

Modeling and Simulation of Induction Motor Drive with Space Vector Control

M. SajediHir, Y. Hoseynpoor, P. MosadeghArdabili, T. PirzadehAshraf

Department of electrical engineering, Sarab Branch, Islamic Azad University, Sarab, Iran

Abstract: Multilevel voltage-fed inverters with space vector pulse width modulation strategy are gained importance in high power high performance industrial drive applications. A number of Pulse Width Modulation (PWM) schemes are used to obtain variable voltage and frequency supply from an inverter. There is an increasing trend of using space vector PWM (SVPWM) because of their easier digital realization and better dc bus utilization. This paper proposes a new simplified space vector PWM method for a three-level inverter fed induction motor drive. Firstly model of a three-phase VSI is discussed based on space vector representation. Next a simple and flexible simulation model of SVPWM is developed using MATLAB/SIMULINK. Simulation results verify the effectiveness of the proposed approach.

Key words: Power Induction motor drive, Space vector, PWM, Voltage source inverter

INTRODUCTION

The voltage source inverters (VSI) fed variable speed AC drives have gained more importance in many industrial applications. To get variable voltage, variable frequency supplies from a VSI, the PWM algorithms are becoming more popular due to their advantages. A detailed survey of various PWM algorithms is given in (Holtz, 1992). Three-level voltage-fed PWM inverters are recently showing popularity for multi-megawatt industrial drive applications (Mondal et al, 2003). In recent years, the space vector PWM (SVPWM) algorithm is attracting many researchers. The Space Vector Pulse Width Modulation (SVPWM) method is an advanced, computation-intensive PWM method and possibly the best among all the PWM techniques for variable frequency drive application (Iqbal, 2008), (Mondal et al, 2003). This technique results in higher magnitude of fundamental output voltage available as compared to sinusoidal PWM. However, SVPWM algorithm used in three-level inverters is more complex because of large number of inverter switching states. Space vector approach has the advantages of lower current harmonics and a possible higher modulation index compared with the three phase sinusoidal modulation method and ease of digital implementation (Willi et al, 1988). The SVPWM method considers interaction of the phase and optimizes the harmonic content of the three phase isolated neutral load as shown in Fig. 1.

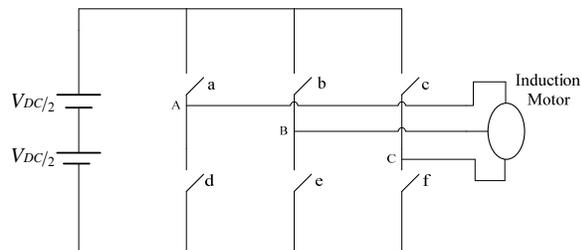


Fig. 1: Voltage source inverter type 3 phase.

This paper presents modeling and simulation of SVPWM algorithms for VSI fed induction motor drives. Finally, the computer simulations using Simulink/ MATLAB package program confirm the capabilities of the new technique.

The 3-phase Inverter:

The structure of a typical 3-phase power inverter is shown in Fig. 2, where V_A , V_B , V_C are the voltages applied to the star-connected motor windings, and where V_{DC} is the continuous inverter input voltage.

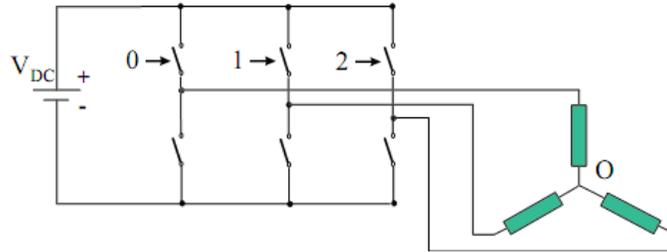


Fig. 2: Basic scheme of 3-phase inverter and AC-motor.

The six switches can be power BJT, GTO, IGBT etc. The ON-OFF sequence of all these devices must respect the following conditions:

- three of the switches must always be ON and three always OFF.
- the upper and the lower switches of the same leg are driven with two complementary pulsed signals. In this way no vertical conduction is possible, providing care is taken to ensure that there is no overlap in the power switch transitions.

The next paragraph presents a technique for generating such pulsed signals.

The Space Vector Pulse Width Modulation (SVPWM):

Space Vector PWM supplies the AC machine with the desired phase voltages. The SVPWM method of generating the pulsed signals fits the above requirements and minimizes the harmonic contents. Note that the harmonic contents determine the copper losses of the machine which account for a major portion of the machine losses. Taking into consideration the two constraints quoted above there are eight possible combinations for the switch commands. These eight switch combinations determine eight phase voltage configurations. The diagram below depicts these combinations.

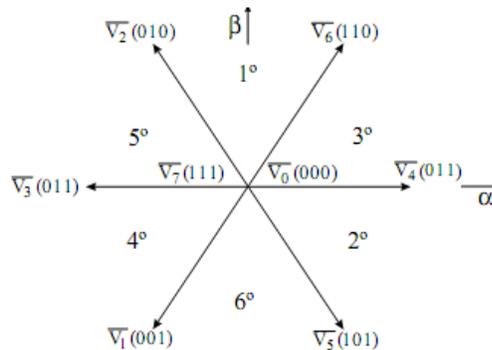


Fig. 3: SVPWM, vectors and sectors.

The vectors divide the plan into six sectors. Depending on the sector that the voltage reference is in, two adjacent vectors are chosen. The binary representations of two adjacent basic vectors differ in only one bit, so that only one of the upper transistors switches when the switching pattern moves from one vector to the adjacent one. The two vectors are time weighted in a sample period T to produce the desired output voltage.

Assuming that the reference vector V_{ref} is in the 3° sector, we have the following situation:

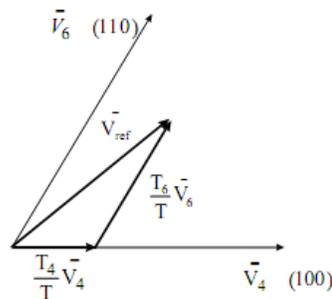


Fig. 4: Reference vector as a combination of adjacent vectors.

Where T_4 and T_6 are the times during which the vectors V_4 and V_6 are applied and T_0 the time during which the zero vectors are applied. When the reference voltage (output of the inverse Park transformation) and the sample periods are known, the following system makes it possible to determine the uncertainties T_4, T_6 and T_0 .

$$\begin{cases} T = T_4 + T_6 + T_0 \\ \vec{V}_{ref} = \frac{T_4}{T} \vec{V}_4 + \frac{T_6}{T} \vec{V}_6 \end{cases}$$

Under these constraints the locus of the reference vector is the inside of a hexagon whose vertices are formed by the tips of the eight vectors. The generated space vector PWM waveforms are symmetrical with respect to the middle of each PWM period. Fig. 5 shows the waveforms in the example presented above.

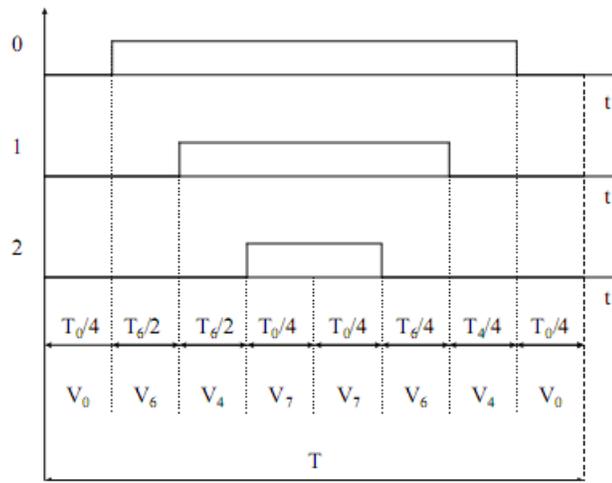


Fig. 5: Pattern of SVPWM.

The following diagram shows the pattern of SVPWM for each sector:

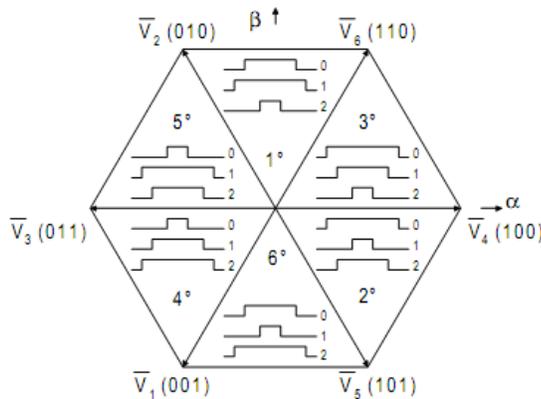


Fig. 6: Hexagon of SVPWM, pattern.

In conclusion, the inputs for the SVPWM are the reference vector components $(v_{\alpha, sr}, v_{\beta, sr})$ and the outputs are the times to apply each of the relevant sector limiting vectors.

Comparison SV- Sinusoidal PWM:

The SVPWM generates minimum harmonic distortion of the currents in the winding of 3-phase AC motor. SV Modulation also provides a more efficient use of the supply voltage in comparison with sinusoidal modulation methods. In fact, with conventional sinusoidal modulation (Ogasawara et al, 1989),(Holtz, 1992),(Pollmann et al, 1986) in which the sinusoidal signals are compared with a triangular carrier, we know

that the locus of the reference vector is the inside of a circle with a radius of $1/2 V_{DC}$. In the SV modulation it can be shown that the length of each of the six vectors is $2/3 V_{DC}$. In steady state the reference vector magnitude might be constant. This fact makes the SV modulation reference vector locus smaller than the hexagon described above. This locus narrows itself to the circle inscribed within the hexagon, thus having a radius of $1/3V_{DC}$. In Fig. 7 below the different reference vector loci are presented.

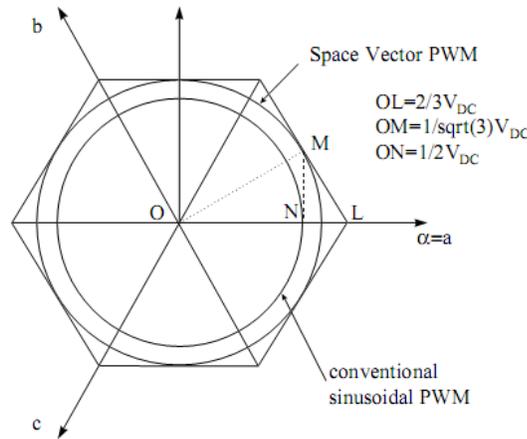


Fig. 7: Locus comparison SV-sinusoidal PWM.

Therefore, the maximum output voltage based on the Space Vector theory is $\frac{2}{\sqrt{3}} \frac{OM}{ON}$ times as large as

that of the conventional sinusoidal modulation. This explains why, with SVPWM, we have a more efficient use of the supply voltage than with the sinusoidal PWM method.

Machine equations are converted in the rotor flux frame. Rotor flux is turning in synchronous speed but in a different angle than stator flux, if there is a sinusoidal excitation. Choosing d-axis on the rotor flux, q component will be zero. This fact simplifies the equations very much. Now the torque and flux equations will be changed as follow:

$$\psi_{qr} = x_r i_{qr} + x_m i_{qs} = 0 \rightarrow i_{qr} = -\frac{x_m}{x_r} i_{qs} \tag{1}$$

$$T_e = -\frac{3P}{4} \lambda_{dr} i_{qr} = \frac{3P}{4} \frac{x_m}{x_r} \lambda_{dr} i_{qs} \tag{2}$$

$$\omega_r - \omega_e = \frac{x_m}{T_r} \frac{i_{qs}}{\lambda_{dr}} \tag{3}$$

$$T_r = \frac{L_r}{R_r} \tag{4}$$

$$\lambda_{dr} = \frac{x_m}{1 + T_r \cdot p} i_{ds} \tag{5}$$

The above relations are the main relations of vector control (Ong, 1997),(Chinchilla et al, 2006). This method simplifies the induction machine controlling. This method is very similar to DC machine's independent excitation where flux is the function of field current and torque is in proportion with flux and rotor current. The main problem of vector control method is flux axis angle calculation where is done by measuring the flux in two points with 90 degrees displacement and then angles are calculated using the resulted fluxes or estimating in regard to rotor speed (Ong, 1997).

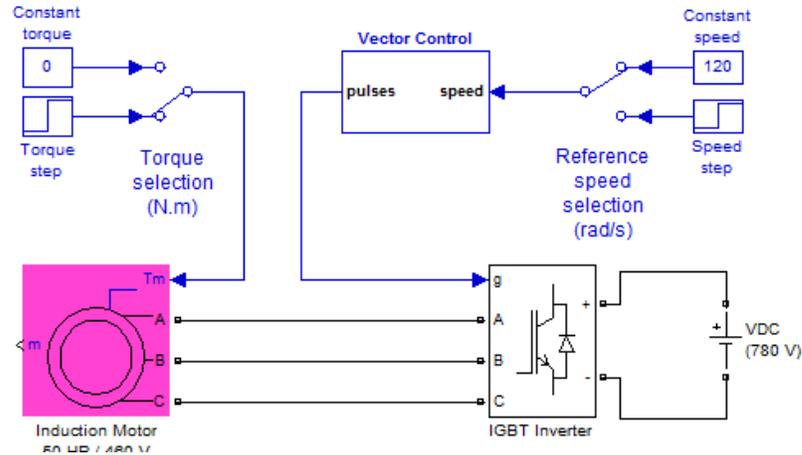


Fig. 8: Simulation in MATLAB.

Proportional and integrated PI controller values used in simulation are $K_p=12$ and $K_I=25$. In respect to the fact that motor power is directly related to air gap flux, this air gap flux will be maintained in its nominal value and d-axis current value can be calculated by air gap flux on the basis of relation 25. Flux axis angle is calculated as:

$$\omega_r - \omega_e = \frac{x_m i_{qs}}{T_r \lambda_{dr}} \tag{6}$$

$$\theta = \int (\omega_r + \omega_m) dt \tag{7}$$

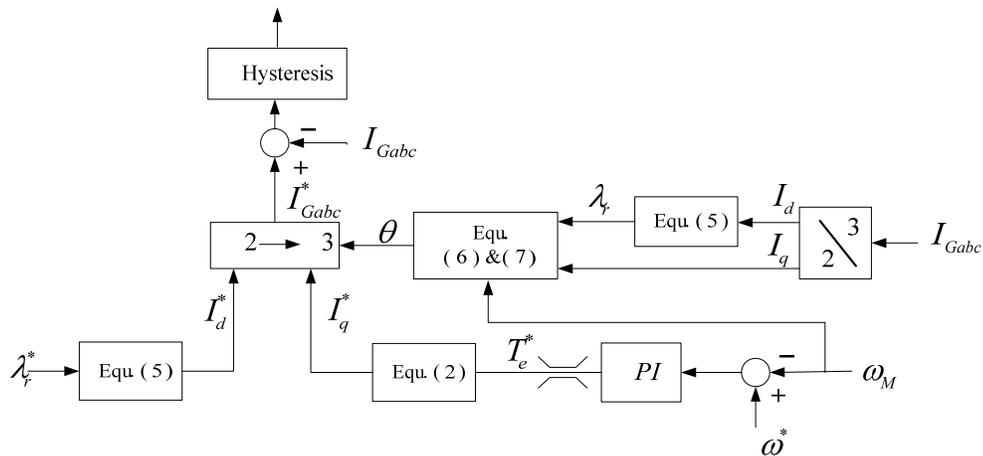


Fig. 9: Space Vector Concept.

Circuit Description:

The induction motor is fed by a current-controlled PWM inverter which is built using a Universal Bridge block. The motor drives a mechanical load characterized by inertia J, friction coefficient B, and load torque T_L . The speed control loop uses a proportional-integral controller to produce the quadrature-axis current reference i_q^* which controls the motor torque. The motor flux is controlled by the direct-axis current reference i_d^* . Block DQ-ABC is used to convert i_d^* and i_q^* into current references i_a^* , i_b^* , and i_c^* for the current regulator. Current and Voltage Measurement blocks provide signals for visualization purpose. Motor current, speed, and torque signals are available at the output of the 'Asynchronous Machine' block.

Simulation Results:

Start the simulation. Observe the motor current, voltage, and speed during the starting on the scope. At the end of the simulation time (3 s), the system has reached its steady-state.

Response to a change in reference speed and load torque is discussed:

The initial conditions state vector 'xInitial' to start has been saved in the 'power_acdrive_init.mat' file. This file is automatically loaded in your workspace when you start the simulation (See Model Properties). In order to use these initial conditions you have to enable them. Check the Simulation/Configuration Parameters menu, then select "Data Import/Export" and check "Initial state".

Now, double click the two Manual Switch blocks to switch from the "Constant speed" and "Constant torque" blocks to the Step blocks. Restart the simulation and observe the drive response to successive changes in speed reference and load torque.

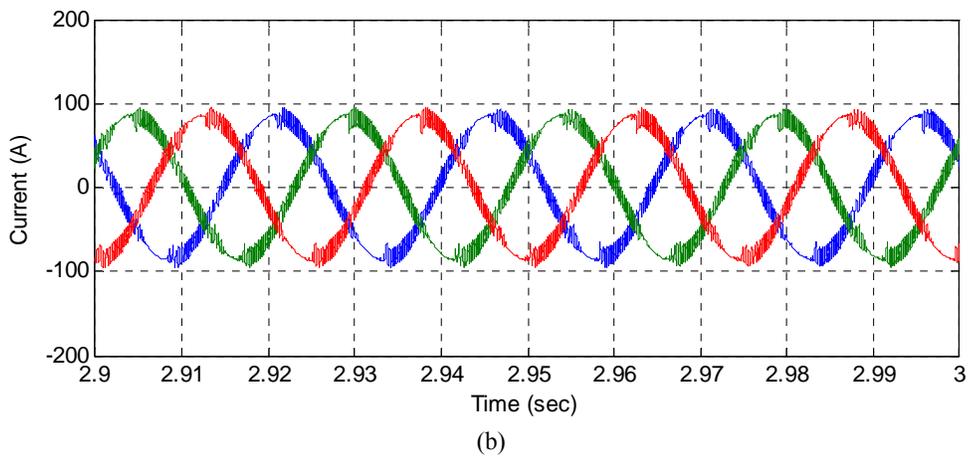
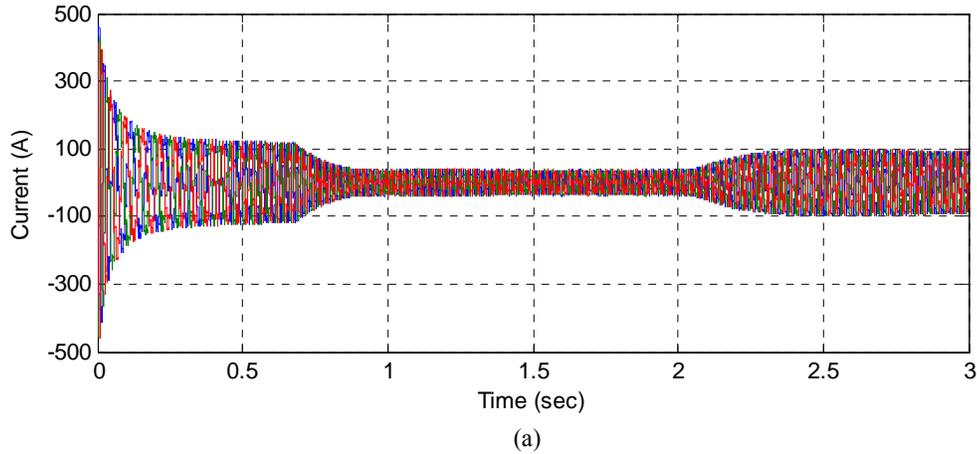


Fig. 10: (a),(b). Motor current.

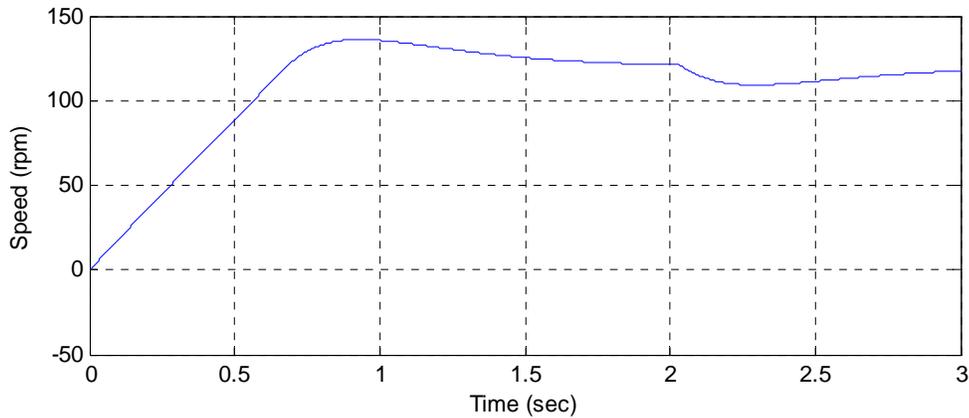


Fig. 11: Speed changes.

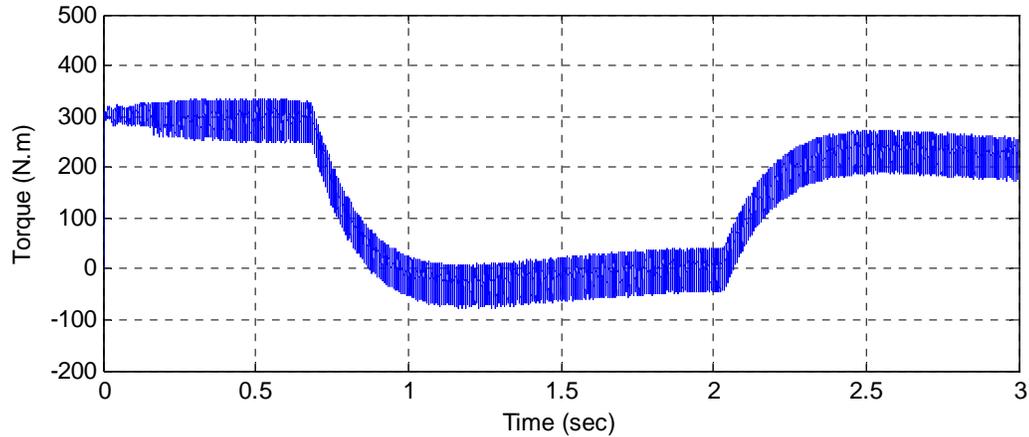


Fig. 12: Torque changes.

We can observe the drive response from Fig. 10. (a),(b) to successive changes in reference speed and load torque that this changes is shown in Figures 12 and 13.

Conclusion:

A simple generalized Matlab/Simulink model is presented to implement SVPWM for a three phase VSI. In this work, a three-level inverter using space vector modulation strategy has been modeled and simulated. Through the simulations, it is confirmed that the proposed SVPWM technique, has good drive response to successive changes in speed reference and load torque. The results obtained by simulation show the feasibility of the proposed strategy.

REFERENCES

- Chinchilla, M., S. Arnaltes and J.C. Burgos, 2006. "Control of Permanent-Magnet Generators Applied to Variable-Speed Wind-Energy Systems Connected to the Grid", IEEE Transaction on Energy Conversion, 21(1): 130-135.
- Holtz, J., 1992. "Pulsewidth modulation – A survey", IEEE Trans. Ind. Electron, 39(5): 410-420.
- Iqbal, A., 2008. "Analysis of space vector pulse width modulation for a five phase voltage source inverter", IE (I) journal-EL, 89(3): 8-15.
- Mondal, S.K., B.K. Bose, V. Oleschuk and J.O.P., 2003. "Three-Level Inverter Extending Operation Into Overmodulation Region", IEEE Trans. on Power Electronics, 18(2): 604-611.
- Ogasawara, S., H. Akagi, A. Nabae, 1989. "A novel PWM scheme of Voltage Source Inverters based on Space Vector Theory", 74(1): 33-41.
- Ong, C.M., 1997. "Dynamic Simulation of Electric Machinery, Using MATLAB and SIMULINK", Upper Saddle River, NJ: Prentice-Hall.
- Pollmann, A.J., 1986. "Software Pulse width Modulation for μ P Control of AC Drives", IEEE 1986 Transactions on industry applications, 22(4): 691-696.
- Willi, H., V. Broeck, H. Skudelny and G. Stanke, 1988. "Analysis and realization of a pulsewidth modulator based on voltage space vectors", IEEE Trans. Ind. Applicat, 24(1): 142-150.