Design and implementation of online uninterruptible power supply system based on STM32

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Abstract: The application of microprocessors in automation and industry has become more and more extensive, especially the application of embedded microcontroller technology has promoted the development of UPS design. This paper designs an embedded uninterruptible power supply system with adjustable output based on STM32, and uses PID algorithm to optimize the control strategy. The advantage of this system is that the output is adjustable and has high precision, the circuit structure is simple, the output power efficiency is high, the system is small in size, and the cost is low, while the stability and safety of the system are guaranteed.

1. Introduction:
With the rapid development of social informatization and modernization, the requirements for the reliability and stability of the power system are getting higher and higher. Some facilities with strict requirements for power supply, such as hospitals and subways, will cause major losses and even disasters if the power supply fails. On-line uninterruptible power supply (UPS for short) is a power supply system with a backup power supply, which can realize uninterrupted power supply to electrical appliances when a power failure occurs. Due to its significant advantages, online UPS has become the primary choice for facilities with high power supply requirements. As the demand continues to grow, the UPS system has also been updated in multiple versions, and the uninterruptible power supply system is increasingly becoming modular and high-frequency [1]. Each module of the traditional UPS system is integrated with a control unit, the cost is high and the information feedback between the modules is difficult to handle.

The purpose of this research is to design a UPS based on high-performance embedded system control. The embedded structure will centralize the control units of the system, so the system will respond more quickly to circuit failures and external factors. The presence of the feedback unit improves the accuracy and quality of the output. More importantly, this will simplify the circuit control system and provide a more flexible and richer control strategy. This design scheme reduces the cost of the power supply, improves the performance of the power supply, and facilitates the maintenance of the power supply. Embedded research will greatly promote the development of UPS [2]. Especially in occasions where a small-capacity uninterruptible power supply needs to be applied, the embedded system can significantly reduce the cost and volume. This is of great significance to the application and promotion of UPS.
2. Overall system design:
The main part of the system is composed of rectifier filter circuit, battery, power-off switching circuit, boost circuit and inverter circuit [3].

The rectifier converts the AC voltage input from the transformer into DC to supply power to the booster circuit and the battery. The boost circuit is responsible for raising the input DC voltage to a position that can meet the output demand and then supplying power to the inverter. The inverter finally converts the input direct current into an alternating current output with stable frequency and low harmonics. When detecting that the AC input disappears, it is switched to the battery power supply mode through the power-off switching circuit. The overall circuit design is shown in Figure 1:

Figure 1 The overall design of the system

3. System hardware design

3.1. Figure 2 Control circuit design diagram
In order to meet the needs of system design, a microprocessor with powerful control performance and high-speed computing capability is required. STM32F407 is a high-performance microprocessor developed by Italian and French STMicroelectronics (ST). It provides the performance of a Cortex™-M4 core (with floating point unit) operating at 168 MHz and multiple timings built-in. The detector and ADC detection port can realize industrial-grade applications and are a good choice as a UPS system microprocessor. STM32 is responsible for the control of the drive circuit and the processing of voltage and current sampling information. The control circuit design is shown in Figure 2:

Figure 2 Control circuit design diagram

3.2. Design of voltage and current sampling scheme
Since the built-in ADC channel of STM32 cannot directly measure AC voltage, the output voltage sampling of the system uses a differential amplifier circuit. Current sampling is implemented using Hall elements. The AC voltage measured by the differential circuit and the voltage raising circuit is received and processed by the microcontroller. The voltage differential sampling circuit is shown in Figure 3:
3.3. Drive circuit design
The drive circuit in this system is realized by a special MOS drive chip UCC27211 and controlled by PWM waves. UCC27211 is a high-voltage high-speed power MOSFET and IGBT gate driver, with a maximum operating voltage of 600V. In this system, two pieces are used to build a full-bridge inverter drive circuit, and one piece is used to build a BOOST boost drive circuit. The inverter drive circuit is shown in Figure 4:

4. System software design
4.1. Overall system design
The core software design of this system includes BOOST circuit control, inverter control, DC voltage and current acquisition. After STM32 receives the setting information from the keyboard, it controls the booster circuit by outputting a PWM wave with a constant frequency, and outputs a software modulated SPWM wave with a changed duty cycle to control the output of the inverter. The system accepts feedback voltage and current information to form a closed-loop adjustment to increase system stability. The control algorithm uses PID for optimization, which makes the system response more
rapid and stable, and the overshoot is significantly reduced. The overall software design flow chart of the system is shown in Figure 5:

![System software design flow chart](image)

Figure 5 System software design flow chart

4.2. Boost circuit and inverter circuit control

In order to realize the adjustable output voltage of the inverter, it is necessary to provide a high power supply voltage to the inverter. The peak value of the maximum output voltage of the inverter will not exceed the input voltage. We need a boost circuit to raise the output voltage of the rectifier to a position greater than the peak value of the inverter output. The BOOST circuit uses a high-efficiency synchronous rectification scheme, and STM32 comes with complementary channels, which can easily control the power tube. Because the BOOST output voltage is relatively high, it is not convenient to directly sample. The output voltage is obtained by the method of resistor divider. After the voltage is measured, the drive circuit is controlled by the pid algorithm [4]. The calculation formula for output voltage and duty cycle is as follows:

\[
V_{OUT} = V_{IN} \left( 1 - D \right)
\]  

\( V_{OUT} \) is the output voltage. \( V_{IN} \) is the input voltage. \( D \) is the duty cycle.
The formula for calculating the resistance partial pressure is as follows:

$$V_{OUT} = (1 + R_H/R_L) V_{FB}$$  \hspace{1cm} (2)

Where $V_{OUT}$ is the output voltage, $V_{FB}$ is the sampling point voltage, $R_H$ is the up-sampling resistor, and $R_L$ is the down-sampling resistor.

Inverter control is a key part of the system. In order to enable the inverter to output a sine wave of a specified frequency, the SWPM wave modulated by the sine code table is used to control the inverter drive. Use unipolar control scheme to improve circuit efficiency and reduce switch tube loss. The switching point calculation method of unipolar SPWM waveform modulation based on natural sampling method is as follows [5]:

$$t_{on}(k) = t + \Delta T/2(1 - a\sin\omega t_s n(k))$$  \hspace{1cm} (3)

$$t_{off}(k) = t + \Delta T/2(1 - a\sin\omega t_s n(k))$$  \hspace{1cm} (4)

In the formula, $t=(k-1)\pi/\omega N$, $\Delta T=\pi/\omega N$, a is the modulation degree, and N is the number of pulses in a half cycle. The system will change the output by changing the modulation ratio. The modulation ratio from 0 to 1 represents the inverter output from 0 to the maximum value.

5. Testing and analysis

The purpose of this research is to design a highly accurate and stable system with adjustable output, which can effectively isolate external grid interference. Use this scheme to simulate a small system to verify the correctness of the research. The physical picture of the system is shown in Figure 6:

![Figure 6 System physical map](image)

5.1. Output performance index test

The key indicators to judge whether the UPS system performance is excellent are whether the output voltage is stable and whether the harmonic content is small. The test environment is input $V_{IN}=36V$, output current $I_{OUT}=1A$. Set the output AC voltage $U_B$ to change in the range of 24V~40V, and the frequency $f=50Hz$.

Test the frequency $f_{out}$ and the harmonic factor THD of the output voltage $U_{OUT}$, and calculate the difference $U_B$ between $U_{OUT}$ and the preset voltage $U_s$. The test result shows that the error between the output voltage and the set voltage does not exceed 0.1%. The system has excellent closed-loop performance and stable output voltage. The harmonic factor THD is very small. The test results are shown in Table 1 below:

| $V_{IN}$ | $I_{OUT}$ | $f_{out}$ | $U_{OUT}$ | $U_s$ | $U_B$ | THD |
|----------|-----------|-----------|-----------|-------|-------|-----|

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5.2. Load regulation test
Test the output load regulation rate $S_I$ when the input $V_{IN} = 36V$ and the output AC current $I_{OUT}$ changes in the range of 0.1A~1.0A. The test results show that the system load adjustment rate is below 0.2%, and the closed loop effect is good. The test results are shown in Table 2 below:

| $V_{IN}$  | $I_{OUT}$ | $S_I$  |
|----------|----------|--------|
| 36.00V   | 0.1A     | 0.13%  |
| 36.00V   | 0.3A     | 0.18%  |
| 36.00V   | 0.6A     | 0.16%  |
| 36.00V   | 1.0A     | 0.17%  |

5.3. Power efficiency test
Disconnect AC power and immediately switch to DC (energy storage element side) power supply. When the battery output side DC voltage $U_D = 24V$, output AC voltage $U_{OUT} = 30V$, output AC current $I_{OUT} = 1A$, frequency $f = 50Hz$, test the output voltage conversion efficiency $\eta$. The traditional efficiency filter of traditional UPS power supply is generally around 90%, and the test results show that the DC conversion efficiency of this system can reach more than 96%. Tests have proved that this system integrates a processor to simplify the circuit and can effectively improve the efficiency of UPS power. The power efficiency test is shown in Table 3, and the output waveform is shown in Figure 7:

| $U_D$   | $U_{OUT}$ | $f$     | $\eta$ |
|---------|-----------|---------|--------|
| 24.00V  | 29.98V    | 50.00Hz | 96.5%  |
| 24.00V  | 30.00V    | 50.02Hz | 96.6%  |

Figure 7 Output waveform
6. Conclusion
Aiming at the slow response of the traditional modular UPS power system, the output accuracy is low, the output is single and the volume is large, this paper studies an online UPS system based on STM32. Since an integrated high-performance processor is used to control all circuits at the same time, the system can use more flexible control strategies. The system responds more quickly, and when a fault occurs, it can be dealt with in time. The use of closed-loop PID algorithm makes the output more accurate. The hardware circuit is simplified, and the output efficiency is significantly improved.

Practice has proved that compared with traditional UPS power supply, this system has better performance and reduced cost and volume. This shows that the research of UPS system with microprocessor as the core is of practical significance. The application of embedded UPS will greatly promote the popularity of UPS.

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