Design of online uninterruptible power supply with AC output

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Abstract. This paper shows the design of an on-line uninterruptible power supply with STM32 as the main controller. It contains rechargeable batteries as the energy storage device and uses inverter technology as the core which can make 29V~42V AC input to 30V AC RMS output. The system uses STM32 as the control core, it is divided into main controller, autotransformer module, rectifier bridge module, PFC module, inverter module, booster module, battery pack, current and voltage detection module. When the utility power is connected, it supplies power to the inverter module and if it is disconnected, the main control terminal allows the battery to supply power to the inverter module in time, thereby realizing online uninterrupted power supply. Experimental results show that this system can supply power to the load without interruption, and has a good load regulation rate and voltage regulation rate.

1. Introduction
Today, electricity has penetrated into daily life, so when the city power is interrupted, life will be hindered and accompanied by economic losses [1]. Uninterruptible power supply was born for this reason. Compared with the traditional power supply to electrical appliances through the mains, it has the advantage of still supplying power when the mains fails, and it is optimized to be sent to the electrical equipment when the mains is normal. When the mains power is under-voltage or cut off, it switches to battery mode to provide uninterrupted power supply.

Previously, due to the limitations of microelectronics technology, designers could only use ICs with a low level of integration to design UPSs, which resulted in shortcomings such as large volume and redundant structure. With the development of technology, the number of integrated ICs has increased and the number of options has increased. It can make the equipment more integrated, intelligent and miniaturized [2-4]. This article proposes a small, precise and stable 30V AC output UPS designed using STM32 master control with UCC28335, LM5109, IR2104, etc. Firstly, the mains is rectified and then the mains is calibrated by PFC for power factor [6], and then it is converted to AC voltage by the inverter to supply power to the electrical appliances. When the mains power is disconnected, the BOOST module is supplied by the battery to output high voltage to replace the mains [7].

This paper first summarizes the overall operation of the system, then introduces hardware design and software design respectively, and finally analyzes the UPS load regulation rate, voltage regulation rate, and output efficiency.

2. Over structure of the system
The system is composed of input module, battery output module, and inverter module, all of which are controlled by an MCU. The system block diagram is shown in Figure 1.
Take out 220V 50HZ and step down to 29V~43V 50HZ at the input end, and then rectify it through a rectifier bridge, and then increase the power factor and the voltage at the same time through PFC, and finally stabilize the 65V DC voltage to the bus for the inverter module.

In the battery output module, take out 24V DC voltage to supply power to the BOOST module. To ensure that it will not interfere with the mains input voltage, a diode is connected in series between the module and the bus to prevent 65V from being poured into the battery. At the same time, it can quickly switch to the battery when the mains fails.

In the inverter module, it is composed of a full bridge circuit connected by four NMOSs. The MCU controls the four switch tubes to alternately conduct to generate alternating current. Add a current and voltage detection module to the output for MCU to read. This allows the MCU to accurately control the output voltage and current, improve the quality of the power supply, and stably output 30V.

3. Theoretical analysis and calculation

3.1. Inverter module filter parameter calculation
Since it needs to output a sinusoidal voltage, an inductor is needed to filter the SPWM modulated square wave alternately generated by the MOS tube. And this inductance has a vital influence on the THD of the inverted voltage. The filtering part is connected in series and parallel with LC, which is equivalent to that shown in Figure 2.

The relevant parameters are calculated as follows: When the output voltage frequency is 50Hz, the MCU control switching tube adopts unipolar modulation, and the switching frequency is 33.6KHz, so the lowest harmonic frequency of the output is 67.2KHz. On the premise that the output waveform is not distorted, the cut-off frequency of the filter must be much greater than the fundamental frequency of 50Hz and at the same time far less than the lowest harmonic frequency of 67.2KHz. Therefore, the cutoff frequency is set to 2KHz, and the load \( R \), that is, \( R=15\Omega \).

\[
L = \frac{\sqrt{2} \cdot R}{\omega}
\]  

(1)
\[ w = 2\pi f \]  
\[ f = 2\text{KHz}, \text{so } L = 1.68\text{mH}, \text{the approximate value is } 1.3\text{mH}. \text{That is } L_1 = L_2 = 1.3\text{mH} \]

\[ C = \frac{1}{\sqrt{2} \omega R} \]

Therefore, \( C = 3.75\text{uF}, \text{the approximate value is } 4.7\text{uF}. \text{That is, } C_1 = C_2 = 4.7\text{uF}. \)

3.2 **BOOST module inductance parameter calculation**

The BOOST circuit is responsible for boosting the 24V DC voltage provided by the battery to 50V, and powering the inverter when there is no city power. The choice of inductance in BOOST plays a key role in the quality of the boosted voltage. The switching frequency is \( f = 21\text{KHz}, \text{output ripple } r = 0.4, \text{output current is } 2\text{A}, \text{the parameters are calculated as follows} \)

\[ D = \frac{V_o - V_i}{V_o} \]  
\[ L = \frac{V_o D (1 - D)}{2I_s f} \]

Calculate \( L = 334.6\text{uH}, \text{take the approximate value } L = 350\text{uH}. \)

4. **Hardware design**

4.1 **Controller**

The system uses ST's STM32 single-chip microcomputer as the controller, with ARM's Cortex™-M4 high-performance core, built-in 8 16-bit timers, the controller can provide high-frequency PWM signals for BOOST modules and inverter modules. At the same time, it has a 12-bit analog-to-digital converter to collect external voltage. The reason for choosing it is the fast response speed, with a processing speed of up to 168MHz, which can control several modules at the same time, and can quickly switch the power supply in the event of a mains accident. And the voltage is accurate, which can improve the quality of the output voltage.

4.2 **PFC module design**

The system receives the rectified voltage of 29V~43V alternating current from the mains step-down, and stabilizes the voltage step-up to 65V, while adjusting the power factor to 1. It is very complicated to build PFC circuit with discrete components, and the power factor index is difficult to reach 1, so the continuous current control mode UCC28335 chip of TI company is selected as the core driver chip of this system, and the MOS tube is selected CSD19536, which has the advantage of low internal resistance and fast switching speed. The schematic diagram of the design of PFC is shown in Fig. 3.
4.3 Design of inverter module
The system receives the 65V or 50V voltage provided by the PFC or BOOST module and inverts it into an alternating voltage with an effective value of 30V.

The inverter system uses a full-bridge structure. According to the power supply and driving requirements, it uses Infineon’s IR2104 driver chip, which has a dead zone and can drive up to 600V. It has a typical 0.21 A source current and 0.36 A sink current. MOS chooses CSD19536, the DS voltage is 100V, and the internal resistance is only 2.4mΩ, which can effectively reduce the power loss caused by the battery power supply and reduce heat generation. The schematic diagram of the design of inverter module is shown in Fig. 4.

4.4 BOOST module design
This module boosts the 24V voltage provided by the battery to 50V to power the inverter system and can withstand currents exceeding 2A.

The boost module uses a bidirectional DCDC topology, that is, the output diode is replaced by a switch tube. This structure can play a role in synchronous rectification and reduce the loss and heat of the overall circuit. The control chip chooses TI’s LM5109, the dead time is freely set, the response speed is fast, the driving voltage is 100V, and the current is 1A. Use the two complementary PWM high frequency signal control provided by MCU. The schematic diagram of the design of BOOST module is shown in Fig. 5.
4.5 Output voltage detection circuit
The MCU cannot directly take the AC voltage, so the voltage needs to be stepped down and raised to the positive voltage area for the MCU to collect.

The voltage can be reduced to within 3.3V through the four-resistor structure shown in Figure 6. Then use TI's INA149 voltage differential amplifier to process the output voltage to make the waveform at a positive voltage for MCU detection. The design diagram is shown in Figure 7.

4.6 Output current detection circuit
This circuit uses the INA282 current detection amplifier to obtain the equivalent current value for MCU detection by collecting the voltage on the constantan resistor and amplifying it by 50 times. The system design principle is shown in Figure 8.

5. Software design
This system is driven by the core of two modules controlled by an MCU, and outputs PWM respectively to make the modules work properly.

It is divided into two parts:
1. Initialization part: MCU initializes the value of each pin and starts to output PWM wave. The output frequency of SPWM of the inverter module is 33.6K, and the output frequency of PWM of the boost module is 21K.
2. Voltage regulation and interruption part: MCU detects the signal transmitted back by the voltage measurement module, and stabilizes the voltage at an effective value of 30V by adjusting the duty cycle of PWM. When the current exceeds 1.2A, the system stops running to avoid safety accidents.

The two parts of the system software process are shown in Figure 9.
6. Experiments and analysis

6.1. Experimental Environment
The system is powered by 29V-43V AC power from the autotransformer and 24V DC power from the battery. First turn on the DC power supply and then turn on the AC power supply. Secondly, a 30Ω~300Ω power resistor is connected in series at the output of the inverter to test whether the output voltage can reach 30V/1A. The physical picture is shown in Figure 10:

6.2 Data Analysis

6.2.1. AC $U_i=36V$ RMS power supply, output AC current $I_o=1A$, load $R_L=30Ω$, the measured output AC voltage $U_o$, frequency $f$ and distortion THD are shown in the table below.

| $U_o/V$ | $f/Hz$ | THD/% |
|--------|--------|--------|
| 30.0   | 50.0   | 0.3    |

It can be obtained that the output voltage, frequency and distortion of the system are in good condition and remain stable under 1A current when the normal input is 36V.

6.2.2. AC $U_i=36V$, change the output resistance to change the AC current $I_o$ between 0.1A and 1A. The measured output AC voltage $U_o (0.1A)$, $U_o (1A)$ and load adjustment rate are shown in the table below.

| $I_o/A$ | $U_o/V$ | Load Regulation |
|--------|--------|-----------------|
| 0.1    | 30.03  |                 |
| 1      | 30.00  | 0.1             |

It can be obtained that when the load changes and the current changes, the system output voltage changes very little, that is, the performance is good.

6.2.3. AC power supply is 1A, when adjusting the input voltage $U_i$ between 29V~43V, the measured output AC voltage and voltage regulation rate are shown in the following table.

| $U_i/V$ | $U_o/V$ | Voltage regulation rate |
|--------|--------|-------------------------|
| 29     | 29.97  |                          |
| 43     | 30.01  | 0.133                    |

It can be seen that this system maintains a good voltage regulation rate in a wide input range.

6.2.4 When the AC power supply is cut off, the DC power supply is $U_d=24V$, and the output AC current $I_o=1A$, the measured output AC voltage $U_o$ and the efficiency of the online uninterruptible power supply are shown in the following table.

| $U_o/V$ | $\eta/%$ |
|---------|---------|
| 29.94   | 94.74   |

When the mains power is interrupted, the system can quickly switch to DC power supply and can maintain stable operation. The efficiency has reached 94%, and the system itself consumes a very small proportion of power.

7. Conclusion
This paper proposes an on-line uninterruptible power supply with an output AC voltage of 30V. The
The system can immediately switch to battery power when the AC voltage supply stops. The output voltage is an AC voltage with an effective value of 30V. When the current varies from 0.1A to 1A, the voltage can be kept stable and the efficiency can reach 94%. It has good THD, voltage regulation rate and load regulation rate.

References
[1] Lu, Y. (2011) The influence of power grid momentary power failure on electrical equipment[J]. Electromechanical information, 15:22-23.
[2] Wang, L.B. & X.N, He, (2003) UPS classification, key technology analysis and development forecast [J]. Journal of Electrical Engineering Technology, 10: 21-24.
[3] Feng, Y.L. & S.P, Zhang, (2006) The status quo and development trend of integrated circuits [J]. Microelectronics, 02: 173-176.
[4] Liu, Z.J. (2011) Research on the development and application of power electronics technology[J]. Electronic World, 09: 19+25.
[5] Xu, H.M, & X.B, Ruan & Yan, Y.G, (2001) Overview of single-stage power factor correction AC/DC converters[J]. Power Electronics Technology, 01: 56-60.
[6] Wang, X.W & Y.H, Cheng, (2004) Design of inverter power supply based on DSP dual-loop control[J]. Power Electronics Technology, 03: 20-21+64.
[7] Zhang, F.H & C.H, Zhu & Yan, Y.G, (2005) Control model of bidirectional DC-DC converter[J]. Proceedings of the Chinese Society of Electrical Engineering, 11: 46-49.