Space Vector Analysis in Electrical Drives for Three-Phase Induction Motor Using MATLAB/SIMULINK to Control the Speed of Motor

Sony Verma[1]

[1]*Department of EE, SRMSCET Bareilly U.P.*

Email: sonysrms@rediffmail.com

Abstract: Space Vector Pulse Width Modulation (SVPWM) has become the successful techniques to construct three phase sine wave Voltage Source Inverter (VSI) parallel to control three-phase induction motor using vector control. We use here transformation of three phase into two phase with the help of equations. We also describe the modulation techniques refer to dq component of three phase induction motor. The simulation result shows the feasibility of the proposed modulation techniques to drive three phase induction motor and control the speed of the motor when VSI load varies.

IndexTerms: Space Vector Pulse Width Modulation (SVPWM), Three Phase Induction Motor, Voltage Source Inverter, Matlab/Simulink.

1. Introduction

In recent years, the field oriented control of induction motor drive is widely used in high performance drive system because of its advantages like high efficiency, very simple, extremely rugged, good power factor and it does not required starting motor [1]. Induction motors are used in many applications such as HVAC (heating, ventilation and air-conditioning), industrial drives (motion control, robotics). Automotive control (electric vehicles), etc. In recent years there has been a great demand in industry for adjustable speed drives [2], [3].

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 [4], [5]. Because of its superior performance superior characteristics, it has been finding widespread application in recent years [6]. The PWM method discussed so far have only considered implementation on half bridge operated independently, giving satisfactory PWM performance. With a machine load the load neutral is normally isolated, which causes interaction among the phases. This interaction was not considered before in the PWM discussion [7].

The aim of this paper is that it shows the dynamics response of speed with PID controller to control a speed of motor for keeping the motor speed to be constant when the load varies. This paper presents design and implementation a voltage source inverter type Space Vector Pulse Width Modulation (SVPWM) for control a speed of induction motor. This paper also introduced a PID controller to the

SVPWM in order to keep the speed of the motor to be constant when the load varies.

2. SPACE VECTOR PULSE WIDTH MODULATION

In the SVPWM scheme, the three phase output voltage is represented by a reference vector which rotates at an angular speed of $\omega=2\pi f$. SVPWM is based on the fact that there are only two independent variables in a 3-phase voltage system. We can use orthogonal coordinates to represent the 3-phase voltage in the phasor diagram. For a three phase voltage source inverter as depicated in figure 1, each pole voltage may assume one of the two values depending upon whether the upper switch or the lower switch is on.

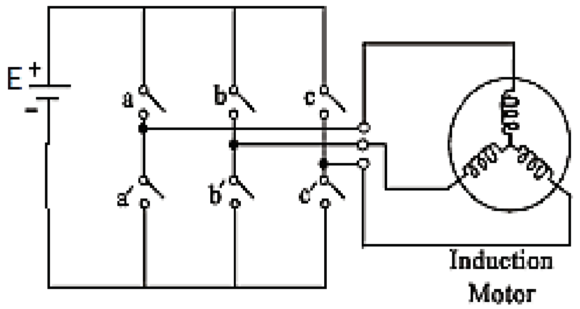

Fig.1 Six-Switch voltage source inverter connect with three phase induction motor

Therefore, only eight combinations of switches are possible: there are shown in figure (1) of these, two of them have zero states. Zero states occur when either the upper three or the lower three switches are conducting simultaneously. The three phase balanced windings of an induction motor, when fed with a balanced three phase sinusoidal voltage-set, will generate a resultant space vector, which has a fixed amplitude and rotates along a circular trajectory in space. The basic aim of the SVPWM inverter is to generate such a 'rotating space-vector'. The switches are termed as SA1, SA2 for pole A. SB1, SB2for pole B, and SC1, SC2 for pole C. Different states are defined as follow.

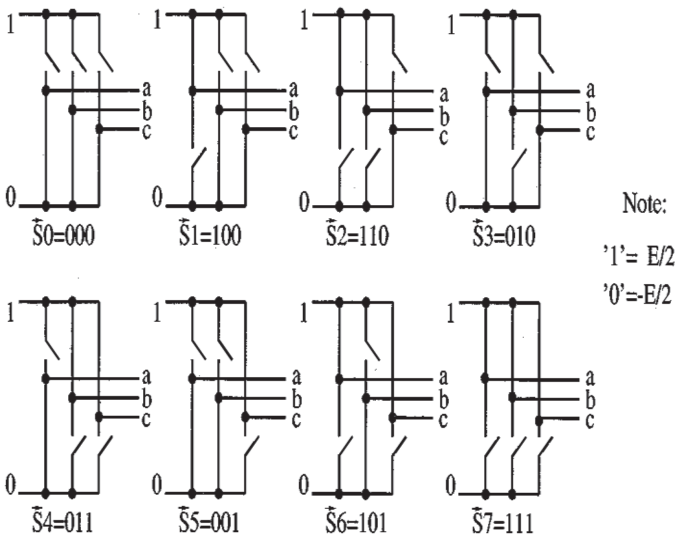

Fig. 2The eight inverter voltage vector

Therefore, only eight combinations of switches are possible: there are shown in figure (2) of these, two of them have zero states. Zero states occur when either the upper three or the lower three switches are conducting simultaneously. The three phase balanced windings of an induction motor, when fed with a balanced three phase sinusoidal voltage-set, will generate a resultant space vector, which has a fixed amplitude and rotates along a circular trajectory in space. The basic aim of the SVPWM inverter is to generate such a 'rotating space-vector'. The switches are termed as SA1, SA2 for pole A. SB1, SB2 for pole B, and SC1, SC2 for pole C. Different states are defined as follow.

A = 0 if SA1 off and SA2 on.
= 1 ifSA1 on and SA2 off.
B = 0 if SB1 off and SB2 on.
= 1 ifSB1 on and SB2 off.
C = 0 if SC1 off and SC2 on.
= 1 ifSC1 on and SC2 off.

The instantaneous values of the line-to line voltages of the inverter can be obtained from the above logic relation given by

$$V_{AB} = V_{dc}(A - B)$$

$$V_{BC} = V_{dc}(B - C) \; V_{CA} = \qquad (1)$$

Where the DC is bus voltage and are line to line voltages. The line to line voltages are given by

$$V_A = \frac{1}{3}(V_{AB} - V_{CA})$$

$$V_B = \frac{1}{3}(V_{BC} - V_{AB}) \qquad (2)$$

Replacing the values of line-to-line voltage in the previous set of equations yields the line to neutral voltages of the inverter.

$$V_A = \frac{V_{dc}}{3}(2A - B - C)$$

$$V_B = \frac{V_{dc}}{3}(2B - C - A)$$

$$V_C = \qquad (3)$$

For state 4(S4), the values are

$$V_A = \frac{2}{3}V_{dc}$$

$$V_B = -\frac{1}{3}V_{dc}$$

(4)

3. BASIC EQUATIONS

Induction motor has always been preferred for its reliability, ruggedness and easier in maintenance. The induction motor drives controlled with the vector control method has found wide acceptance in the industry. However, this control technique requires complex coordinate transformation, inner current control loop and accurate system parameters. Sofirstly we derive the steady state equation from the dynamic equation. The steady state equation of the induction motor can be derived by substituting for the d and q axes voltages in the system equations:

$$V_{as} = V_m \sin \omega_s t$$
$$V_{bs} = V_m \sin(\omega_s t - \frac{2\pi}{3})$$
$$V_{cs} = V_m \qquad (5)$$

Hence

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_o \end{bmatrix} = [T_{abc}] \begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} V_m \sin \omega_s t \\ V_m \cos \omega_s t \\ 0 \end{bmatrix} = \begin{bmatrix} V_m\ 0 \\ V_m\ 90 \\ 0 \end{bmatrix}$$

In steady state

$p = j\omega$

$V_{qr} = V_{dr} = 0$

Substituting these into the system equations yields

$$\begin{bmatrix} V_m \\ jV_m \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + j\omega_s L_s & 0 & j\omega_s L_m & 0 \\ 0 & R_s + j\omega_s L_s & 0 & j\omega_s L_m \\ j\omega_s L_m & -\omega_r L_m & R_r + j\omega_s L_r & -\omega_r L_r \\ \omega_r L_m & j\omega_s L_m & \omega_r L_r & R_r + j\omega_s L_r \end{bmatrix} \qquad (6)$$

The input voltages are in quadrature, so the currents have to be in quadrature, because the system steady state is linear, they can be represented as

$i_{ds} = ji_{qs}$

$i_{dr} = ji_{qr}$

Substituting these equations into the above equations and considering only one stator and rotor equation with rms value yields

$V_s = (R_s + j\omega_s L_s)I_s + j\omega_s L_m I_r$

$0 = jL_m(\omega_s - \omega_r)I_s + (R_r + j(\omega_s - \omega_r)L_r)I_r$

Where is the stator rms voltage and stator and rotor rms currentrespectively. Rearrange the rotor equations with the aid of

$\omega_{sl} = \omega_s - \omega_r = s\omega_s$

The rotor equation then is

$0 = jL_m \omega_s I_s + \left(\frac{R_r}{s} + j\omega_s L_r\right) I_r$

The rotor and stator equation when combined, with an understanding that the sum of stator and rotor currents gives the magnetizing current. Note that the stator and stator referred rotor self-inductances are equal to their magnetizing inductance and respective leakage inductances and are given as

$L_s = L_m + L_{ls}$

$L_r = L_m + L_{lr}$

So finally electrical system equations are:

$$V_s = R_s \qquad (7)$$

$$V_r = R_r i_r + \frac{d\lambda_r}{dt} + (\quad (8)$$

Where the space vector and the rotational operator

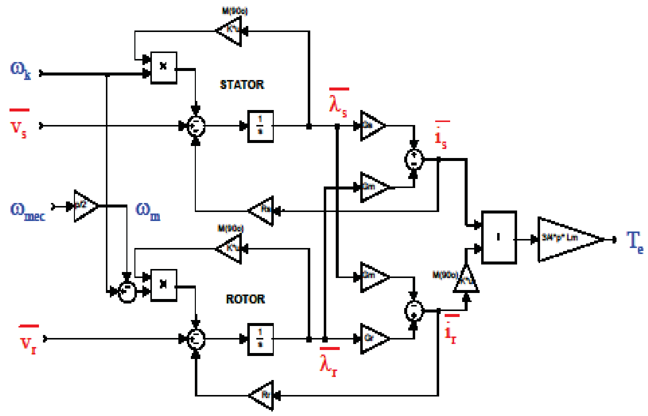

Fig.3 Induction motor modeling circuit

4. INVERTER FOR AC DRIVES

For variable speed control, the voltage applied tothe main and auxiliary windings should be of variable frequency and such magnitude and phase orientation as to maintain the winding currents in time quadrature at all times.

A. BASIC SWITCHING VECTORS AND SECTORS

One of the approaches to achieve this would be to use PWM bridge so as to create the required fundamental ac voltage. An alternative approach is to use 6 switches three-phase PWM, connecting the two motor windings as an unbalanced load between two phases. such a converter configuration, it is necessary to determine how the motor will respond to a variable supply frequency across both windings, and determine modulation strategy that most effectively achieve the objective of maintaining quadrature winding *currents* at any fundamental frequency. Alternatively, for a simple controller, it will probably be easier to modulate for quadrature *voltages* across the windings, correcting for any difference between the winding impedance angles.

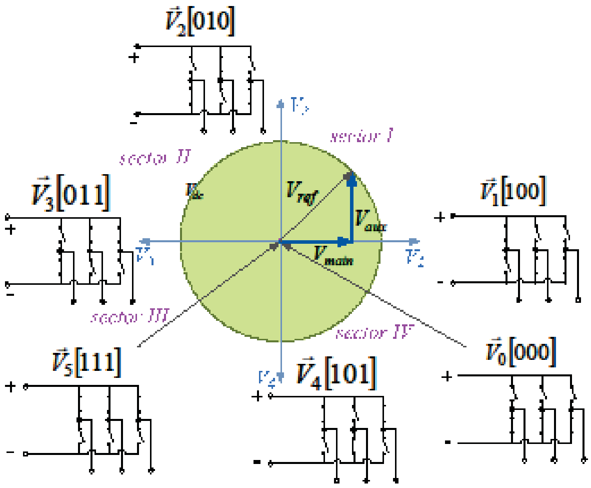

Fig.4 Space vector of voltage

The rotating voltage vector within the four sectors can be approximated by sampling the vector and switching between different inverter states during the sampling period. This will produce an approximation of the sampled rotating space vector. By continuously sampling the rotating vector and high-frequency switching, the output of the inverter will be a series of pulses that have a dominant fundamental sinewave component, corresponding to the rotation frequency of the vector.

B. SIMULATION BLOCK DIAGRAM

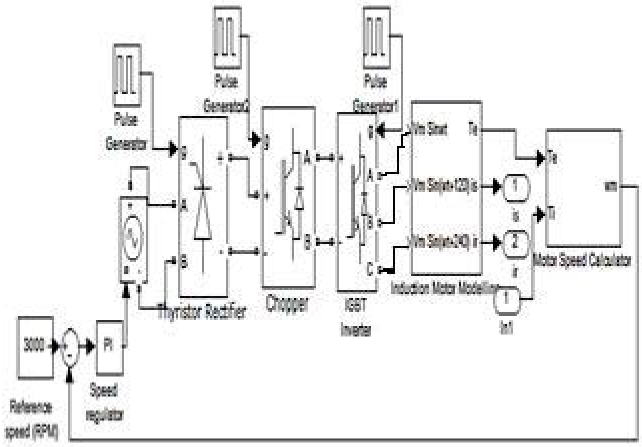

Fig.5 Simulation Block Diagram

5. RESULT AND DISCUSSION

The proposed two-phase SVPWM inverter to drive the three-phase induction motor has been simulated using MATLAB/SIMULINK. It assumed that the model motor has Pn = 0.25HP, Vn = 240V (Vrms), f = 50Hz, Rs = 2.02 Ohm, LIs = 7.4mH, Rr' = 4.12 Ohm, LIr' = 5.6mH, Lms = 0.1772H RS = 7.14, LIS = 8.5mH. SVPWM inverter has
fs= 10 kHz, with m = 9.8.

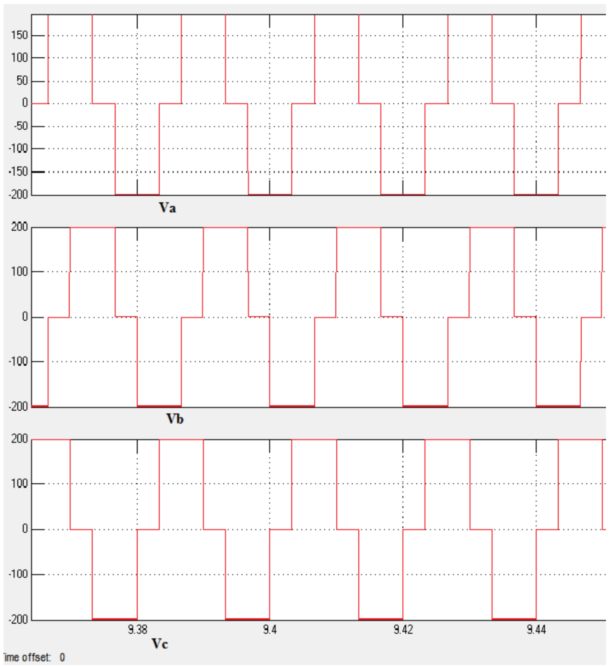

Fig.6 Inverter output voltage

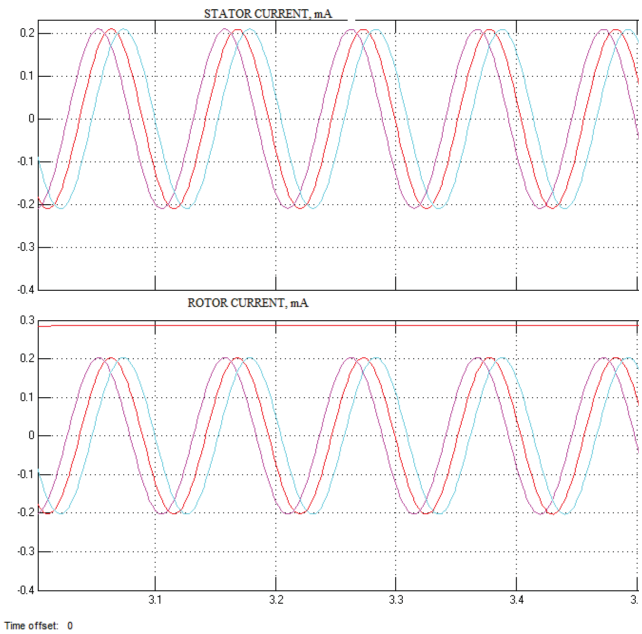

Fig.7 Stator and rotor current waveform

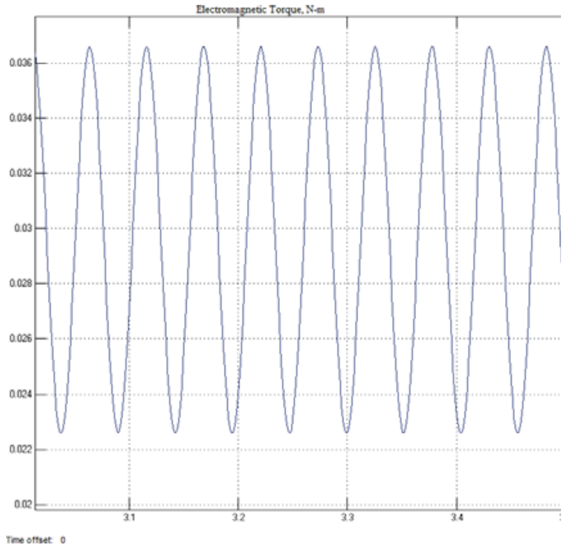

Fig.8 Electromagnetic torque

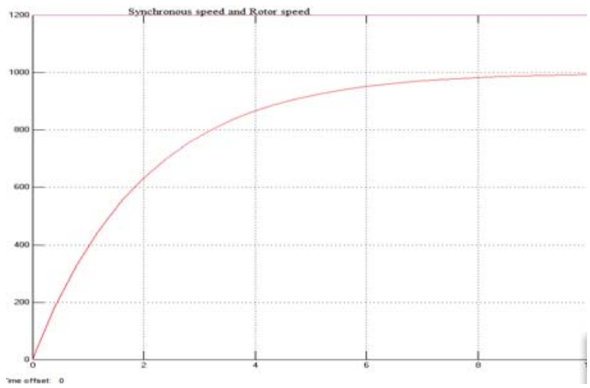

Fig.9 Induction motor speed

6. CONCLUSION

In this paper the space voltage vector pulse width modulation technique is proposed to drive three-phase induction motor. Such technique is applied to adjustable speed control of single-phase induction motor drives. There are four space voltage vectors and two zero vectors in the two-phase inverter. The switching sequence of the two-phase SVPWM is proposed. This technique actually can utilize 100% DC source since there is no center tap from the dc source, and allow index modulation greater than 1 (enable over modulation). This technique proposed to eliminate the using of capacitor to running the motor. The aim of this paper is that it shows the dynamics response of speed with design the PID controller to control a speed of motor for keeping the motor speed to be constant when the load varies. This paper presents design and implements a voltage source inverter type space vector pulse width modulation (SVPWM) for control a speed of induction motor. This paper also introduce PID controller to the SVPWM in order to keep the speed of the motor to be constant when the load varies.

References

[1] W. Leonhard, Control of Electric Drives, Springer-Verlag Berlin Heidelberg, New York, Tokyo, 1985.

[2] Bimal K. Bose. “Modern Power Electronics and Ac Drives”, Pearson Education.

[3] R. Krishnan, “Electric Motor Drives”, Prentice-Hall India, New Delhi 2005.

[4] A. Iqbal,”Analysis of Space Vector Pulse Width Modulation for a Five Phase Voltage Source Inverter”IE (I) journal-EL, Volume 89 Issue 3. September 2008 Pages 8-15

[5] Mondal S. K. Bose, B. K.;Oleschuk, V.; Pinto, J. O. P., Space Vector Pulse Width Modulation of three-level inverter extending operation into over modulation region”, IEEE Transaction on Power Electronics Volume 18, Issue 2, March 2003 Page(s):604-611

[6] Peter Vas,”Artificial-Intelligence Based Electrical Machines and Drives”, Oxford University 1999.

[7] Andrzej M. Trzynadlowski,” Introduction To Modern Power Electronics”, Copyright© 1998 By John Wiley & Sons, Inc. All Right Reserved.

[8] R. Rajendran, Dr. N. Devarajan,”Analysis and FPGA Realization of A Pulse Width Modulator Base On Voltage Space Vectors” International Journals of Computer Applications (0975-8887) Volume 2-No.6, June 2010.

[9] P. C. Krause, 0. Wasynczuk, and S. D.Sudhoff, “*Analysis of electric machinery*”, IEEE Press, Piscataway, N.J., 1996, ISBN0-7803-1 101-9, pp. 415 -447.

[10] H. Kragh, *Modeling, analysis andoptimisation of power electronic circuits* for low-cost drives, Ph.D. Thesis, Aalborg University - Denmark, Institute of Energy Technology, February, 2000.

[11] Bai Hua, et al “Comparison of Three PWM Strategies – SPWM, SVPWM &One-cycle Control” Power Electronics and Drive Systems, 2003. PEDS 2003. The Fifth International Conference on Volume 2, 17-20 Nov. 2003 Page(s):1313 - 1316 Vol.2

[12] P. C. Krause, Wasynczuk, and S. D. Sudhoff, “Analysis of electric machinery”, IEEE Press, Piscataway, N.J., 1996, ISBN 0-7803-1 101-9, pp. 415-447.Frede Blaabjerg, et. al, “Comparison of Variable Speed Drives for Single- Phase Induction Motors”. Power Conversion Conference 2002, PCC Osaka 2002, Proceedings of the Volume 3, 2-5 April 2002 Page(s):1328-1333 vol.3.

[13] P. C. Krause, “A constant frequency induction motor speed control,” presented at the1964 IEEENat’l Electron. Conference, Chicago, III.

[14] Space Vector Modulation-An introduction, Tutorials.