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SVPWM Algorithm in Using Variable-Frequency Air Conditioner Control System

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This article proposed the advanced SVPWM algorithm for realization with the air conditioning compressor frequency conversion controlling. By changing the power frequency make motor speed change and achieve to control capacity of air conditioner compressor. And has carried on the theoretical analysis and the research to this algorithm. Based on the basic idea of space vector modulation, by integration of software and hardware, realizing method of PWM waves generated by DSP PWM module in interrupt, and gave the test result. It testified that using DSP to achieve SVPWM have some excellences, such as simple control arithmetic, high speed and convenient realization.

1. Introduction

Variable frequency air conditioner is a new type of air-conditioner with the development of refrigeration technology, motor control technology, power electronic technology, microelectronics technology and modern digital intelligent control technology. It's compressor can adjust the refrigeration and heating power continuously and dynamically according to the requirements of the indoor heating and cooling. To achieve higher power refrigeration and heating quickly, also can maintain room temperature constant in low power. To change the compressor power is accomplished by adjusting the working frequency of compressor.

Variable frequency air conditioner because its energy saving, high efficiency, low operating noise, and could build a more comfortable temperature for room control environment. So are gradually become development direction of household air conditioning industry. And compared with common air conditioning is concerned, frequency conversion air conditioning control system more complex. The advanced control algorithm of SVPWM (space voltage vector PWM) is studied in this paper. Using DSP fast operation and data processing ability, by changing the power frequency make motor speed change of air conditioner compressor and achieve the aim of control capacity.

2. Principle of SVPWM

At the electric transmission system, is widely usedPWM (pusle width modulated) control technology. There are many ways for PWM signal generation. SPWM is the more familiar PWM technology used in household frequency conversion air conditioning system. This algorithm is based on the law to control the sine wave PWM signal duty cycle. Using inverter appliances some switch components, by a control circuit according to certain rules control switch components hige. SPWM is a set of constant amplitude but inconstant width rectangular serial pulse produced by control return circuit to approximate sinusoidal voltage waves. Can usually by comparator, timer and sine data form to realize.

SVPWM control is a kind of novel pulse width modulation method different with SPWM. It takes three-phase symmetric sinusoidal voltage power supply, three-phase symmetric motor stator magnetic chain round as the ideal benchmark, the formation of the actual magnetic chain vector by the three-phase inverter different switch mode to track the benchmark magnetic chain round. On the tracking process, inverter switch mode must be transformed properly, thus form PWM waves. This method is simple, easy to real-time control by micro-controller, and has the torque ripple voltage little, low noise, high efficiency advantages. So no matter what in the open loop speed regulation system or closed loop control system are used widely.

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3. SVPWM control algorithm implemented

3.1 PWM waveform analysis

The basic idea of space vector modulation, which means any reference voltage vector Vr fallen in hexagon area, can all use adjoining vector and zero vector to weighted synthesis. That is to say, in each carrier cycle can use four vector (two adjacent vector and two zero vector) switching to achieve any needed vector. Figure 1 said form a new space vector Ur between 0 ~ 60°. This new vector Ur's output in a PWM period (T) is equivalent to U001 role time T1 and U011 role time T2, such as type (1) below.

Ur*T=(T1*U001)+(T2*U011)+T0*U000(T0*U111) (1)

i.e $T*|Ur|*\begin{bmatrix}\cos\theta\\ \sin\theta\end{bmatrix}=T1*|Us|*\begin{bmatrix}1\\ 0\end{bmatrix}+T2*|Us|*\begin{bmatrix}\cos\pi/3\\ \sin\pi/3\end{bmatrix}$ (2)

Among them, Ur is synthetic space vector, |Ur| is its voltage amplitude, |Us| is the voltage amplitude of U011 or U001, T0 is zero vector duration.

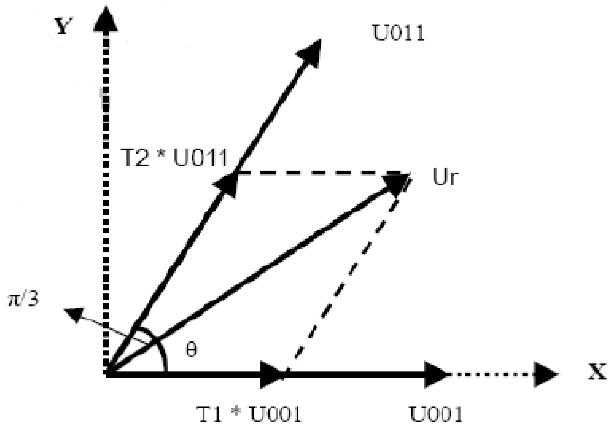

Figure 1: Space vector Ur synthetic map

Use $|Ur|=\frac{\sqrt{3}}{2}$ |Us|*M replace type (2) then we can get type (3).

$$T1=T*M*\sin(\pi/3-\theta)$$

$$T2=T*M*\sin\theta$$

$$T0=T-T1-T2 \quad (3)$$

Among them, M is modulation depth, relevant to motor amplitude frequency characteristics and operation speed. Because of T1 and T2 sum may not equal PWM period length, so insert zero vector represent to replenish the working status in the rest of the time T0, and it does not affect the output voltage. purpose adding zero vector is to control of the Ur sagittal in linear modulation area, in order to form more ideal magnetic chain round.

3.2 Determine place sector of rotation space voltage vector

In implementing SVPWM algorithm with variable frequency control, and PWM waves generated by outside machine MCU, first need to determine place sector of rotation space voltage vector. This paper introduces a simple and easy to implement method. Use defined and effective six space voltage vector for border, form hexagonal round, will circle is divided into six sector, obviously each sector corresponds to 1/6 cycles of the fundamental frequency modulation wave output. Then each sector is divided into n equal parts factitiously, then the corresponding time interval Ti being equal, can be written as TI. This algorithm is called synchronization modulation, and it has less amount of calculation. And there is nTi=TB/6, TB is base wave cycle in the type. In that way, rotate voltage vector Ur shall be uniformly turned the corresponding electric Angle △θi in Ti time.

Theory and practice has proved, output of inverter has less low-order harmonic component when n take odd, and output voltage waveform of inverter has good three-phase degree of symmetry. See from the above analysis, only need to accumulate the corresponding △θI for TI generating. And compared accumulative results with the border of six sector, Ur can be judged in which sector. And these border are respectively: 0, π/3, 2π/3, 3π/3, 4π/3, 5π/3. This method is easy to be realized in program, and can reduce some complex operation.

3.3 T0 / T1 / T2 calculation
To achieve the desired PWM wave form, must know the parameter of T0, T1, T2, it can calculate by type (3), but modulation depth M must be calculated firstly.

M≈ (Running frequency ×V/F curre slope of induction motor)/Maximum output voltage amplitude+ offset(3)

In practical applications, because of inverter switch ullage, motor load size, and other factors, calculation of modulation depth M need to be adjusted according to output voltage of the actual take load cases. M value can be calculated, according to the type (3) to calculate value T0 / T1 / T2. In this design, generated PWM cycle T by DSP for the effective width values 15bits, therefore need to use 16bits width data representation show PWM cycle value T. Because of sine value between 0 to 1, also need to be converted fixed-point operations. To accelerate the speed of calculation, usually will make sine value into data tables, direct access to a number of sine through the look-up tables operating.

In computing, using a variable of 16bits width as angles canning. If the variable value from 0 to 65536 increasing, voltage space vector rotate the corresponding angle from 0 to 2π. A cycle will to be divided into 1024 electricity angle in this design, such need to have 1024 length look-up tables stored corresponding 0 ~ 2π sine value. But because of the same calculation method for T0/T1/T2 within the six quadrant, so actually only need to be stored 0 ~ π/3 sine value, and the corresponding look-up tables are: 1024/6≈171.

In the motor running process, and in each PWM cycle, angle variable is updated again according to the corresponding step speed. Scanning look-up tables to recalculate T0 / T1 / T2 values. And update duty cycle of PWM output signal at the same time.

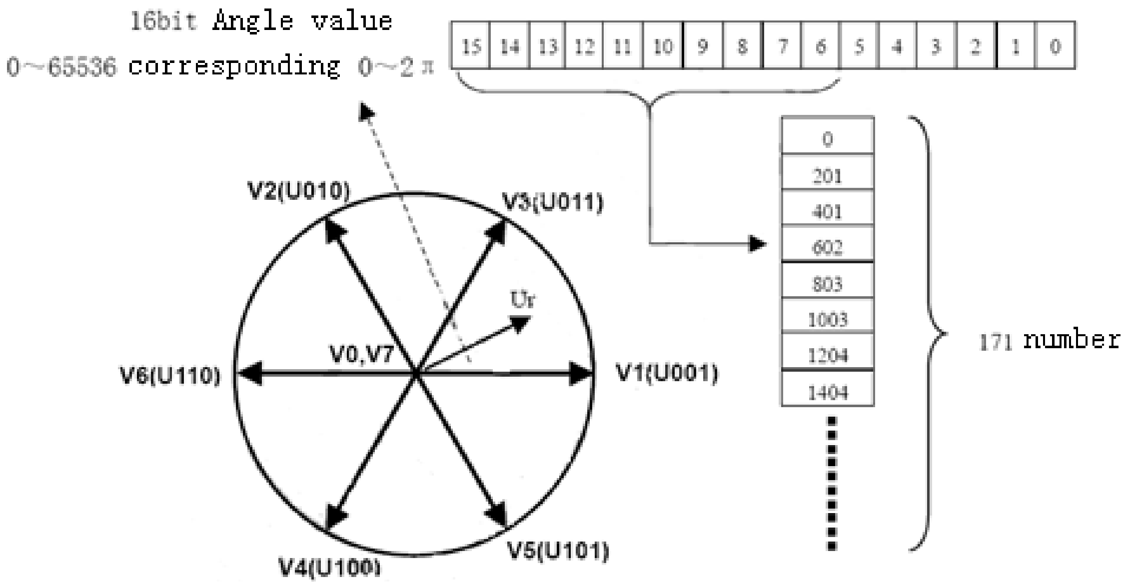

Figure 2: T0 / T1 / T2 calculation scheme

In addition, because of only 1, 024 electricity angle, so the only high 10bit s(or low 10bits) of angle variable as the index address for lookup tables(refer to Figure 2). The first need to decide the current angle in which quadrant in the calculation, and minus initial angle in corresponding quadrant to get index address of 60 °sine table.

3.4 Running frequency of motor
As what mentioned before, scanning velocity of angle variable is equal to angular velocity of inverter AC output. When angle variable scanning again look-up tables from 0 to 65536, corresponding to a cycle (0 ~ 2π) of the AC output. Therefore:

Motor's running frequency = carrier frequency/ scanning speedof look-up tablesorfreq= $\frac{step*fs}{2^m}$

Among them: freq is motor's running frequency, fs is carrier frequency of PWM, m is angle variable's bit width (Take m = 16, or m = 10, namely 2^m =1024), step is each step angle value.

4. SVPWM waveform generated based on dsp

DsPIC30F2010 is the high-end microcontroller products of Microchip dsPIC series. This device is a 16bits MCU, with embedded DSP core, it has a 17*17 multiplying unit, two 40bits' accumulators and other DSP support circuit. Can support complicated calculation for the real-time applications. Motor control PWM (MCPWM) module of dsPIC30F2010, can produce various synchronous pulse width modulation output. In particular, it can also support three-phase AC induction motor, switched reluctance (SR) motor, DC brushless motors (BLDC) control applications.

Use the SVPWM algorithm in this design, PWM wave is generated by the PWM module of dsPIC30F2010. To realizein the PWM interrupt (interrupt happened once at every PWM cycle), the key process in this realization:

● Phase angle (16bits) calculated, to determine which sector (there are six sectors, see section before mentioned);

● Calculated each PWM channel's duty cycle according to the phase, in fact is to calculate T1, T2, T0 values as mentioned before;

● According to the sector and duty cycle compared to determine the three complementary sequence of PWM output, corresponding values of duty cycle (by T1, T2 and T value are calculated) is wrote in corresponding registers.

Need the timing function of timer to generate the PWM waves, many MCU PWM generation module used a self-contained general timer. And the PWM generation module of dsPIC30F2010, it's PWM time base control is provided by the 15bitsspecial timer with a pre scaler and frequency divider.

Through the PTCON (PWM time base control registers) can be configured for PWM time base under four different work patterns: Free running mode, Single-event mode, Successive up/ down counting mode and Successive up/ down counting mode with double update interrupting. According to requirements of PWM wave generated in this design, choose Successive up/ down counting mode (PTCON<1:0> = 10).

Polarity control and mode settings of output: the polarity of PWM I/O pin is configured in the process of device programming, through configuration bits HPOL and LPOL (FBORPOR<9:8>) of the device configuration register FBORPOR. According to the PWM output way in this design, give PWM1H - PWM3H low-level effective. In the mode registers of PWMCON1, PWM pattern control bitPMOD3-PMOD1 (PWMCON1 <10:8> =000) settings for three complementary output mode to six pin.

As the center aligned of PWM working process is: When PWM time base is configured to Successive up/ down counting mode (PTMOD <1:0> = 10), module will produce PWM signal of center aligned. Output process of PWM signal as follows: When the value of duty cycle registers matching the value of time base registers PTMR, and time base of PWM is counting down (PTDIR = 1), the output of PWM compared drive is effective state(low-level). When time base of PWM is counting up (PTDIR = 0),and the value of duty cycle registers matching the value of time base registers PTMR, the output of PWM compared drive is invalid state(high-level). The working process as Figure 3 shows. Three values are writed in duty cycle registers: PDC1 = T0/4+T1/2+T2/2, PDC2=T0/4+T1/2, PDC3=T0/4. When time base of PWM is counting up and the value counting matching the value of PDC3 (M point as Figure 3 shows), output invalid level (high-level). When time base of PWM is counting down and the value counting matching the value of PDC3 (N point as fig.03 shows), output effective level (low -level), two other road waveform is similar analysis. So, the center aligned of PWM waveform can be outputted as Figure 3 shows. When the value of PTMR register is 0 and time base of PWM begin counting up, will happen a time-based interrupt (PWMIF=1), to update the value of duty cycle, and to generate three-phase PWM waves in the next cycle.

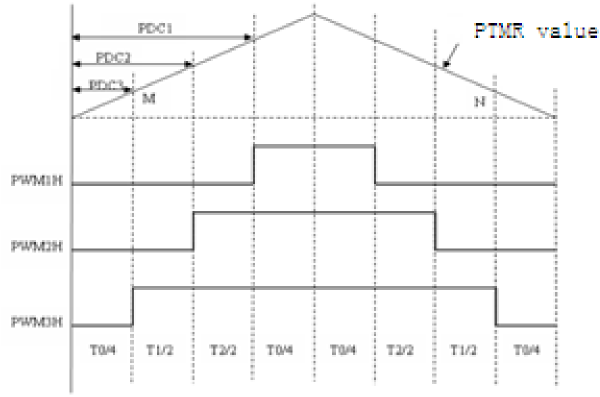

Figure 3: Illustrations of three-phase PWM waves generated

5. The experimental results related to waveform analysis

The following provides some take load cases of motor, generate voltage waveform of motor in different running speed by SVPWM algorithm. System control object is a rotor compressor of 220 V / 50 Hz. Given below in compressor no-load running, to make use of the oscilloscope measurement of each part results. And the different wave form for qualitative analysis.

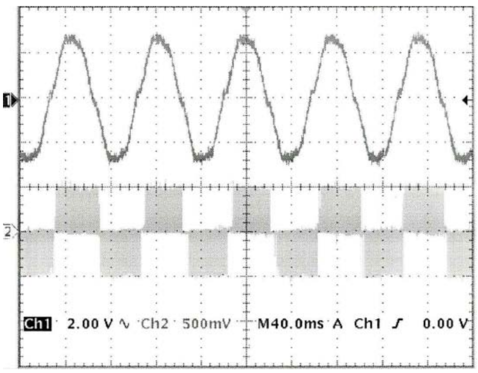

Figure 4: Waveform of output current and voltage

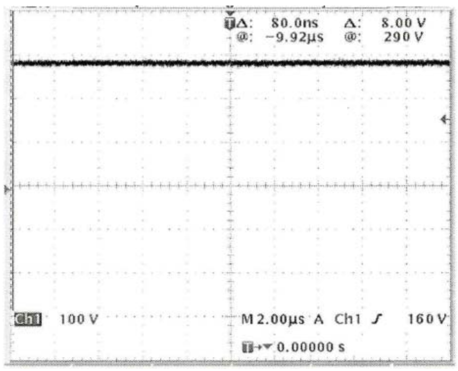

Figure 5: Waveform of DC voltage

As shown in figure 4 the wave form of output current and voltage with frequency 50 Hz. The figure shown, the system's output current and voltage waveform are very stable, through the SVPWM modulation, the high order harmonic component has been basically eliminated. The fundamental wave wave form meet the requirements of the output of the system.

As shown in figure 5 for the DC side voltage waveform in the process of the system running. The figure shows, keep steady DC voltage, thus proves that the system works normally.

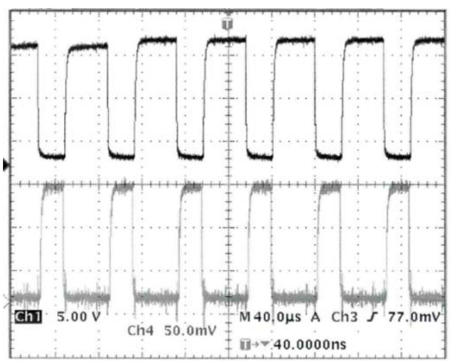

Figure 6: Waveform of SVPWM control

As shown in figure 6 for SVPWM control signal in the MCU output after processing, can set the carrier frequency of the system. The current system of carrier frequency set to 15.6 KHZ, basic can't hear the electromagnetic noise in the actual operation, up to the very good effect on mute, could meet all kinds of quiet places.

6. Conclusions

This paper mainly discussed the advantages of SVPWM algorithm for frequency conversion control, described the basic principle of the proposed algorithm. And the specific methods of realization for this algorithm was given, meanwhile analyzed the process of generating SVPWM waveform in dsPIC30F2010. And provided some voltage test waveforms using this algorithm. It testified that digital realization of SVPWM in this system, could reduce power device switch loss and improve efficiency of voltage utilization, so it was an ideal control method.

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