A Design of SVPWM Algorithm for Inverter Based on Pan-Boolean Algebra

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Abstract. In this paper, Pan-Boolean algebra is designed in SVPWM algorithm for inverter. The switch control of the conventional SVPWM algorithm is expressed by the Pan Boolean algebra, which named the Pan-Boolean control SVPWM algorithm. The results of simulation test in MATLAB Simulink and physical model test show that the proposed SVPWM algorithm for inverter based on Pan-Boolean control is correct and effective. So this paper has important significance for studying the inverter control algorithm by using the logic algebra method.

Introduction

The development and utilization of new energy such as wind, solar and fuel cells, has become a new focus in the world. The large-scale utilization of new energy is regarded as an important symbol of the progress of human society. Inverter as an important part of the new energy conversion has become a new research focus and its system block diagram is shown in Figure 1.
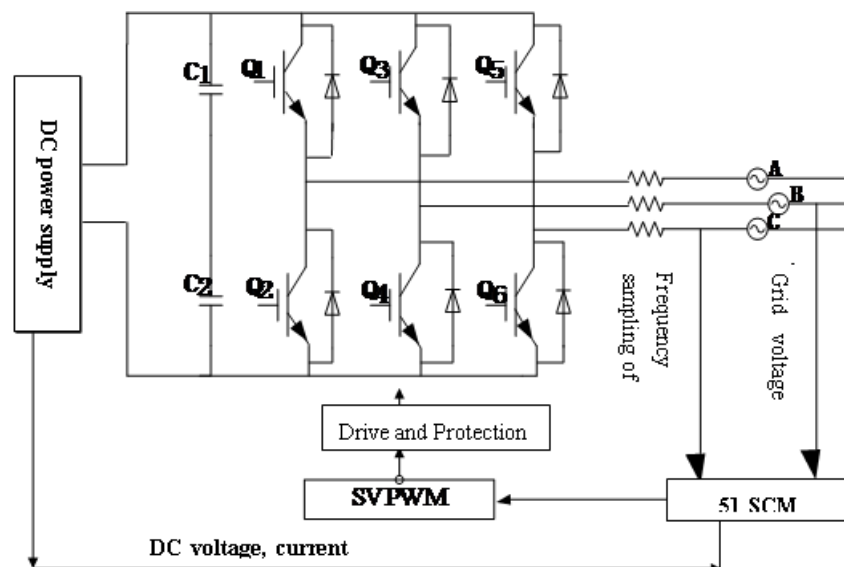

Fig. 1 Block diagram of three-phase grid-connected inverter system

In essence, the control of SVPWM for inverter is to achieve that trajectory of the space vector of output voltage approximates circle by controlling the switch on upper and lower bridge arm. Each switch is considered as a state, then the whole system has six states and each state has two state parameters. Therefore, the Pan-Boolean algebra can be applied to the control algorithm of SVPWM for inverter. This paper, based on the Pan-Boolean algebra theory, used MATLAB simulation software to simulate and verify the application of Pan-Boolean algebra in the space vector pulse width modulation (SVPWM) and has set up the platform of grid-connected inverter which has tested the control algorithm for inverter.

Application of Pan-Boolean algebra in SVPWM

Pan-Boolean algebra modulates and generates SVPWM and the calculation steps are as follows[6-10]: (1) Calculating and judging a sector area of the reference voltage vector; (2) Analysis of the corresponding angle of this sector area and the size of the angle can be used to calculate function time of voltage vector; (3) Calculating each switch's switching time; (4) Modulating the switch's switching time and sampling triangular wave and using pulse wave which has been generated to drive switching devices of inverter.

Judging a sector area. According to the formula of P=A+2B+4C (Define A、B、

C：$U_1 = U_\beta$; $U_2 = \frac{\sqrt{3}}{2}U_\partial - \frac{\sqrt{3}}{2}U_\beta$; $U_3 = -\frac{\sqrt{3}}{2}U_\partial - \frac{\sqrt{3}}{2}U_\beta$; If $U_1 > 0, A = 1$,on the contrary, A=0； On the analogy of this, B and C can be calculated),the corresponding relation between P and N can be calculated. In Pan-Boolean algebra, sector numbers N and P are regarded as logical variables, and they all contain six state variables. The logical expressions for N's Pan-Boolean are as follows.

$$N^1 = P^3 \tag{1}$$
$$N^2 = P^1 \tag{2}$$
$$N^3 = P^5 \tag{3}$$
$$N^4 = P^4 \tag{4}$$
$$N^5 = P^6 \tag{5}$$
$$N^6 = P^2 \tag{6}$$

Calculating the switching time of vector. According to the principle of volt-second balance, we can calculate the function time of each vector in sector area.

$$\int_0^{T_s} U_{ref}\mathrm{dt} = \int_0^{T_0} U_0 dt + \int_0^{T_x} U_x dt + \int_0^{T_y} U_y dt + \int_0^{T_7} U_7 dt \tag{7}$$

Assuming a proportional coefficient is $K = \sqrt{3}T_s/U_d$, U_d is DC voltage，T_s is sample period. $X = KU_1$, $Y = KU_2$, $Z = KU_3$。Based on Pan-Boolean algebra logic system, assuming three states which have two state variables and represent respectively the plus or minus of KU_1, KU_2, KU_3 are T_1、T_2、T_3。The Pan-Boolean algebra's logical expressions of T_x、T_y which can be obtained by sector judgment are as follows:

$$T_x = N^1 T_2^2 + N^2 T_2^1 + N^3 T_1^2 + N^4 T_1^1 + N^5 T_3^2 + N^6 T_3^1, \quad \sum_{i=1}^6 T_d^i = 1 \tag{8}$$
$$T_y = N^1 T_1^2 + N^2 T_3^1 + N^3 T_3^2 + N^4 T_1^1 + N^5 T_2^2 + N^6 T_1^1, \quad \sum_{i=1}^6 T_q^i = 1 \tag{9}$$

Calculating the switching time of vector. Assuming a state is T_{cm} including three state variables， respectively, $T_{cm}^1 = (T_s - T_x - T_y)/4$、$T_{cm}^2 = T_{cm}^1 + T_x/2$、$T_{cm}^3 = T_{cm}^2 + T_y/2$. The state factors of the three-phase switch can be expressed by T_{cmA}、T_{cmB}、T_{cmC}. Pan-Boolean logic expressions are：

$$T_{cmA} = N^1 T_{cm}^1 + N^2 T_{cm}^2 + N^3 T_{cm}^3 + N^4 T_{cm}^3 + N^5 T_{cm}^2 + N^6 T_{cm}^1, \quad \sum_{i=1}^6 T_{cmA}^i = 1 \tag{10}$$
$$T_{cmB} = N^1 T_{cm}^2 + N^2 T_{cm}^1 + N^3 T_{cm}^1 + N^4 T_{cm}^2 + N^5 T_{cm}^3 + N^6 T_{cm}^3, \quad \sum_{i=1}^6 T_{cmB}^i = 1 \tag{11}$$
$$T_{cmC} = N^1 T_{cm}^3 + N^2 T_{cm}^3 + N^3 T_{cm}^2 + N^4 T_{cm}^1 + N^5 T_{cm}^1 + N^6 T_{cm}^2, \quad \sum_{i=1}^6 T_{cmC}^i = 1 \tag{12}$$

By the formula(10)~(12), we can find that the switching time of the voltage vector in each sector area. Accordingly, we can control switch's turn-on and turn-off of three-phase bridge[4-5].

Simulation test of inverter on MATLAB.

The MATLAB SIMULINK of SVPWM is shown in Figure 2.Using the logic control method of Pan-Boolean algebra to calculate input three-pulse voltage, which modulates and generates SVPWM wave to control turn-on and turn-off of IGBT.

The illustrations of simulation are Figure 3 and Figure 4. The results of the operation are in line with the AC side output voltage and current of the general PWM three-phase inverter and the conventional SVPWM inverter. It is proved that the control algorithm of SVPWM is feasible.

The Experimental verification of the inverter1

Design of three-phase grid-connected inverter. This paper developed Experimental platform of miniature three-phase grid-connected inverter. The mode of inverter's preceding stage DC boost is that the electric motor drives the electric generator. Compared to conventional boost circuit, it insulates the electrical connection well between the DC side and the AC side, meanwhile, it can control the size of output DC voltage by means of controlling the rotational speed of the motor. It is convenient, simple and economic. The boost mode is shown in Figure 5.

Increasing the output power or transforming the generator wiring into delta connection scheme can improve the rotational speed. After the module of rectification, the corresponding relationship between the speed and the output DC voltage is shown in Table 1.

1) HIN is high level，LIN is low level

When input of pin 10 is high level(HIN is high level), the bootstrap capacitor C3(has full power and voltage is VCC) can be regarded as voltage source, and voltage is loaded between gate and source of IGBT(Q1). C3 which is connected between pin 6 and pin 7 , resistance R1 and the gate and source compose a discharge circuit ,so Q1 turns on. Pin 10(LIN)and pin 11(HIN) is a pair of complementary input signals, so pin 11 is low level (LIN is low level) this moment. Pin 1 and 3 turn off, pin 2 and 1 turn on, the electric charge gathered in gate and source of Q2 discharges to ground through R2, so Q2 turns off.
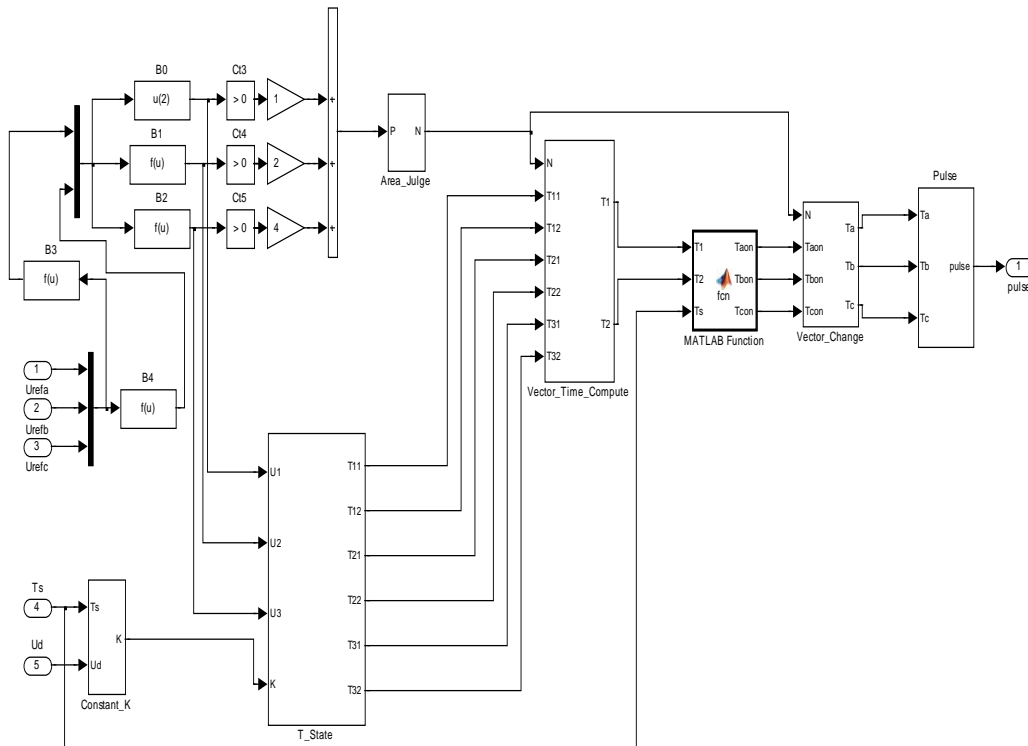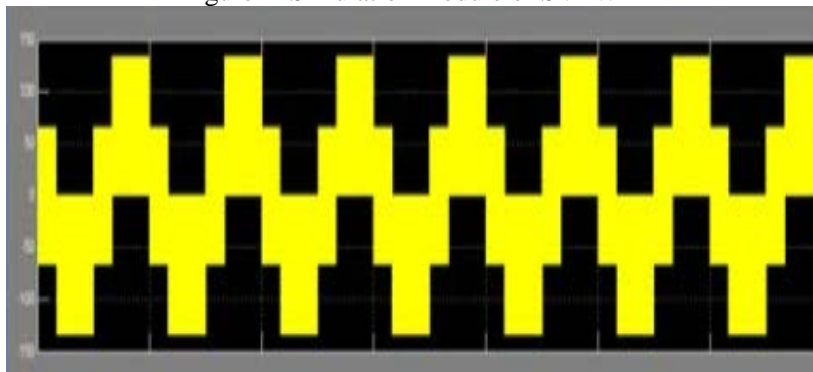
Figure 2 Simulation module of SVPWM

Figure 3 Phase voltage waveform

Figure 4 Phase current waveform

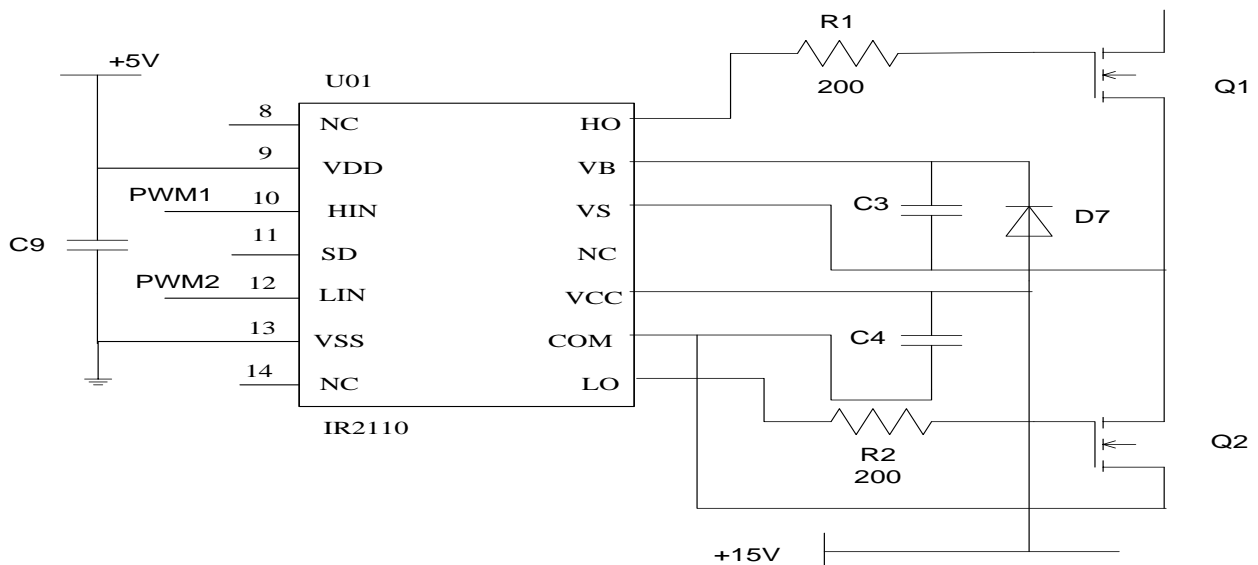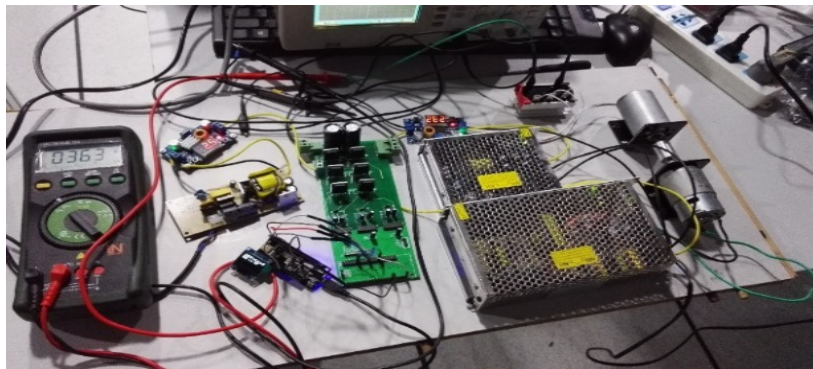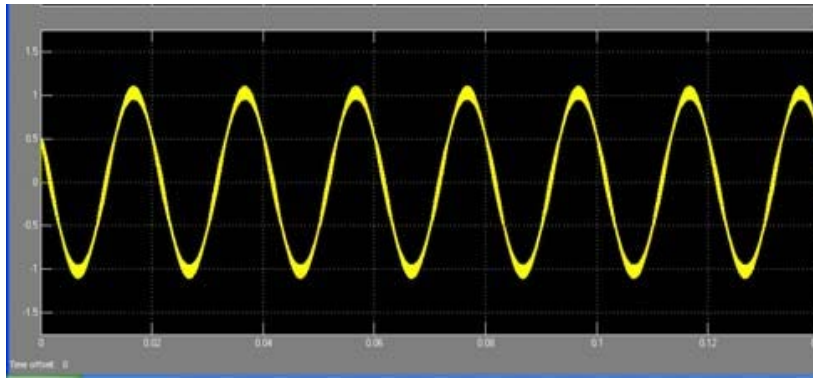Figure 5 Pan Boolean control inverter

Figure 6 IR2110 drive circuit

Table 1 The speed and the output DC voltage

Driving speed (rad / min)	Output voltage (V)	Full-bridge rectifier (V)	Full-bridge rectifier filter (V)
1500	35.7	48.2	50
3000	71.7	96.3	100.2
5400	127.9	172.7	180.4
10000	237	318.3	334.2
17000	265.4	374.6	393.2

2) HIN is low level, LIN is high level

When the HIN is low level, pin 6 and 7 turn off and pin 5 and 7 turn on, and the electric charge gathered in gate and source of Q1 discharges quickly through R1, so Q1 turns off. When the LIN is high level, pin 1 and 3 turn on and pin 1 and 2 turn off. An electric source of +15V is loaded on the

capacitor C4, which directly loads to the gate and source of Q2, so Q2 turns on. After Q2 turned on, the electric source of +15V flow through the bootstrap diode D7, C3 and Q2, which composed with a loop and charged C3. Repeatedly, it is formed a circulation to control the on-off of the switch.

The three-phase grid-connected inverter is controlled by 51 Microcontroller. The AD sampling circuit is designed with the pre stage DC voltage and current sampling, the inverter's output AC voltage and current sampling and voltage and current sampling of grid connection. The input voltage analogy quantity is 0-5V and the sampling result will be displayed on the LCD so that the working state of the inverter can be adjusted in time. DC current sampling circuit uses ACS712-20 A chip which consists of a precise low-offset linear Hall sensor circuit and a copper foil located near the surface of IC. The power supply is +5V, the measuring range is -20A to +20A and accuracy is 100mV/A. The relationship between input and output is:

$$V_{OUT} = 2.5 + 0.1 \times I_P \tag{13}$$

The sensor of DC and AC voltage sampling circuit uses LV-25P and the sensor is packaged in pin 5. The power supply is $\pm 15V$ and the range of measuring voltage V_{PN} is 10V to 500V. The sensor of AC current sampling circuit selects ACS758LCB-050B and this sensor is suitable for the detection of DC and AC current. The supply voltage is 3.3V to 5V and the range of measuring current is -50A to +50A.

Design of three-phase grid-connected inverter . In this paper, an experimental

Platform of three-phase grid-connected inverter is shown in Figure 7. In the experiments, to use the digital oscilloscope of double input channel for detecting waveform of output voltage and current. Meanwhile, comparing the voltage and current measured by digital multi meter with showed in oscilloscope, we can analyze the operation performance of the circuit. The figure of AD sampling circuit directly displays on the screen and output results are shown in Figure 8 and Figure 9.
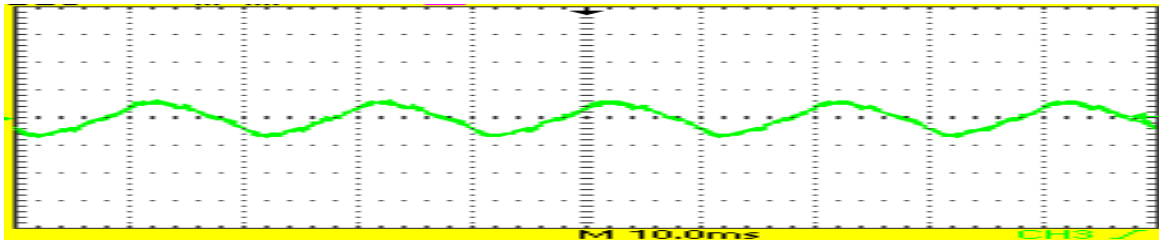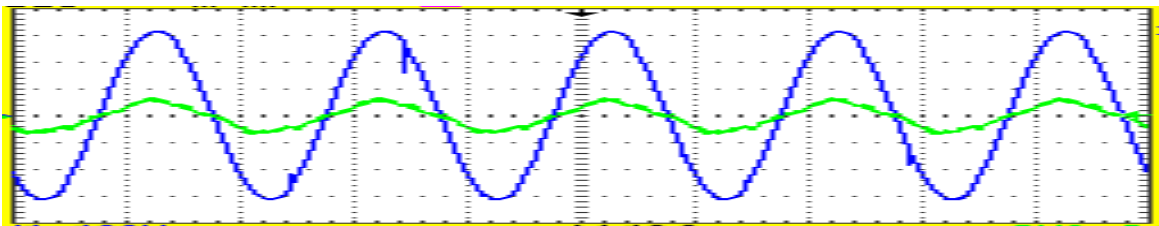

Fig.8 Grid-connected current output

Fig.9 Grid-connected voltage and current

Discussions

By the MATLAB simulation and the experiment of three-phase and grid-connected inverter, comparing and analyzing the simulation waveform and the experimental output waveform, the result shows that both the simulating and experimental output waveform is approximately the same and some deviation can be caused by the loss of devices. The normal operation of the grid-connected inverter verified that the Pan-Boolean algebra can be used in grid-connected inverter and SVPWM wave can correctly control and drive grid-connected inverter. The process of Pan-Boolean algebra control SVPWM algorithm is simple. It avoids complex calculation of trigonometric function, uses code 0 and 1 to be easier for computer's identification and operation, and makes more rapid development of control technology, clearer the concepts and easier to adjust parameters.

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