A type of inverter power supply based on harmonic elimination PWM control

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Abstract: In order to output sine wave with small degree of distortion and improve stability, a type of inverter power supply is designed based on harmonic elimination pulse-width modulation (PWM) control. The rectifier and filter are added to input circuit of the inverter. Single-phrase full-bridge inverter performs the function of converting direct current into alternating current (DC/AC). In the control circuit, single chip micyoco (SCM) AT89C2051 is used for main control chip to accomplish the hardware design of the control system. A given value of output frequency of the inverter is input in the way of coding. According to the output frequency code which is read, SCM AT89C2051 defined harmonic elimination PWM control data which will be selected. Through internal timing control, the switches are switched under this provision of PWM control data. Then the driving signals of the switches in the inverter are output from I/O of SCM AT89C2051 to realize harmonic elimination PWM control. The results show that adding Newton homotopic algorithm of harmonic elimination PWM control to corresponding software of the control system can make the quality of output voltage of the inverter higher and it will have broad application prospects.

Key words: inverter power supply; pulse-width modulation (PWM); harmonic elimination PWM control; Newton homotopic continuation method

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Inverter power supply is the key part of many types of equipment such as uninterrupted power supply (UPS), static aircraft power and those with new energy generation technologies[1]. In point of power conversion, the inverter can realize the function of converting direct current into alternating current (DC/AC). That means DC can be converted to a certain frequency AC. However, inverter power supply is usually required to output sine wave with small degree of distortion[2], so eliminating harmonics is one of the basic requirements of the inverter power supply. Effective control strategy can eliminate harmonics well, in addition, the circuit topology of inverter power supply can be simplified and the cost will be reduced. In this paper, a basic structural framework of inverter power supply is introduced firstly, and then input circuit, inverter circuit as well as control circuit are highlighted. In control circuit, internal resources of AT89C2051 are utilized legitimately through harmonic elimination PWM control to reduce harmonics which exist in output voltage of the inverter. The basic idea and algorithm of harmonic elimination PWM control are proposed and the flow charts of software programs reflect the control algorithm. At last, a conclusion is drawn.

1 Hardware design

Inverter power supply consists of input circuit, output circuit, inverter circuit, control circuit, auxiliary circuit and protection circuit. The basic structural framework and the relationship between them are shown in Fig. 1.

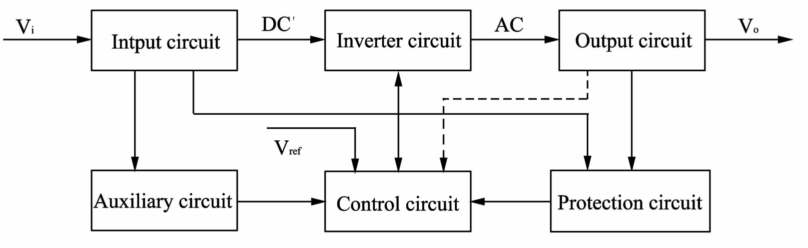

Fig. 1 Basic structural framework of inverter power supply

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1.1 Input circuit

In Fig. 1, V_i can be either direct voltage or allternating voltage. When V_i is alternating voltage, besides considering the electro magnetic interference (EMI) filter processing in alternating voltage side, rectifier and filter are also needed. The circuit of this part is shown in Fig. 2.

In Fig. 2, R2 and C19 make up differential mode filter circuit. L7, C20 and C21 make up common mode filter circuit. AC passes EMI filter. The filter is composed of R2, C19, L7, C20 and C21. It is able to inhibit differential and common mode. The rectifier is made up of VC3 and filter capacitors. VC3 consists of 4 diodes (VD1 - VD4), which can convert input alternating voltage to direct voltage. C17 and C18 are filter capacitors, the output direct voltage passes them. Then the input of the inverter can obtain a relatively smooth direct voltage. R36 is temperature sensitive resistor. It has a high resistance when the temperature is low and can inhibit the initial charging current of C17 and C18. When the temperature of R36 increases, the resistance of R36 will lower, so the resistive loss can be reduced.

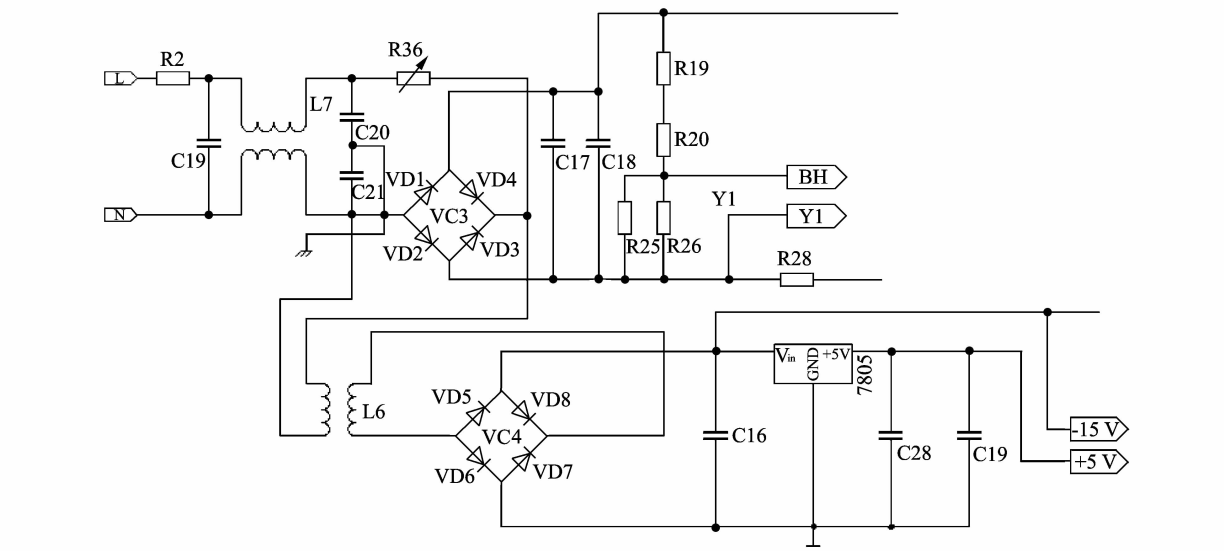

Fig. 2 Input Circuit

The voltage measurement part is composed of R19, R20, R25 and R26. It can share the voltage for measuring the output direct voltage of the part of filter and rectifier. The current measurement part is comprised of the sampling resistor R28. The voltage of R28 can reflect the amplitude of the current of the main circuit of inverter power supply. The signal of voltage measurement will output from BH. The signal of current measurement will output from Y1. Then these feedback signals will input to the control system.

The section of circuit power supply consists of L6, VC4, C16, C19, C28 and 7805. VC4 is made up of four diodes (VD5 - VD8). C16, C19 and C28 are filter capacitors. 7805 is regulator device. This can provide working voltage + 5 V or + 15 V for the digital circuits and analog circuits of inverter power supply. L6 can deliver the alternating voltage signal which has been after EMI filter to the rectifier bridge. Then a fluctuating direct voltage can be obtained. The voltage after the regulator (filter capacitor C16) will become a stable + 15V direct voltage. Then it passes 7805, C19 and C28, thus a stable + 5 V direct voltage can be obtained.

1.2 Inverter circuit

This section can realize DC/AC. The circuit consists of four switches (V5 - V8), eight diodes (VD4 - VD7 and VD10 - VD13), five capacitors (C4 - C6, C7 and C8), one inductance L2 and several resistances. The circuit of this part is shown in Fig. 3.

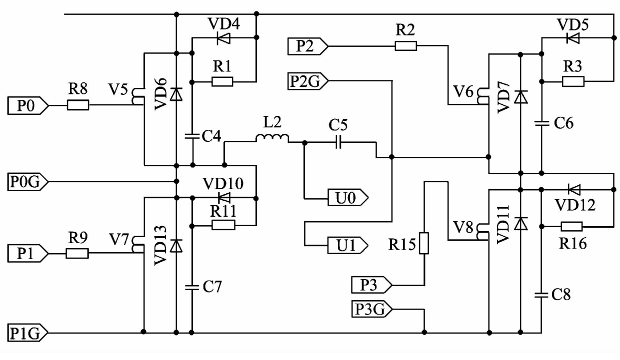

Fig. 3 Inverter circuit

In Fig. 3, the filter circuit consists of L2 and C5. In addition, each switch connects with a snubber circuit in parallel, which is composed of resistance, inductance and diode. It is a typical "RCD" snubber circuit. It can achieve buffer in the process of switching of the main switches of the inverter circuit. The control signals which consist of signal UP and DN are from control circuit. The inverter circuit will generate some feedback signals.

1.3 Control circuit

Single chip micyoco (SCM) is the control core of the section. According to the feedback signals from the inverter circuit, it can control the operation of inverter power supply.

In this paper, AT89C2051 is used as control core, which has fifteen I/O ports, two 16-bit timers, 2 KB memory, 128 B RAM[3].

It is a micro controller unit (MCU) with high integration and low cost. The circuit of this part is shown in Fig. 4.

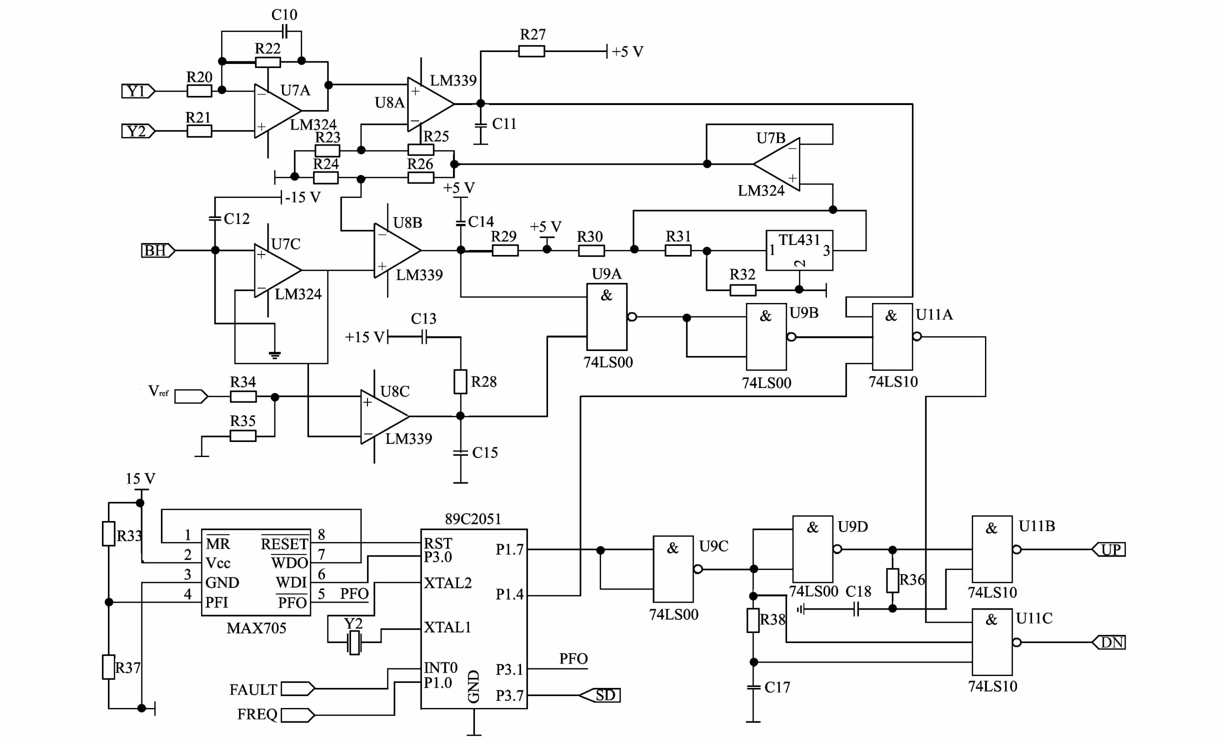

Fig. 4 Control system circuit

In Fig. 4, Y1, Y2 and BH are feedback voltage signals which are proportional to the current of the inverter circuit. When the control system starts to work, the signal P3.0 output from SCM will be conducted as the input signal of "Watchdog" chip MAX705. This signal must change once within the stipulated time for ensuring that "Watchdog" chip can not output the signal "Reset". If CPU crashes because of interference or other reasons, the signal P3.0 will not change. "Watchdog" chip will generate the signal "Reset". CPU will reset the operation. The harmonic elimination PWM control signals of the inverter are output from P1.7. After logical processing and dead-time delay, the signals will be turned into two driving signals which can complement the conduction and have a certain dead-time zone. Then the two driving signals are sent to the driving chip to control on/off switch of the inverter circuit. "SD" of the driving chip is controlled by P3.7. When "SD" is high level"1", the driving chip will be blocked. When "SD" is low level"0", the driving chip can operate. The frequency code input signal is input to P1.0. The output signal of P1.4 is conducted as blockade signal of the driving chip through anti-phasing. When CPU is in the state of initial reset, it can avoid driving signals appearing high level"1". When the driving signals all appear high level"1", the switches will lead to short circuit fault. The fault caused by over voltage, under voltage, output over current and short circuit is fed back from auxiliary circuit and protection circuit. The fault passes logic "And", and then is sent to INT0 of AT89C2051. Now SCM can send out interrupt request signal.

2 Idea and algorithm of harmonic elimination PWM control

The basic idea of harmonic elimination PWM control is described as follows:

The phase of switching point of the PWM pulse is conducted as unknown number. Then through analysis on Fourier series of PWM pulse, the expressions of fundamental component and harmonic component of output voltage will be obtained. According to the requirements of fundamental amplitude and harmonic amplitude, an equation which is equal to the value of unknown number will be established. The switching time of each pulse can be acquired by solving the equation. When controlling in the light of the switching time, the fundamental amplitude and harmonic amplitude of output voltage will be expectations. In general, the fundamental amplitude is always selected as an expected non-zero value while the harmonic amplitude is selected as zero value. As a result of equation of harmonic elimination PWM control, inverter power supply will not consist of specified low-order harmonic value[4]. Supposed that there are N switch points in the fourth cycle of PWM waveform which are the inverter output. The phase angle corresponding to each switch point is $\alpha_i\,(i=1,2,\cdots,N)$ and $0\leqslant\alpha_1<\alpha_2<\cdots<\alpha_N\leqslant 90^\circ$.

According to PWM waveform of the unipolar modulation shown in Fig. 5, Fourier series of the inverter is described as

$$u_0=\sum_{n=1,3,\cdots}^{\infty}\frac{4}{n\pi}\Big(\sum_{k=1}^{N}(-1)^{k+1}\cos n\alpha_k\Big)\sin n\omega t. \quad (1)$$

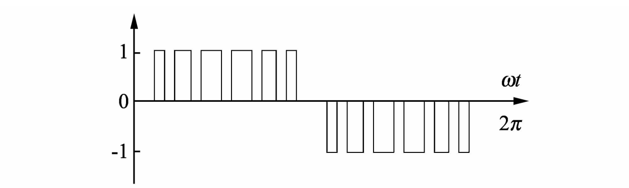

Fig. 5 PWM waveform of unipolar modulation

According to PWM waveform of the bipolar modulation shown in Fig. 6, Fourier series of the inveruer are described as

$$u_0=\sum_{n=1,3,\cdots}^{\infty}\frac{4}{n\pi}\Big(-1-2\sum_{k=1}^{N}(-1)^{k}\cos n\alpha_k\Big)\sin n\omega t, \quad (2)$$

$$u_0=\sum_{n=1,3,\cdots}^{\infty}\frac{4}{n\pi}\Big(1+2\sum_{k=1}^{N}(-1)^{k}\cos n\alpha_k\Big)\sin n\omega t. \quad (3)$$

The number of switching angle "N" in Eq. (2) is odd number while in Eq. (3) is even.

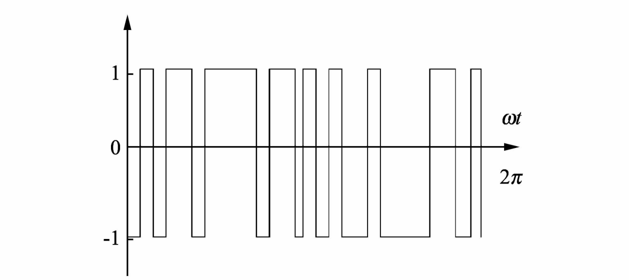

Fig. 6 PWM waveform of bipolar modulation

Supposed that the amplitude of the output fundamental voltage of the inverter is U_1, the input direct voltage of bus is U_2. If $M=U_1/U_2$, then from Eq. (1), the equation of harmonic elimination will be written as

$$\begin{aligned}&\frac{4}{\pi}\sum_{k=1}^{N}((-1)^{k+1}\cos\alpha_k)=M,\\&\sum_{k=1}^{N}(-1)^{k+1}\cos n\alpha_k=0,\\&n=3,5,\cdots,2N-1.\end{aligned}\quad (4)$$

According to Eq. (2), the equation of harmonic elimination can be written as

$$\begin{aligned}&\frac{4}{\pi}\Big[-1-2\sum_{k=1}^{N}(-1)^{k}\cos\alpha_k\Big]=M,\\&-1-2\sum_{k=1}^{N}(-1)^{k}\cos n\alpha_k=0,\\&n=5,7,\cdots,3N-2.\end{aligned}\quad (5)$$

According to Eq. (3), the equation of harmonic elimination can be written as

$$\begin{aligned}&\frac{4}{\pi}\Big(1+2\sum_{k=1}^{N}(-1)^{k}\cos\alpha_k\Big)=M,\\&1+2\sum_{k=1}^{N}(-1)^{k}\cos n\alpha_k=0,\\&n=5,7,\cdots,3N+1.\end{aligned}\quad (6)$$

In Eq. (6), if $\boldsymbol{\alpha}=[\alpha_1,\alpha_2,\cdots,\alpha_n]^T$, then

$$f(\boldsymbol{\alpha})=[M,0,\cdots,0]^T. \quad (7)$$

Newton iteration method has amount of calculation and local convergence. When selecting inappropriate initial value, solving speed will be reduced, even the equation will not have convergence. The initial value need to be given again[5-8].

In order to expand the domain of convergence and speed up the convergence[9], the paper introduces homotopic algorithm to solve the equation of harmonic elimination firstly[10,11]. Then the result obtained from homotopic algorithm is conducted as the initial value of Newton iterative method. Finally, an accurate solution can be obtained.

Solving Eq. (7) can acquire a group of switch angles. They are transformed into a table of timer count pulse of SCM and stored in program memory to realize real-time query.

3 Software design

The control software of inverter power supply mainly includes the main program, time interrupt service routine and external interrupt service routine.

3.1 Main program

The main program initializes operating mode of SCM and reads the output frequency code setting value of inverter power supply. When the given frequency changes, the code can also change with it. Now set the frequency change sign. According to the new harmonic elimination PWM switching angle data, it can facilitate time interrupt service routine to achieve timing and realize the conversion of the driving signals. The flow chart of main program is shown in Fig. 7.

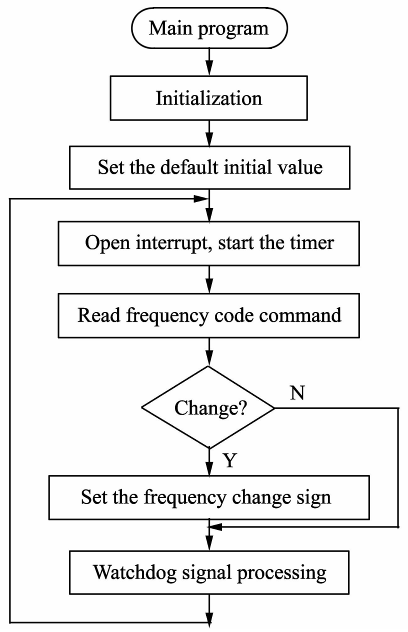

Fig. 7 Flow chart of main program

3.2 Time interrupt service routine

Time interrupt service routine can complete the timing of the switching angle data and output of the corresponding driving signal. It can realize harmonic elimination PWM control strategy. The flow chart of time interrupt service routine is shown in Fig. 8.

3.3 External interrupt service routine

External interrupt service routine is responsible for dealing with fault protection of inverter power suppLy.

When fault interrupt request occurs, SCM responds the interrupt and inquires whether fault occurs again. If fault exists, the driving signal will be blocked and the fault code will be input. The flow chart of external interrupt service routine is shown in Fig. 9.

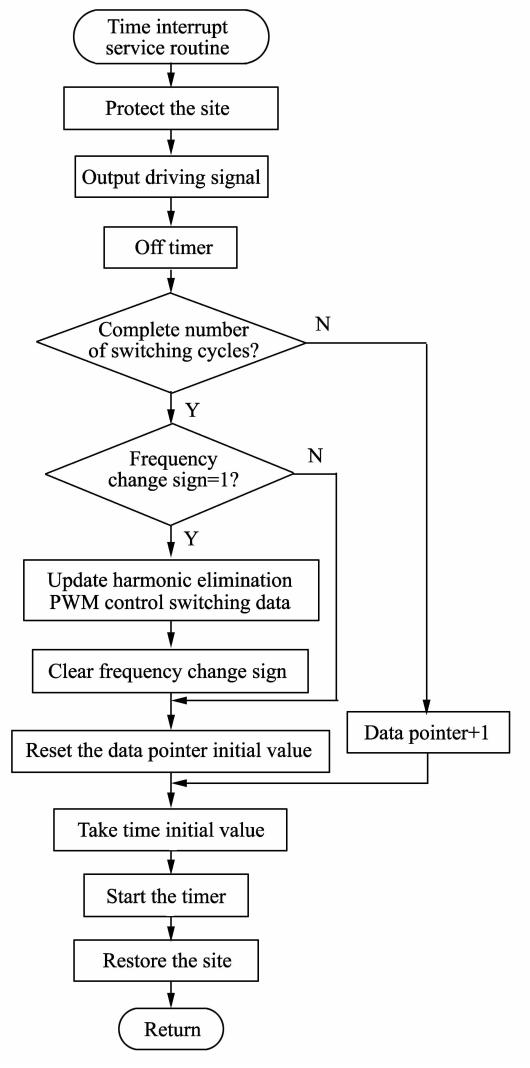

Fig. 8 Flow chart of time interrupt service routine

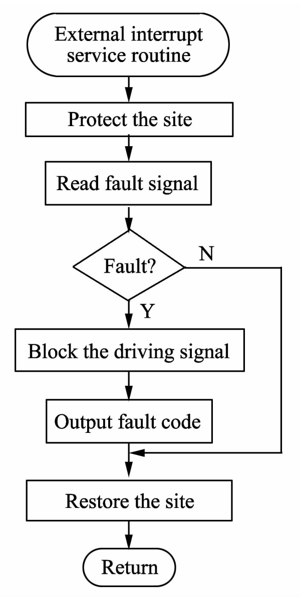

Fig. 9 Flow chart of external interrupt service routine

4 Results and analysis

Through simulation and debugging, the results are obtained as follows:

The number of switching angle N is 10 while the initial value is 0.9, the waveform of output voltage of single-phase inverter power supply adopting bipolar modulation is shown in Fig. 10.

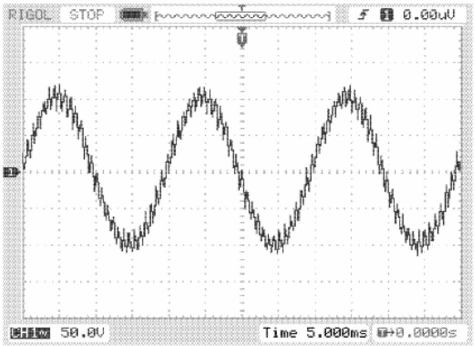

Fig. 10 Waveform of output voltage of single-phase inverter power supply adopting bipolar modulation

The number of switching angle N is 18 while the initial value is 0.9, the waveform of output voltage of single-phase inverter power supply adopting bipolar modulation is shown in Fig. 11.

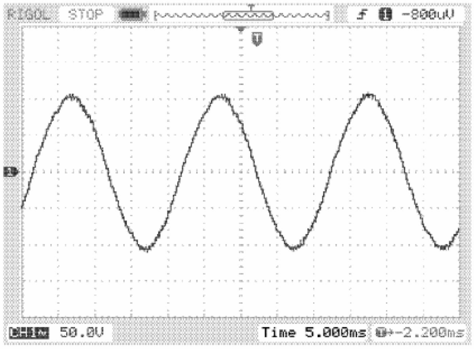

Fig. 11 Waveform of output voltage of single-phase inverter power supply adopting bipolar modulation

As N increases, the quality of output voltage becomes higher and higher. It is rational that this paper combined Newton iteration method with homotopic algorithm to solve harmonic equation.

5 Conclusion

In summary, PWM control strategy can adjust the output voltage of inverter power supply conveniently. This paper chooses harmonic elimination PWM control. Based on this, the whole structure of control system is designed and related software is accomplised. In addition, high cost-effective CPU as well as safe and reliable components are used to ensure economy and applicability of the power. The new modulation harmonic elimination PWM control mode which applied to inverter power supply can ensure its adaptability to the fluctuation of the input side of direct voltage. It will have broad application prospects.

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