voltage sampling and current sampling circuit, rectifier and filter circuit, full-bridge inverter circuit, auxiliary power supply circuit, host computer and panel communication circuit and so on. The overall block diagram of the system is shown in figure 1.

The main technical parameters of the system are as follows.
(1) the input rated voltage is 220VAC(±15%).
(2) the output voltage range is 0 to 12 VDC.
(3) the output current range is 0 to 50A.
(4) the maximum output power is 600W.
(5) the switching frequency is 100 kHz.

![Figure 1. Block diagrams of digital controlled switching power supply system.](image)

3. Design of system hardware

3.1. Selection of main topology of power supply

Full-bridge DC/DC converter is a kind of power conversion circuit suitable for medium and high power switching power supply. It is composed of full-control single-phase full-bridge inverter, high-frequency transformer and output rectifier filter circuit. Its main features are simple circuit structure, easy to improve circuit frequency, high transformer utilization, fast system dynamic response, high system stability, strong anti-high-frequency interference capability, etc[5].

In recent years, the DC/DC converter with single-phase full-bridge inverter as the main circuit has been widely studied, the control technology has been further improved and mature, and its application is very common. In this design, phase-shifted full-bridge is chosen as the topology of DC/DC converter, as shown in figure 2.
3.2. Design of control circuit

The control circuit is designed based on STM32 microcontroller. The microcontroller can operate at a frequency of up to 72 MHz, on-chip integrated high-speed memory (256 KB of memory and 48KB of SRAM). It has abundant multi-function I/O interface and analog-to-digital converters and other peripherals, greatly simplifying the difficulty of engineering design. The figure 3 gives a key part of the circuit.
3.3. Design of voltage sampling and current sampling circuits

In order to realize the function of digital closed-loop control and protection, the system must collect the output voltage, output current and other signals of power supply. The required level signals are obtained by isolating amplifiers, and the power circuit is electrically isolated from the STM32 control board.

In order to realize the function of electrical isolation between main circuit and control circuit of power supply, an isolated optocoupler called HCPL7840 is used to detect output current and output voltage. The output voltage sampling circuit is shown in figure 4. In the output current sampling circuit, the shunt is used to convert the current signal into the voltage signal for easy sampling. The schematic diagram is similar to the output voltage sampling schematic diagram.

![Figure 4. The output voltage sampling circuit.](image)

3.4. Design of main device parameters

3.4.1. Selection of single-phase uncontrolled rectifier bridge. The single-phase alternating current generates a direct current after uncontrolled rectification, and the direct current is supplied to the inverter through capacitive filtering. In this paper, the rectifier bridge is used for uncontrolled rectification. According to the technical specifications of switching power supply, the maximum input power can be obtained as

$$P_{im} = P_{om} / \eta$$  \hspace{1cm} (1)

The maximum input current can be obtained as

$$I_{im} = P_{im} / V_{min}$$  \hspace{1cm} (2)

The average current flowing through diode can be obtained as

$$I_D = I_{im} / 2$$  \hspace{1cm} (3)

The maximum reverse voltage for diodes can be obtained as

$$V_{RM} = \sqrt{2} * V_{max}$$  \hspace{1cm} (4)

According to the two main parameters $V_{RM}$ and $I_D$, and considering that enough margin should be left in the actual work, the single-phase uncontrollable rectifier bridge suitable for this subject can be selected.

3.4.2. Capacity calculation of input filter capacitor. It can be seen from the previous section that the single-phase alternating current is subjected to uncontrolled rectification to obtain a relatively large pulsating DC voltage. The function of the input filter capacitor is to smooth the DC voltage. Therefore, the selection of the input filter capacitor is more important. If it is too small, the DC voltage ripple is too large. Conversely, the charging current pulse width is narrowed and the amplitude is increased, resulting in a decrease in the input power factor and an increase in EMI.
In general, the pulsation of DC voltage after rectifying and filtering is 15% of the peak value of the lowest input AC voltage. Set the range of known AC input voltages to \( V_{\text{inmin}} \) to \( V_{\text{inmax}} \), follow these steps to calculate the capacity of \( C_{\text{in}} \):

\[
V_{\text{inmin}} = \sqrt{2}V_{\text{line}} \times (1 - 15\%) \\
V_{\text{inmax}} = \sqrt{2}V_{\text{line}} \times (1 + 15\%)
\]

The pulsation value of DC voltage after rectifying and filtering can be obtained as

\[
V_{\text{pp}} = \sqrt{2}V_{\text{line}} \times 30\%
\]

The value range of DC voltage after rectifying and filtering is \( (\sqrt{2}V_{\text{line(min)}} - V_{\text{pp}}) \) to \( \sqrt{2}V_{\text{line(max)}} \). When the input DC voltage is the minimum, the energy \( W_{\text{in}} \) stored in capacitor \( C_{\text{in}} \) in each cycle is as follows

\[
W_{\text{in}} = P_{\text{im}}f_{\text{min}}
\]

Where \( f_{\text{min}} \) is the frequency and \( P_{\text{im}} \) is the maximum input power. The input filter capacitance can be obtained as

\[
C_{\text{in}} = \frac{W_{\text{in}}}{[(\sqrt{2}V_{\text{line(min)}})^2 - (\sqrt{2}V_{\text{line(min)}} - V_{\text{pp}})^2]}
\]

3.4.3. Selection of spacer capacitance. In order to reduce the loss of the capacitor and improve the efficiency of the converter, the capacitors should not be too small. At the same time, in order to reduce the volume and save the cost, the capacitors should not be too large. In summary, the following conditions should be satisfied for the selection of the capacitors \( C_{\text{b}} \). It is obtained as

\[
C_{\text{bmin}} \geq \frac{2CV_{\text{i}}}{10\%V_{\text{i}} - \frac{L_{\text{s}}V_{\text{i}}}{nL_{\text{e}}}}
\]

Where \( C \) is the shunt capacitor of the switch.

3.4.4. Design of primary side series resonant inductor. When selecting resonant inductor, it should be ensured that the energy stored by the inductor can meet the conditions of realizing soft switching. It is obtained as

\[
\frac{1}{2}L_{\text{p}}I_{\text{p}}^2 > CV_{\text{i}}^2 + \frac{1}{2}C_{\text{TR}}V_{\text{i}}^2
\]

Where \( I_{\text{p}} \) is the current passing through the resonant inductance, \( C \) is the shunt capacitor of the switch, and \( C_{\text{TR}} \) is the parasitic capacitance of the primary winding of the transformer.

4. Design of system software
This system adopts C language to design the software and realizes the functions of digital control power supply. The software includes main control program, A/D conversion subroutine, PI subroutine, host computer communication subroutine, subroutine to realize the function of over-voltage and over-current protection and so on. The main control program includes the initialization of each function of the system, configuration enabling interrupt, waiting interrupt, etc. The main control program block diagram is shown in figure 5.
Switching converter is a time-varying, nonlinear system, which cannot establish an accurate mathematical model. The advantage of the fuzzy PID algorithm used in this paper is that it does not need accurate modeling and is very suitable for the DC/DC converter system. The flowchart of the algorithm is shown in figure 6. Set the current reference value to \( r(k) \), the sampling value is \( j(k) \).

Set the fuzzy rule according to the error value \( e(k) \) and the change rate \( ec(k) \) of the deviation, then the adjustment amount of the PID parameter can be adjusted.

5. Debugging and testing
In this paper, a digital control phase-shifting full-bridge switching power supply is built and tested in the laboratory to verify its integrity. The experimental platform is shown in figure 7. High voltage differential voltage probe P2200 and AC/DC current probe A622 are used to detect voltage and current signals, which are fed into digital storage oscilloscope DS1074Z-S.
Figure 7. The power prototype.

Figure 8 is the IGBT driver waveforms at 90 degrees phase shift, and figure 9 shows the output voltage waveform. Through the analysis of the experimental results, it can be seen that the digital control phase-shifted full-bridge switching power supply system designed in this paper can achieve the required voltage stabilization effect in the voltage stabilization stage, and the output voltage ripple of the system is also controlled within the design scope. The results show that the digital control phase-shifting full-bridge switching power supply system meets the design requirements.

Figure 8. The IGBT driver waveforms at 90 degrees phase shift.

Figure 9. The output voltage waveform.
6. Conclusions
The digitally controlled DC power supply designed by the paper improves the power supply from low ripple, high precision, high efficiency and strong human-machine interaction. The range of output voltage is 0 to 12V, the range of output current is 0 to 50A. The touch screen realizes human-machine interaction and real-time monitoring of voltage and current. It has the advantages of convenient operation, high control precision, high voltage stability and strong practicability. If the digital control power supply has deeper development in the field of soft switching technology, and further reduce the noise and reduce the switching loss while further improving the operating frequency and output power of the converter, it will be further popularized and applied in the future.

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