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Short Communication

Space vector pulse width modulation based two level inverter

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Abstract

With the rapid development of semiconductor devices, a variety of pulse width modulation (PWM) methods have been developed in order to provide gating signals to the inverter. Popularly used methods for various industrial applications are sinusoidal PWM and space vector PWM. In contrast to SPWM, SVPWM is more advantageous because of its simple implementation and better utilization of DC bus voltage. This paper presents the implementation of SVPWM from sinusoidal PWM by addition of common mode component to sinusoidal phase voltage. The sampled value of sinusoidal phase voltage produces the time equivalent of phase voltage signal, which when passed through PWM generator drives the inverter. The simulation results shows feasibility of this technique for various values of modulation index.

Keywords: Two-level Inverter, Total Harmonic Distortion (THD), Voltage Source Inverter (VSI), Sine PWM (SPWM), Space Vector Pulse Width Modulation (SVPWM).

Introduction

Three-phase VSI's are extensively used for industrial drives as it is capable of producing varying voltages and frequencies. PWM techniques provide gating signals to the VSI for its operation. In recent years various pulse width modulation techniques have been developed and extensively studied in order to achieve the following aims: less switching losses, low THD, wide linear modulation range, easier implementation, and lesser computation time[1]. Applicability of each and every PWM method is different and for obtaining varying voltages and frequencies a number of PWM schemes have been developed. Widely used methods are sinusoidal PWM and SVPWM. For sinusoidal PWM the DC bus utilized for the operation is restricted $V_{dc}/2$ while SVPWM shows a better utilization of $V_{dc}/\sqrt{3}$, which is around 15% more when compared to sinusoidal PWM[2]. Thus space vector modulation techniques provide higher amplitude modulation indexes and also there is reduction in switching losses and THD when compared with conventional Sinusoidal PWM techniques.

For the implementation of SVPWM, to drive a VSI many methods have been developed. Generally, the conventional SVPWM implementation requires the calculation of switching time, sector identification, determination of voltage space vector and optimal switching time for each sector. Sector identification can be done by calculating the sector angle by coordinate transformation using Clarke's transformation. For determining the switching sequence for the legs of inverter lookup table is required. The main purpose of this paper is to provide a simple approach towards the implementation of SVPWM, were the inverter legs gets the gating signal obtained from the instantaneous value of sampled phase voltage amplitude. The technique used is considerably simple when compared to conventional approach and is implemented in MATLAB/ SIMULINK without using any lookup table.

Two-level inverter: Figure-1 shows the schematic circuit diagram of a three-phase six step bridge inverter where S_1, S_3 and S_5 switches stands for upper switches while S_2, S_4 and S_6 switches are bottom switches. The ON/OFF of these switches in various switching combination determines the output of the six step inverter. It is assumed that the switches in each leg are operated in complementary to each other i.e. when S_1 is ON; S_4 is OFF, in a similar way S_3 and S_6, and S_5 and S_2 are also switched.

When the upper switches are ON that is their complementary switches are OFF (separately or together) it is represented by 1. Similarly when lower switches are ON that is their complementary switches are OFF (separately or together) it is represented by 0, so the probable combinations of switching states for three leg inverter (2^3=8 states) are: V_0 (000); V_1 (100); V_2 (110); V_3 (010); V_4 (011); V_5 (001); V_6 (101); V_7 (111), here two states are zero inverter states (V_0, V_7), that produces zero output and six states are active vectors $(V_1 - V_6)$ that produces certain magnitude of DC bus voltage at the output.

Space vector plane is separated identically to form sectors with uniform size of 60^0 (Figure-2). These identical sectors form a hexagon in which six active vectors lie along the radii of hexagon and zero vector lies at the center of hexagon[2]. Six steps are taken to make complete revolution. Sinusoidal voltage is treated as constant magnitude voltage which is revolving at a fixed frequency. This is known as the average variation of voltage space vector which is moving along a circulatory trajectory. We need to sample this rotating reference voltage given by V_{ref} with high sampling frequency which depends upon the inverter. V_{ref} is making small stationary jumps depending upon the sampling frequency to complete a circular trajectory.

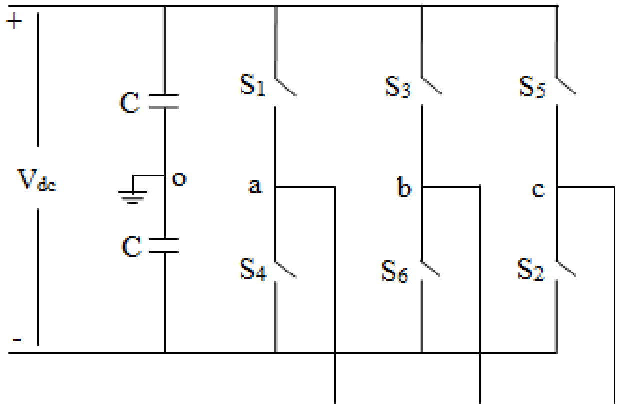

Figure-1: Schematic Diagram of Three-phase Bridge Inverter.

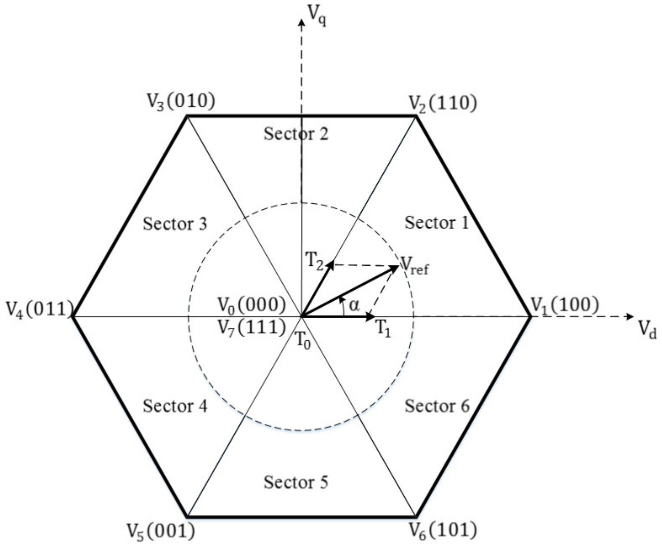

Figure-2: Inverter States and Sectors of Two-Level Inverter.

Methodology

In order to implement SVPWM, the technique used is completely based upon the instantaneous value of reference phase voltage of all the phases[3]. In this technique calculation of reference voltage (V_{ref}) and its exact position from the direct axis is not required. If the exact position of V_{ref} is between $0° - 60°$ i.e. in sector 1, then switching times T_1, T_2, and T_0 are calculated as

$$T_1 = \frac{T_s * V_{ref} * \mathrm{Sin}(60° - \alpha)}{V_{dc} * \mathrm{Sin}(60°)} \tag{1}$$

$$T_1 = \frac{T_s * V_{ref} * \mathrm{Sin}(\alpha)}{V_{dc} * \mathrm{Sin}(60°)} \tag{2}$$

$$T_0 = T_s - (T_1 + T_2) \tag{3}$$

Here α is measured from start of sector and $0 \leq \alpha \leq 60°$

Where: T_s is the sampling time and T_1, T_2, and T_0 are the time periods for which V_1, V_2, and V_0 are applied for particular sample and V_{dc} is the DC link voltage.

The abc to dq transformation in stationary reference frame is achieved by using Clarke's transformation which is given in equation-4.

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \tag{4}$$

The direct axis and quadrature axis voltage obtained by resolving V_{ref} along both the axis is given by

$$V_q = V_{ref} \sin(\alpha) \text{ and } V_d = V_{ref} \cos(\alpha)$$

$$\text{Where: } V_{ref} = \sqrt{{V_d}^2 + {V_q}^2} \; ; \; \alpha = \tan^{-1}\left(\frac{V_q}{V_d}\right) \tag{5}$$

Hence time periods T_1 and T_2 may to further simplified as

$$T_1 = \left(\frac{T_s}{V_{dc}}\right) V_{an} - \left(\frac{T_s}{V_{dc}}\right) V_{bn} = T_{as} - T_{bs} \tag{6}$$

$$T_2 = \left(\frac{T_s}{V_{dc}}\right) V_{bn} - \left(\frac{T_s}{V_{dc}}\right) V_{cn} = T_{bs} - T_{cs} \tag{7}$$

Implementation of this SVPWM method, by using instantaneous value of sampled phase voltage for the two-level inverter the following steps are to be used: i. Calculation of time equivalent of phase voltages i.e., T_{as}, T_{bs}, T_{cs}, ii. Finding T_{offset} as

$$T_{offset} = 0.5T_s - 0.5(T_{max} - T_{min}) \tag{8}$$

Where, T_{max} and T_{min} are the maximum and minimum values of T_{as}, T_{bs} and T_{cs}

iii. Calculating T_{ga}, T_{gb} and T_{gc} as:

$$T_{ga} = T_{as} + T_{offset} \tag{9}$$

$$T_{gb} = T_{bs} + T_{offset} \tag{10}$$

$$T_{gc} = T_{bs} + T_{offset} \tag{11}$$

Where, T_{ga}, T_{gb} and T_{gc} are the signals which when compared with high frequency triangular wave in PWM generator, produces the six gating signals for the six switches $(S_1 - S_6)$ of the inverter. Hence gating signal is generated without the requirement of sector angle[4], also we do not require look up table for calculation of T_1, T_2, T_0 In the proposed method only sampled reference phase amplitude is required.

Simulink model: The detailed simulation model of the proposed technique, which has been implemented using MATLAB/SIMULINK, is shown in Figure-3. Simulation is carried out for a star connected RL load, a DC link voltage of V_{dc}= 400 V, fundamental frequency of 50 Hz; switching frequency f_{sw}= 18 KHz and modulation index of 0.5 and 0.85.

Results and discussion

The switching pattern obtained using SVPWM is shown in Figure-4. This pattern when compared to high frequency triangular carrier wave produces gating signal to drive the inverter. It is clear from the waveform that there is an extra boost in voltage compared with sinusoidal PWM as there is an addition of common mode component in SVPWM compared to SPWM[5].

Figure-5(a) - 5(d) shows the phase voltage, line voltage and current across the load for various values of modulation index.

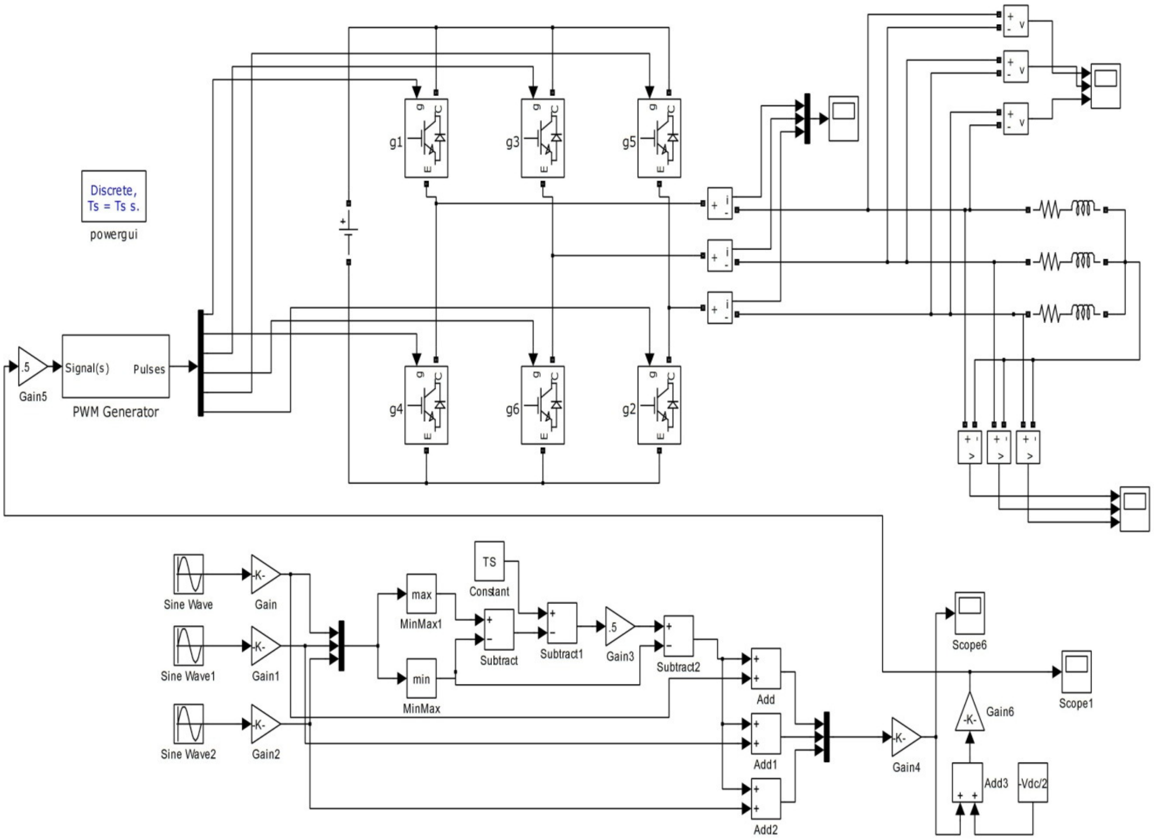

Figure-3: Simulation Model of SVPWM based VSI Connected to RL Load.

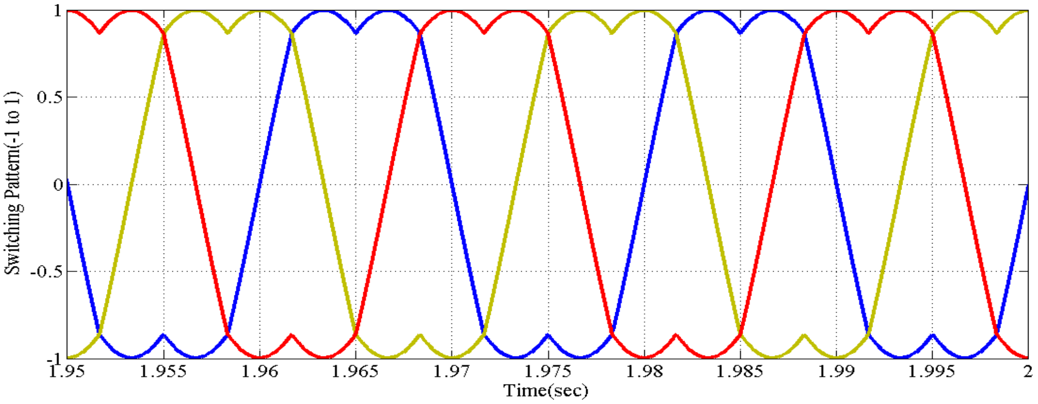

Figure-4: Switching Pattern of SVPWM Inverter.

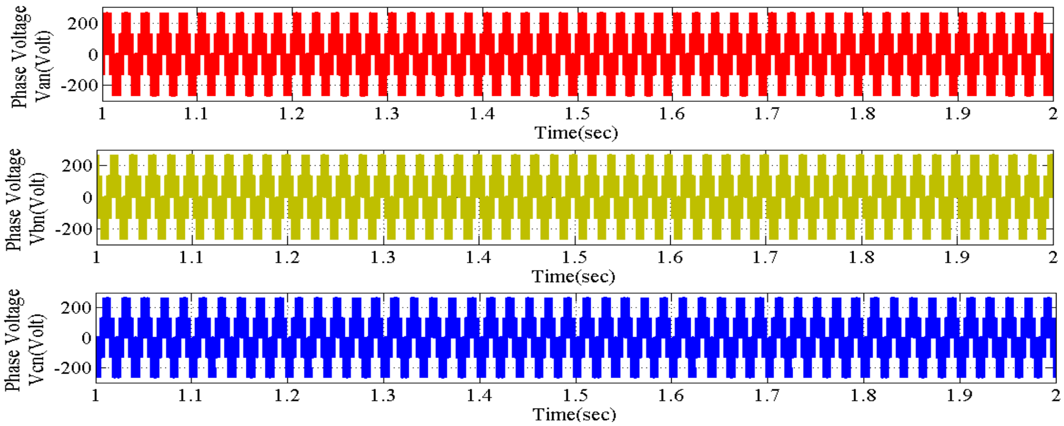

Figure-5(a): Phase Voltage ±2/3V$_{dc}$ and ±1/3V$_{dc}$.

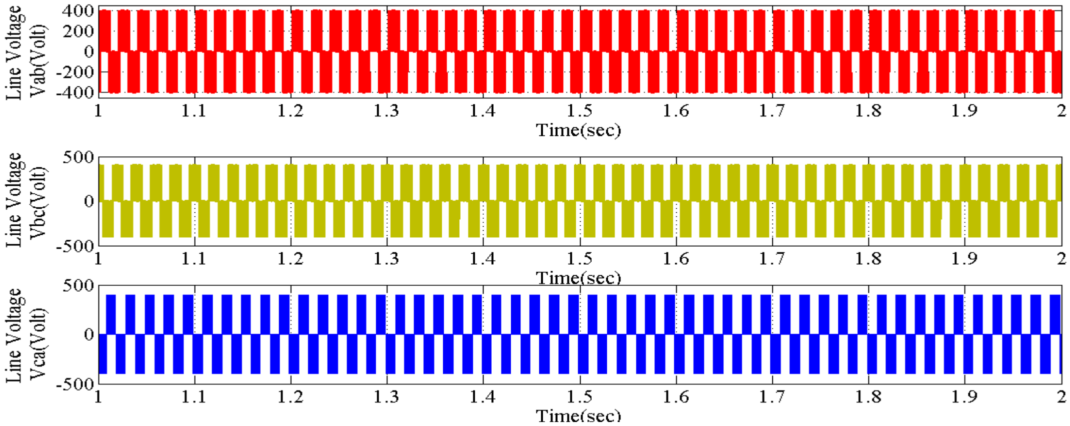

Figure-5(b): Line Voltage ±V$_{dc}$.

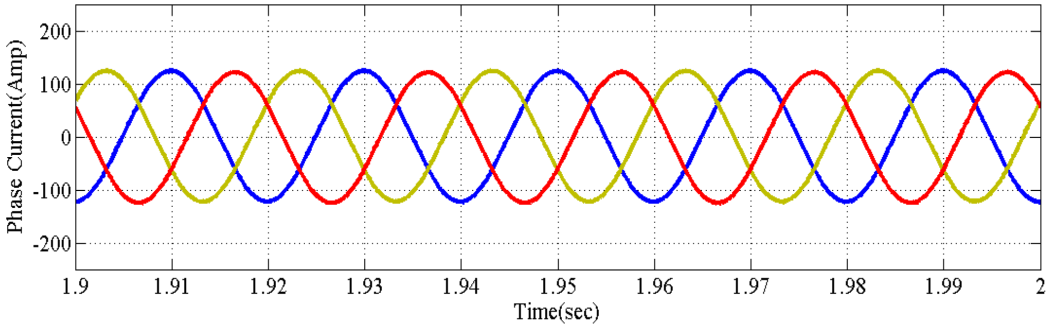

Figure-5(c): Current across the load for m = 0.5.

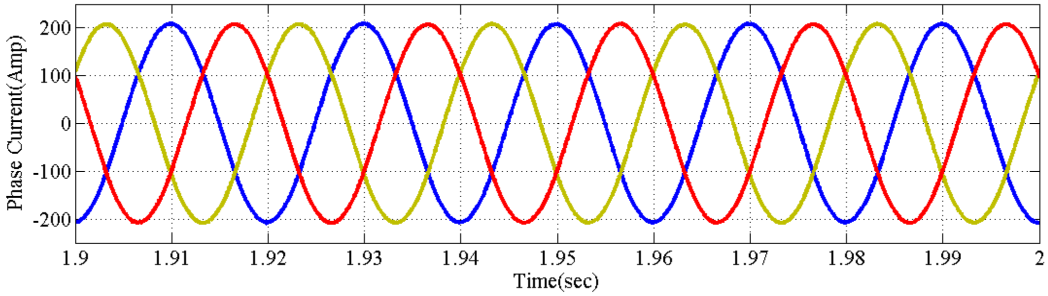

Figure-5(d): Current across the load for m = 0.85.

Thus from load current waveform it is clear that there is a change in amplitude of load current for different values of modulation index.

Conclusion

In this paper, simulation of SVPWM based two level inverter is done using MATLAB/SIMULINK. Results demonstrate that the proposed approach to implement SVPWM is feasible and effectively drives the two-level inverter. This method is easier and computationally simpler than the conventional method as it does not require lookup tables for the calculation of the position of reference voltage and the switching time.

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