Application and Simulation of SVPWM in three phase inverter

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***Abstract*—Comparing with commonly used sine-wave pulse-width modulation(SPWM) method, Space Vector Pulse Width Modulation (SVPWM) method has higher utilization rate of DC voltage and smaller output waveform distortion. This article introduced SVPWM control technology into three-phase grid-connected inverter, created a main circuit mathematical model of three-phase grid-connected inverter and detailed the implementation of SVPWM modulation method with Matlab software. Through the establishment of a complete closed-loop system to simulate and research, giving the simulation waveforms and output grid-connected current waveform. The simulation results showed the advantages of SVPWM technique are more suitable for high-power applications.**

Keywords- SVPWM; Matlab simulation; three-phase grid-connected inverter

I. PREFACE

Different from the commonly used Sine-wave Pulse-width Modulation (SPWM) control method, Space Vector Pulse Width Modulation (SVPWM)which is from the viewpoint of power supply, and pursuing of providing a variable output frequency and voltage and three-phase symmetric sinusoidal waveform power supply, it is proposed from the point of view which seems inverter and motor as a whole, and through selecting appropriate switch state of three-phase bridge to make the rotating flux synthesized by three-phase stator follow a circular path. SVPWM method can overcome the shortcomings of low DC voltage utilization rate of SPWM method, it does not need to take some measures such as being injected the third harmonic SPWM and other remedies to make the modulation ratio M> 1, and will not produce over-modulation, where M can be up to 1.1547.So it can greatly improve the DC voltage utilization[1]. Moreover, SVPWM also has the advantages of reducing current waveform distortion. This paper will conduct a detailed analysis of SVPWM technique, and gives details of the algorithm, and finally the verification of simulation.

II. SWITCH MODEL OF THREE-PHASE INVERTER

Three-phase grid-connected inverter model is shown in Figure 1, first make the following assumptions:

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- a stable three-phase power grid electromotive force of pure sine waveform (e_a, e_b, e_c) ;
- grid side filter inductance L (a single inductor is usually used when building mathematical model) is linear, and ignore the saturation ;
- power switch loss is represented by resistance r_S , namely the actual power switch can be equivalently expressed by an ideal switch in series with loss resistance r_S ;

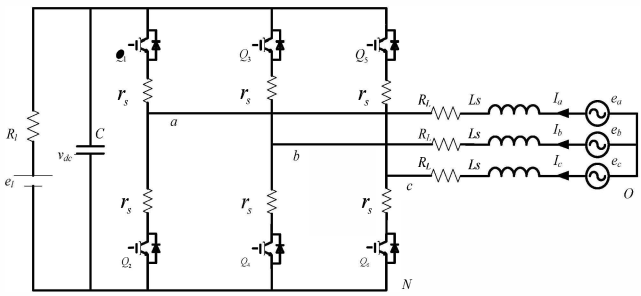

Figure 1 Three-phase grid-connected inverter model diagram

Set switch function

$$S_k = \begin{cases} 1, \text{k phase upper bridge opened, and lower bridge closed} \\ 0, \text{k phase lower bridge opened and upper bridge closed} \end{cases} (k = a, b, c)$$

IGBT loss equivalent resistance and equivalent resistance of AC filter inductor are combined, and make it R_s .

According to Kirchhoff voltage and current law:

$$\begin{cases} L_S \dfrac{di_a}{dt} + R_s i_a = e_a - (v_{dc} S_a - \dfrac{v_{dc}}{3} \sum\limits_{k=a,b,c} S_k) \\ L_S \dfrac{di_b}{dt} + R_s i_b = e_b - (v_{dc} S_b - \dfrac{v_{dc}}{3} \sum\limits_{k=a,b,c} S_k) \\ L_S \dfrac{di_c}{dt} + R_s i_c = e_c - (v_{dc} S_c - \dfrac{v_{dc}}{3} \sum\limits_{k=a,b,c} S_k) \\ C \dfrac{dv_{dc}}{dt} = i_a S_a + i_b S_b + i_c S_c - i_L \end{cases} \quad (1)$$

There were 8 models of working condition (000 ~ 111) for three-phase grid-connected inverter under the switching function, including six non-zero vectors and two zero vectors (000,111). Using the six non-zero voltage vectors and two zero voltage vector to approximate the voltage circle, the equivalent of three-phase SVPWM sine waveform will be gotten in the three-phase AC side of the bridge, therefore, achieving the equivalent SVPWM control.

III. SVPWM ALGORITHM

SVPWM is a kind of method that binding SPWM and circular track of motor flux directly, it is proposed in 1983 by J. Holtz, etc., and its algorithm is as follows [2]:

A. Determine the sector N which the reference voltage vector U^*_{ref} is in

Define the following variables:

$$U_{ref1} = U_{\beta}$$
$$U_{ref2} = \frac{\sqrt{3}}{2}U_{\alpha} - \frac{1}{2}U_{\beta} \qquad (2)$$
$$U_{ref3} = -\frac{\sqrt{3}}{2}U_{\alpha} - \frac{1}{2}U_{\beta}$$

Redefinition:

if $U_{ref1} > 0$, $A = 1$, or else $A = 0$

if $U_{ref2} > 0$, $B = 1$, or else $B = 0$

if $U_{ref3} > 0$, $C = 1$, or else $C = 0$

$$S = A + 2B + 4C$$

So S can be the six integer value from 1 to 6, coinciding with the six sectors correspondently, Roman numerals is for the sector numbers, so as Arabic numerals for the calculated S value, and the specific sector where the is in is obtained according to the S value, and through which finding the corresponding number of sectors and vector. Figure 2 shows the specific correspondence:

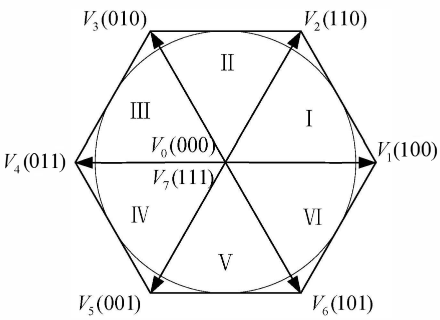

Figure 2 Sectors correspondence diagram

B. Calculate two adjacent voltage vector switching time T_x, T_y

Order that:

$$X = \sqrt{3}TU_{\beta}T_S / U_d$$
$$Y = (\frac{3U_{\alpha}}{2} + \frac{3U_{\beta}}{2})T_S / U_d \qquad (3)$$
$$Z = (\frac{-3U_{\alpha}}{2} + \frac{3U_{\beta}}{2})T_S / U_d$$

For different sectors, T_x, T_y are assigned according to the following table, T_x is a vector that immediately follows the starting zero-vector, T_y is the vector that after T_x.

TABLE I. THE CORRESPONDING WORKING TIME T_x, T_y OF THE SIX SECTORS ADJACENT VOLTAGE VECTORS

NO.	Time		
	T_x	T_y	T_0
I	$-Z(T_4)$	$X(T_6)$	$T_0 = T_s - T_4 - T_6$
II	$Z(T_2)$	$Y(T_6)$	$T_0 = T_s - T_2 - T_6$
III	$X(T_2)$	$-Y(T_3)$	$T_0 = T_s - T_2 - T_3$
IV	$-X(T_1)$	$Z(T_3)$	$T_0 = T_s - T_1 - T_3$
V	$-Y(T_1)$	$-Z(T_5)$	$T_0 = T_s - T_1 - T_5$
VI	$Y(T_4)$	$-X(T_5)$	$T_0 = T_s - T_4 - T_5$

C. CalculateA,B,C three-phase corresponding switching time T_{cm1} T_{cm2} T_{cm3}

Define that

$$T_a = (T_s - T_x - T_y) / 4$$
$$T_b = T_a + T_x / 2 \qquad (4)$$
$$T_c = T_b + T_y / 2$$

Then in different sectors, if A, B, C three-phase switching time T_{cm1} T_{cm2} T_{cm3} are assigned according to Table 2, SVPWM control time array can be obtained.

TABLE 2 SVPWM CONTROL CHRONOLOGY

Time	NO.					
	I	II	III	IV	V	VI
T_{cm1}	T_a	T_b	T_c	T_c	T_b	T_a
T_{cm2}	T_b	T_a	T_a	T_b	T_c	T_c
T_{cm3}	T_c	T_c	T_b	T_a	T_a	T_b

IV. SVPWM SIMULATION

Matlab is powerful tool software, in which the contained Simulink model provides a large number of standard modules to achieve a variety of basic functions and different module functions in accordance with their classification are stored in different libraries. Utilizing these modules can easily achieve the above analyzed SVPWM algorithm [3] [4] [5]. Realization is shown in Figure 3-7:

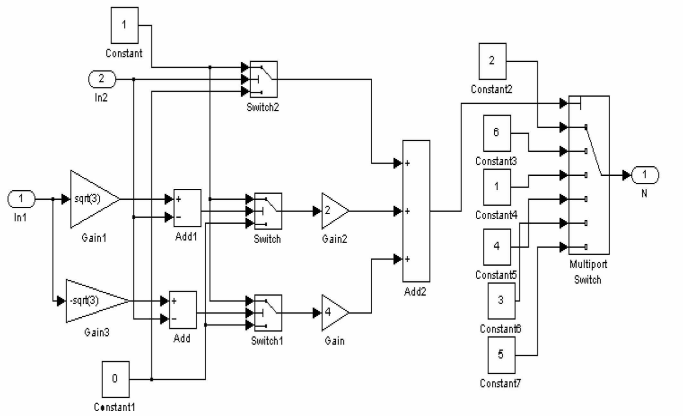

Figure 3 Sectors judgement

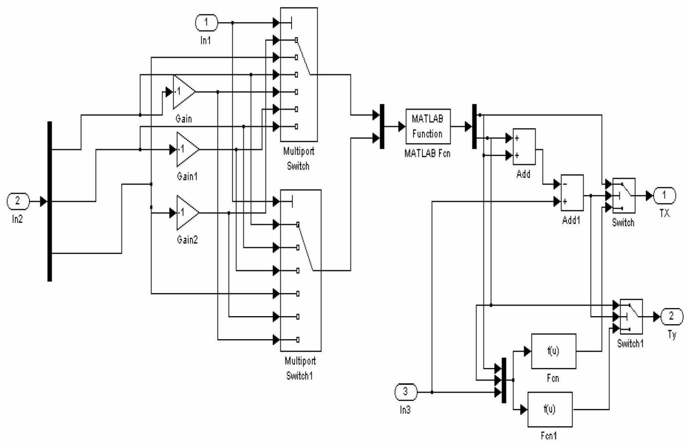

Figure 4 Calculation of T_x, T_y

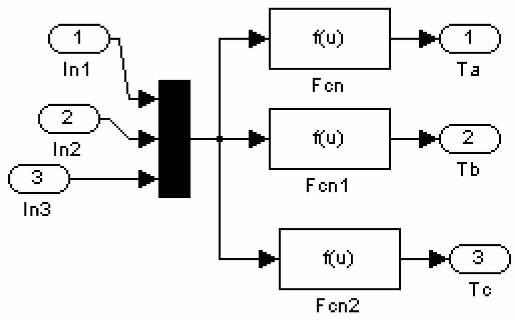

Figure 5 Calculation of T_a, T_b, T_c

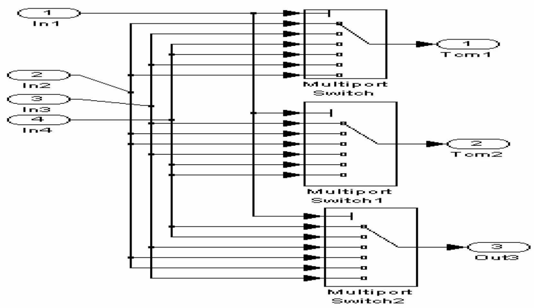

Figure 6 Calculation of T_{cm1}, T_{cm2}, T_{cm3}

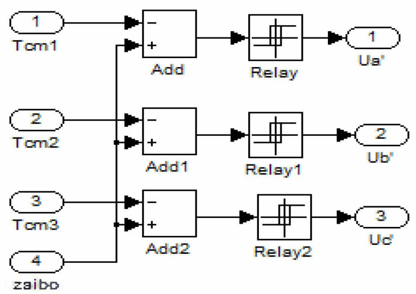

Figure 7 SVPWM drive waveform generation

V. SIMULATION RESULTS ANALYSIS OF SVPWM

In order to apply SVPWM into three phase grid-connected inverter, the system-level simulation model of three-phase grid-connected inverter based on SVPWM algorithm is established as shown in Figure 8, in which the inverter model is built based on switch function mathematical model derived from the above discussion. The simulation results are as figure 9-12, Figure 9 shows the waveform of Sectors judgement ,there are 6 Sectors . SVPWM modulation wave - saddle-shaped waveforms as shown in Figure 10, It shows that SVPWM is different from SPWM. Figure 11 shows that the waveforms of IGBT drive. the result 12 shows the grid-connected current and grid voltage waveform, it can be seen that current tracking performance is much better, using Matlab's powergui module to test the THD is only 1.46%.

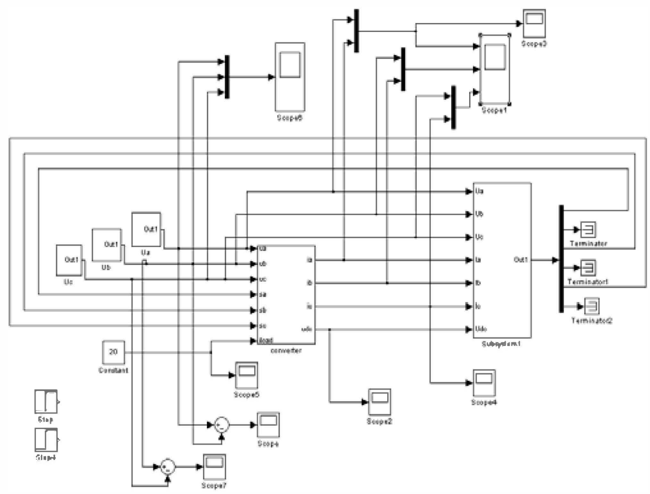

Figure 8 Establishment of the three-phase grid-connected inverter system-level simulation model based on switching function

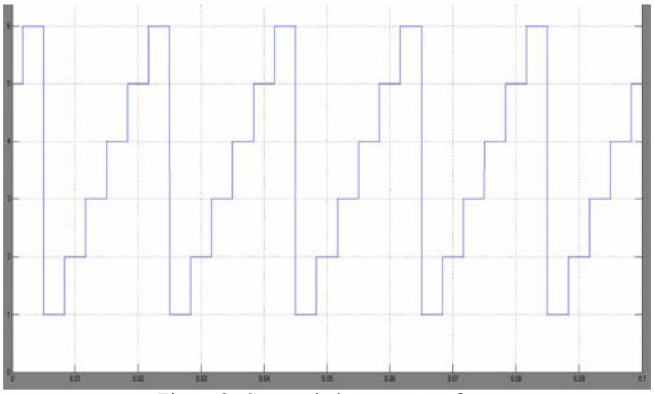

Figure 9 Sectors judgement waveform

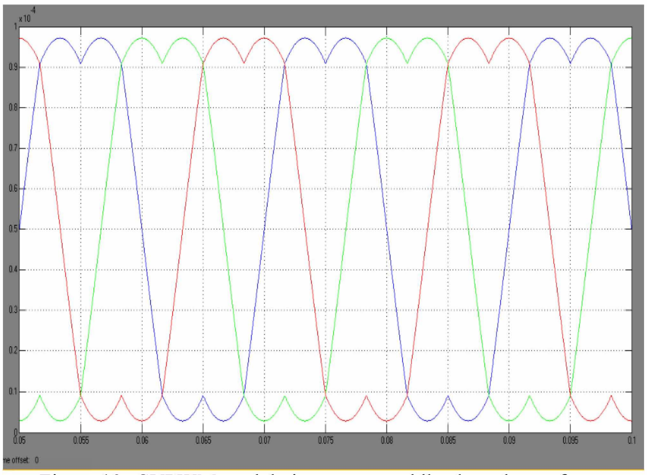

Figure 10 SVPWM modulation wave - saddle-shaped waveforms

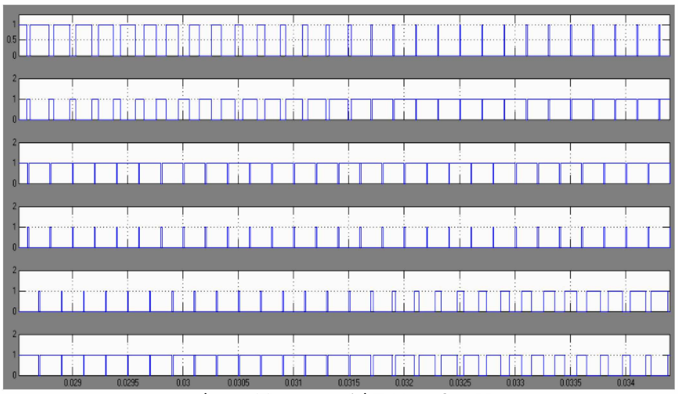

Figure 11 IGBT drive waveforms

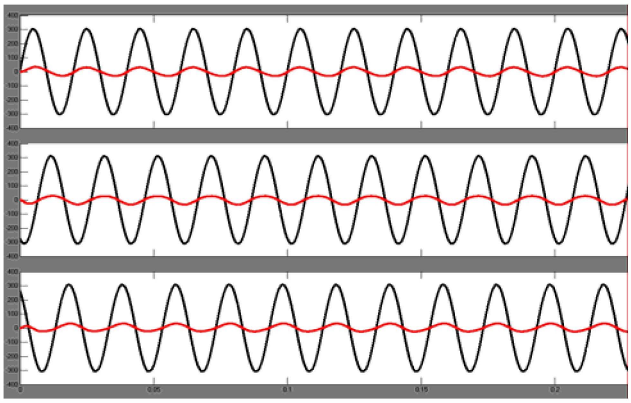

Figure 12 Closed-loop output voltage and current waveforms

VI. CONCLUSION

In this paper deeper analysis of the SVPWM algorithm is taken and the three-phase inverter system-level simulation model based on SVPWM algorithm is built, it can be seen from the simulation model that this control algorithm has good dynamic performance, when doing current control, according to the tracked current vector, selecting optimized voltage vector to conduct PWM current tracking control in order to gain better tracking current command under relatively lower switching frequency. Under the same waveform quality conditions, SVPWM control has a lower switching frequency, which can effectively reduce the switching loss of the power switch, and is more suitable for high power load applications.

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