Design and Implementation of Three-phase Sine Wave AC Power Supply Based on the Embedded System STM32

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Abstract. Because of inverter power supply with high power consumption, low transfer efficiency rate, a three-phase sine wave AC power supply is designed based on the embedded system STM32 which has the advantage of low power consumption and high speed. It has the capacity of output frequency of 50 Hz, the RMS of line voltage and current of star load connection up to 24V and 2A. The system consists of a three-phase inverter drive circuit, filter circuit, STM32 minimum system, the isolation circuit, SPWM (sinusoidal pulse width modulation) signal generator, measurement circuit of voltage and current and LCD display circuit. The experiments show that when the input voltage is set at 36V at room temperature and the line current of load is 0~2A, the load regulation rate is less than 0.3% and transfer efficiency can reach 88%.

1. Introduction
With China's continuous attention to environmental protection, green, low-carbon, recycling and energy saving emerging industries are gaining popularity. Power supply technology applied in emerging industries requires higher efficiency, reliability and lower cost, while inverter technology has prominent advantages in high efficiency, low power consumption, high precision and so on, and can be widely applied in emerging industries. Therefore, the research on inverter technology has become an important research topic.

This paper designs a three-phase pure sinusoidal ac power supply with low power consumption and high speed STM32 processor as the core. The main circuit of inverter driver adopts intelligent power module (IPM) PM30CSJ060. When the input dc voltage is 36V, the output sinusoidal signal frequency is 50Hz, and the line voltage effective value can reach 24V when load y-type connection; At the same time, when the effective value Io of load line current varies between 0 and 2A, the load adjustment rate of each phase is not more than 0.3%, and the energy conversion efficiency can reach 88%.

2. The system structure of three-phase pure sine wave power supply
Three-phase pure sine wave power supply consists of DC power module, three-phase inverter driving main circuit, filtering circuit, STM32 minimum system, signal isolation circuit, SPWM (sinusoidal pulse width modulation) signal generator, voltage and current measurement circuit, LCD display and other functional circuits, as shown in figure 1. STM32 generates sinusoidal pulse width modulation signal (SPWM), controls the three-phase inverter drive circuit (intelligent power module) after the optocoupler isolation circuit, and filters through a low-pass filter. Finally, the dc voltage inverter is converted into a
three-phase pure sinusoidal voltage signal, and the load is a three-phase symmetric y-type connection of pure resistance. The voltage and current measurement circuit measures the voltage and current of each phase of three-phase pure sine wave and displays it on the liquid crystal display after passing STM32.

Figure 1. Block diagram of three-phase pure sine wave power supply system.

3. Functional module design

3.1. Three-phase inverter drives the main circuit

Three-phase inverter drive main circuit using mitsubishi’s intelligent power module (IPM) PM30CSJ060, it is not only the power switch device and the drive circuit integration in together, but also including the overvoltage, overcurrent and overheating fault detection circuit, even if the load accident or improper use, also can protect themselves from being damaged, to the detection signal processor at the same time, according to the specific fault type.

PM30CSJ060 is suitable for frequency up to 20K power conversion occasions, internal by six IGBT units constitute H bridge inverter circuit, rated voltage of 600V, rated current of 15-75a. The grid drive circuit of the 6 units requires a total of 4 sets of isolated power sources, among which the grid drive circuit of the 3 units of the upper bridge arm USES a set of independent dc 15V power sources, and the grid drive circuit of the 3 units of the lower bridge arm USES a set of dc 15V power sources. The internal circuit is shown in figure 2.

PM30CSJ060 pin is defined as: P is the positive pole of bus dc power supply; N is the negative pole of the bus DC power supply; U, V and W are output of AC voltage signals of U, V and W phases; \( V_{UPI} \), \( V_{VPI} \) and \( V_{WPI} \) are positive poles of U, V and W phase upper bridge arm drive power supply; \( V_{UPC} \), \( V_{VPC} \) and \( V_{WPC} \) are power sources of U, V and W phase upper axle arm drive; \( U_P \), \( V_P \) and \( W_P \) are signal inputs of U, V and W phase upper bridge arm; \( U_{FO} \), \( V_{FO} \) and \( W_{FO} \) are U, V and W phase upper axle arm fault outputs; Positive pole of lower bridge arm drive power supply under VNI; VNC lower bridge arm drive power supply ground; \( U_N \), \( V_N \) and \( W_N \) are signal inputs of lower bridge arm in groups U, V and W respectively. \( F_O \) lower bridge arm fault output.

Figure 2. PM30CSJ060 internal circuit.
3.2. Signal isolation circuit
The photocoupler is used to isolate the processor STM32F103 from PM30CSJ060 to improve the security and anti-interference of the system. Four low light coupling PC817 2 pin respectively with PM30CSJ060 fault signal at the output of the UFO, VFO, WFO connection, 1 pin with PM30CSJ060 four groups respectively isolated 15 v power supply connection, 4 pin connected to the processor STM32F103 I/O port, 3 pins are connected to the signal source to GND5 public, but GND5 isolation with four groups of 15 v power supply not altogether, as shown in figure 3.

![Figure 3. PC817 optocoupler circuit.](image)

The processor STM32F103 generates 3 pairs of complementary SPWM signals, which are output through I/O port, and then connected with PM30CSJ060's UP, VP, WP, UN, VN and WN driver signal pins through high-speed optocoupler 6N137. Therefore, 6 6N137 optocouplings are required, as shown in figure 4. Among them, all the 3 pins of 6N137 are connected with GND5 at the common ground of signal source, and the 3 6N137 connected with UN, VN and WN share a group of 15V power supply and ground.20 k Ω resistance and 0.1 uF capacitance pull-up resistors and decoupling capacitance respectively.

![Figure 4. PC817 optocoupler circuit.](image)

3.3. SPWM (sinusoidal pulse width modulation) signal generator
Sinusoidal pulse width modulation signal (SPWM) adopts the natural sampling method, but instead of finding the intersection point of carrier and modulation wave, a sinusoidal table is formed in STM32F 103. By comparing the size of carrier and modulation wave through the software table lookup method, the pulse width is controlled to generate six complementary SPWM signals. This method has the advantage of producing waveform close to sine wave and small computation.

3.4. Filter circuit
The output waveform of PM30CSJ060 needs to be filtered by a filter circuit to get the sinusoidal signal. The main filters to be removed in this system are carrier frequency $\omega_c=20$KHz, $\omega_c$ and the adjacent harmonics, LC-$\pi$ filter circuit as shown in figure 5. Inductance adopts high frequency magnetic winding to make hollow core coil, capacitance adopts non-polar polyester capacitor.

![Figure 5. Filter circuit.](image)
3.5. Voltage and current measurement circuit

3.5.1. Effective value measurement circuit of phase voltage. Since the RMS measurement chip AD637 has the advantages of high measurement accuracy, short relative stability time and wide frequency band, and its output voltage is equal to the RMS value of the voltage to be measured, this chip is used to measure the RMS value of three-phase ac voltage. However, the measurement range of RMS of input voltage of AD637 is 0~7V, so RMS of output voltage of 14V of three-phase inverter circuit cannot be directly measured. The 5mA/5mA miniature current type voltage transformer MH8009PT can convert ac high voltage into ac low voltage output with good linearity and high accuracy. The measurement circuit is shown in figure 6. Resistance R1 and R2 are current limiting and sampling resistance, ensuring that the primary and secondary side current of the voltage transformer is 5mA.CAV pins of AD736 are connected to the average capacitance of 33uF to reduce the ac error caused by ripple voltage. Vout pins are connected to the eighth conversion channel of ADC1 of STM32.

![Figure 6. Effective value measurement circuit of phase voltage.](image)

3.5.2. Effective value of phase current measurement circuit. The effective value of phase current was measured by voltage output current transformer ZMCT102. There is a linear relationship between the input current and the output voltage of the ct, in which the primary side current and the secondary side current are 2000:1. Therefore, the input current value can be obtained by measuring the voltage value, as shown in FIG. 7. The current transformer is isolated from the circuit under test when measuring large ac current signals, and has little influence on the circuit under test. It has the advantages of low energy consumption, wide frequency band, good signal reduction and low price.

![Figure 7. Effective value of phase current measurement circuit.](image)

3.6. Power supply module
The output voltage signal of 36V from one DC stabilized power supply passes through four dc-dc isolated power modules sysy10-24s15, and four 15V isolated power sources are generated to supply the main circuit of three-phase inverter drive. At the same time, the DC stabilized power supply is connected to one dc-dc isolated power module SY5S-24S05, which generates ±5V voltage and ±5V power supply voltage respectively for AD637 and STM32 processors.
3.7. STM32 minimum system

STM32F103 is a 32-bit ARM microcontroller, its peripheral resources are very rich, including ADC, general timer, I2C bus interface, SPI interface, etc., which is specially designed for motor control and advanced timer, with 6 dead zone time programmable PWM generator, so programmable to produce 6 complementary SPWM signal drive IPM; 12-bit adc, realizing high speed and high precision adc without considering AD converter on the outside of the controller. The minimum system of STM32F103 includes reset, crystal oscillator, JTAG, 1602 LCD and other unit circuits, as shown in figure 8.

4. The software designs

The system software flow is shown in figure 9. After system initialization, if no key is pressed after the delay of 50ms, the ac signal waveform converted by the main circuit of three-phase inverter drive will be displayed on the oscilloscope. If the key is pressed, the measured phase voltage and phase current will be displayed on the LCD 1602 after data processing.

Figure 8. STM32F103VBH6 minimum system circuit.

Figure 9. System flow chart.
5. Test results and discussion
According to the test, when the input dc voltage is 36V and the RMS of load line current of U, V and W phases is 2A, the frequency of sinusoidal signal, the RMS of each line voltage and the load adjustment rate of each phase of three-phase power supply are output, as shown in table 1. When the effective value \( I_o \) of load line current varies between 0 and 2A, the phase load adjustment rate \( S_{i1} \) is less than or equal to 0.3%. The calculation method of load adjustment rate is:

\[
S_{i1} = \frac{U_{oi1} - U_{oi2}}{U_{oi1}},
\]

where \( U_{oi1} \) is the output terminal line voltage when \( I_o = 0A \), and \( U_{oi2} \) is the output terminal line voltage when \( I_o = 2A \). When the input dc voltage is 36V and the input dc current is 1A, the efficiency of the inverter is 88%.

DC voltage stabilizer power supply, current and voltage measurement circuit stability and accuracy, manual welding of inverter circuit, filter circuit performance will produce measurement errors, affect the test results.

| Table 1. The test results. |
|---------------------------|
| Three-phase | Frequency/Hz | Effective value of line voltage \( U_{i2}/V \) | Effective value of line voltage \( U_{oi}/V \) | Load regulation/% |
|-------------|--------------|---------------------------------|-----------------|------------------|
| U           | 50.1         | 24.10                           | 24.05           | 0.20             |
| V           | 50.2         | 24.00                           | 23.95           | 0.21             |
| W           | 49.1         | 23.90                           | 23.87           | 0.12             |

6. Conclusion
Aiming at the disadvantages of inverter power supply, a three-phase pure sine wave ac power supply is designed. When the input dc voltage is 36V, the output sinusoidal signal frequency is 50Hz. At the same time, when the effective value \( I_o \) of load line current varies between 0 and 2A, the load adjustment rate of each phase is not more than 0.3%, and the energy conversion efficiency can reach 88%.

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