Speed Control of Space Vector Modulated Inverter Driven Induction Motor

R. Linga Swamy and P. Satish Kumar

Abstract: **In this paper, v/f control of Induction motor is simulated for both open loop and closed loop systems. The induction motor (IM) is fed from three phase bridge inverter which is operated with space vector modulation (SVM) Technique. Among the various modulation strategies Space Vector Modulation Technique is the efficient one because it has better spectral performance and output voltage is more closed to sinusoidal. The performance of SVM technique and Sine triangle pulse width modulation (SPWM) technique are compared for harmonics, THD, dc bus utilization and Output voltage and observed that SVM has better performance. These techniques when applied for speed control of Induction motor by v/f method for both open loop and closed loop systems it is observed that the induction motor performance is improved with SVM.**

Index Terms: **Space vector modulation, SPWM, v/f control of Induction motor.**

I. INTRODUCTION

With the development in power electronic switches and low cost computational hardware ac induction motor drives now compare favorably to DC motors on considerations such as power to weight ratio, acceleration performance, maintenance, operating environment, and higher operating speed without the mechanical commutator, cost and robustness of the machine, and perhaps control flexibility are often reasons for choosing induction machine drivers in small to medium power range applications. Up to date, due to the improvement of fast-switching power semiconductor devices and machine control algorithm, more precise PWM (Pulse Width Modulation) method finds particularly growing interest. A large variety of methods for PWM exists on which a survey was recently given. For the ac machine drive application, full utilization of the dc bus voltage is extremely important in order to achieve the maximum output torque under all operating conditions. In this aspect, compared with any other PWM method for the voltage source inverter, the PWM method based on voltage space vectors results in excellent dc bus utilization. Moreover as compared to sine triangle PWM method, the current ripple in steady state operation can minimized in this method. The speed or torque of an induction machine can be controlled by various modulation strategies for inverter. In this paper v/f control of IM for both open loop and closed loop systems using the best modulation strategy known as SVM technique is simulated and compared with the conventional SPWM technique and shown that IM performance is improved. With SVM the performance of IM is improved because it eliminates all the lower order harmonics in the output voltage of the inverter (stator voltage of the IM) when compared to the conventional SPWM technique. The performance of the IM can be further improved by eliminating the current harmonics in the stator currents of the IM.

Manuscript received December, 14, 2007.This research work was supported by Electrical engineering Department, University college of engineering, Osmania University, Hyderabad, Andhra Pradesh, India.
R. Linga Swamy is with Electrical engineering Department, University college of engineering, Osmania University, Hyderabad, A.P., India (email id: rlswamy@gmail.com).
P. satish kumar is with Electrical engineering Department, University college of engineering, Osmania University, Hyderabad, A.P., India (email id: satish_8020@yahoo.co.in).

II. SPACE VECTOR MODULATION

In Fig 1(a) the typical power stage of the three phase inverter and the equivalent circuit of a machine are presented. As shown in this figure, the voltages applied to machine is defined as $V_{an,bn,cn}$ and the $V_{aN,bN,cN}$ denote the pole voltages produced in the inverter stage in this paper. And, the available eight different switching states of the three phase inverter are depicted in the Fig 1(b). Note that all the machine terminals are connected to each other electrically and no effective voltages are applied to machine when the zero vectors presented by Vo and V7 are selected.

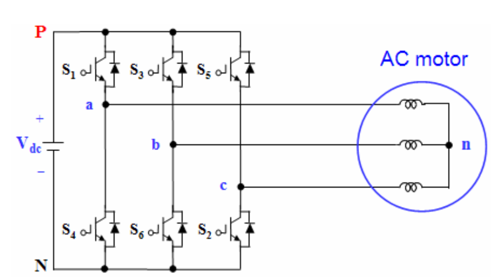
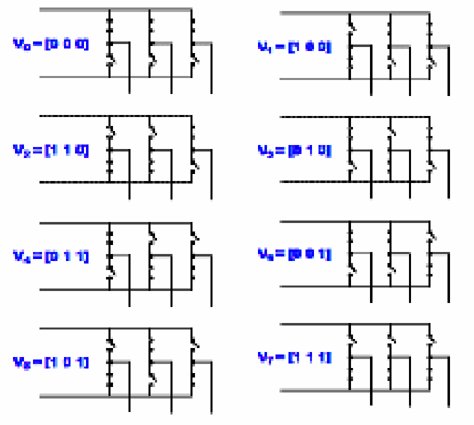


Fig.1. (a) Three phase inverter fed induction motor



(b)
Fig.1.(b) Switching state diagram with Eight switching states

Therefore the six voltage vectors can be selected to apply an "effective voltage" to the machine and these vectors can be located on the vector space represented with the stator fixed d-q reference frame as shown in the fig 2. If a constant reference voltage vector V*or V_{ref} is given in one sampling period, this vector can be generated using zero vector (V_0 or V_7) in combination with only two nearest active vectors ($V_{[n]}$ and $V_{[n+1]}$). These two active vectors are considered as the effective vectors to generate desired output voltage. From the average voltage concept, the reference vector can be written as followings during one sampling period.

$V^* = (T_1 . Vn + T_2 . Vn+1)/T_3$ ----------------------- (1)

(Where T_1, T_2 are the applied effective times corresponding to the active vectors.)
And, the effective time can be deduced as,

$$T1 = \frac{|V^*|.T_3}{V_{DC}.2/3} \cdot \frac{\sin(\pi/3-\alpha)}{\sin(\pi/3)} \quad \text{-------------------- (2)}$$

$$T_2 = \frac{|V^*|.T_3}{V_{DC}.2/3} \cdot \frac{\sin(\alpha)}{\sin(\pi/3)} \quad \text{------------------ (3)}$$

$T_0 = T_3 - T_1 - T_2$ ------------------- (4)

Where T_0 is the time corresponding to null vector
V_{DC} is the DC linkage Voltage and T_3 is sampling time

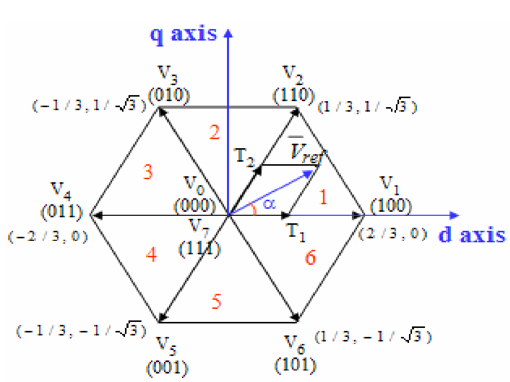


Fig.2.Space vector diagram of the effective vectors

Note that, in fact the effective time doesn't imply the actual switching time. The switching time complies with the time delay from the initial point of one sampling period the activation time of switching device. Therefore in order to evaluate the active switching times, the effective times should be recombined to the location of the reference vector.

In fig 3, the relationship between the effective times and the actual gating times is depicted when the reference vector is located in the Sector-1. In this case the V_1 vector is applied to the inverter during T_1 interval, and consequently V_2 vector is applied during T_2 interval. In the three phase symmetry modulation method, the zero sequence voltage vectors is distributed symmetrically in one sampling period to reduce the current ripple. Thus, in general, the switching sequence is given by 0-1-2-7-7-2-1-0 within two sampling periods. With the point of view of the upper switching devices of one inverter leg, the former sequence (0-1-2-7 sequence) is called 'ON' sequence, and the latter (7-2-1-0) is called 'OFF' sequence in this paper. Therefore, the actual switching times corresponding to the case of sector -1 can be written as,

On gating Sequence	Off Gating Sequence	
$T_{ga}=T_0/2$	$T_{ga}= T_0/2+T_1+T_2$	
$T_{gb}=T_0/2+T_2$	$T_{gb}=T_0/2+T_2$	--- (5)
$T_{gc}=T_0/2+T_1+T_2$	$T_{gc}=T_0/2$	

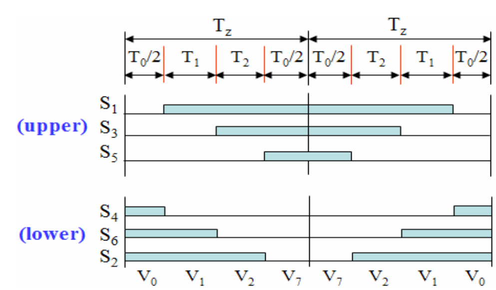


Fig.3. Actual gating signal pattern of the space vector PWM
(in the case of the sector -1)

From this analysis, the conventional space vector modulation task can be solved into following steps to make the actual PWM pattern.

Step: 1) Sector Identification: By comparing the stationary frame d-q components of the reference voltage vector, the sector where the reference vector is located is identified.

Step: 2) Calculating the Effective Timer: Using the d-q components of reference vector and the DC link voltage information, the effective times T1, T2 are calculated.

Step: 3) Determining the switching Times: using the corresponding sector information the actual switching time for each inverter leg is generated from the combination of the effective times and zero sequence time.

III. MATHEMATICAL MODEL OF INDUCTION MACHINE

The induction machine is implemented in simulink using the following mathematical model

$V_{qa}=r_s\, i_{qs} + \omega\lambda_{ds} + p\,\lambda_{qs}$ ----------- (6)

$V'_{qr}= 0 = r'_r i'_{qr} + (\omega-\omega_r)\,\lambda'_{dr} + p\,\lambda'_{qr}$ ----------- (7)

$V_{ds}= r_s\, i_{ds} - \omega\lambda_{qs} + p\,\lambda_{ds}$ ---------- (8)

$V'_{dr}= 0 = r'_r\, i'_{dr} - (\omega-\omega_r)\,\lambda'_{qr} + p\,\lambda'_{dr}$ ----------- (9)

ω =angular speed of arbitrary reference frame

P=d/dt

Where

$\lambda_{qs}=(l_s+L_m)i_{qs} + L_m i'_{qr} = L_s i_{qs} + L_m i'_{qr}$………(10)

$\lambda'_{qr}=(l'r+L_m)i'_{qr} + L_m i_{qs}=L'_r i'_{qr} + L_m i_{qs}$ ………(11)

$\lambda_{ds} = (l_s+L_m)\, i_{ds} + L_m i'_{dr}=L_s i_{ds} + L_m i'_{dr}$……...(12)

$\lambda'_{dr}=(l'_r + L_m)i'_{dr} + L_m\, i_{ds}=L'_r i'_{dr} + L_m i_{ds}$…......(13)

Therefore

$$\begin{bmatrix} i_{qs} \\ i'_{qr} \\ i_{ds} \\ i'_{dr} \end{bmatrix} = \begin{bmatrix} L_s & L_m & 0 & 0 \\ L_m & L'_r & 0 & 0 \\ 0 & 0 & L_s & L_m \\ 0 & 0 & L_m & L'_n \end{bmatrix}^{-1} \begin{bmatrix} \lambda_{qs} \\ \lambda'_{qr} \\ \lambda_{ds} \\ \lambda'_{dr} \end{bmatrix} \text{ - (14)}$$

And

$$T_e=\frac{Pm}{\omega_m} = \frac{3}{2}\frac{P}{2}\frac{L_m}{L'_r}\left[\lambda'_{dr} i_{qs} - \lambda'_{qr} i_{ds}\right] \text{ - (15)}$$

$$\omega_m = \frac{T_e - T_L}{J_s + B}\ ;\ \omega_r = \frac{P}{2}\,\omega_m \qquad (16)$$

IV. SIMULATION

Simulation were carried out for constant v/f control of induction motor drives using SVM and SPWM techniques for open and closed loop system. The parameters of the induction motor used for simulation are as follows:

220V, 50Hz, 4pole, 3hp

R_s=0.55Ω, L_s=93.38mH

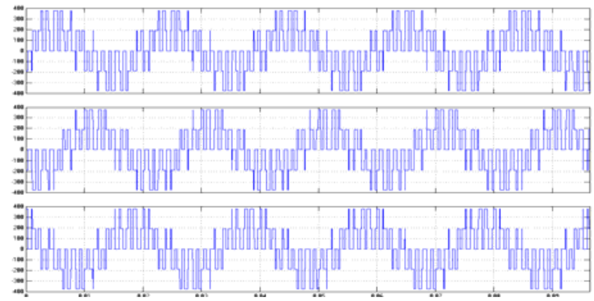
R_r=0.78Ω, L_r=93.36mH, Lm=90.5mH

J=0.019KG-M^2, B=.000051, T_L=10.32N-m;

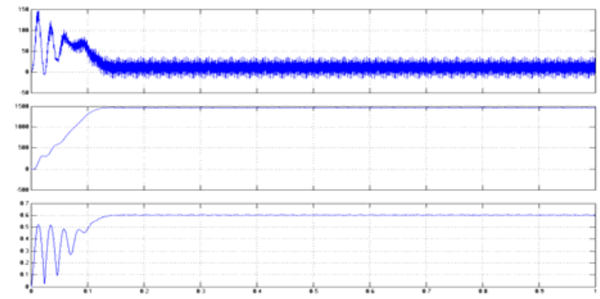
The inverter switching frequency is 2.1 kHz the D.C link voltage is 282.84Vand the modulation index is 0.7 for both SVM and SPWM

a) Open loop SPWM

Fig.4a. show the output phase voltages of SPWM inverter and Fig.4b shows torque developed, speed and flux of IM with open loop control .



(a)

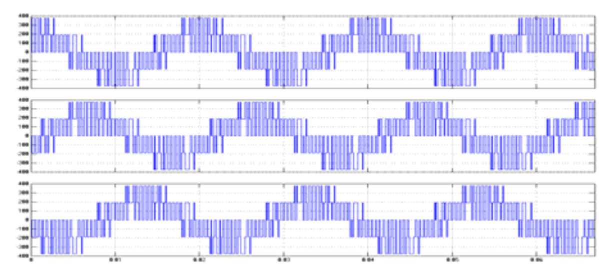


(b)

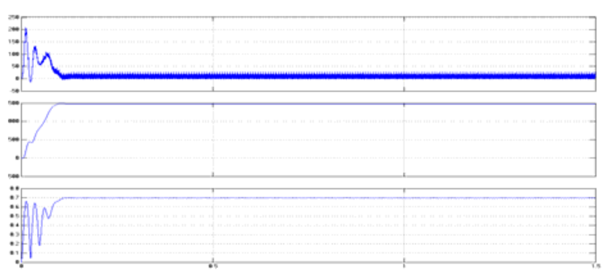
Fig.4. (a) Phase voltages Van,Vbn,Vcn using SPWM
(b) Torque developed, Speed (rpm), Flux

b) Open loop SVM

Fig.5a. show the output phase voltages of SVM inverter and Fig.5b shows torque developed, speed and flux of IM with open loop control. It can be observed that speed of the induction motor is increased with SVM for same D.C input voltage



(a)



(b)

Fig.5. (a) Phase Voltages Van,Vbn,Vcn using SVM
(b) Torque developed, Speed (rpm), Flux

d) Close loop SVM

Fig.6 & 7 shows the Ref speed, actual speed, torque developed and flux for closed loop control of SVM inverter fed IM.

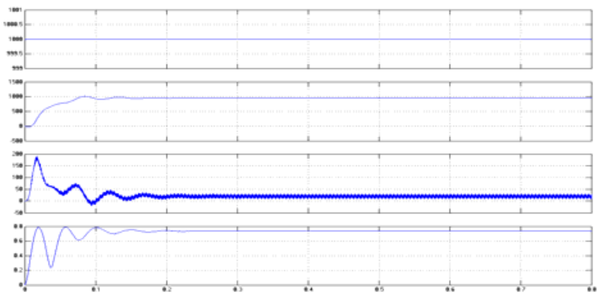


Fig.6. Ref Speed N*, Actual Speed N (rpm), Torque developed, Flux

e) Close loop SVM

Fig.7 shows the SIMULINK block diagram of closed loop speed control of SVM Inverter fed IM.

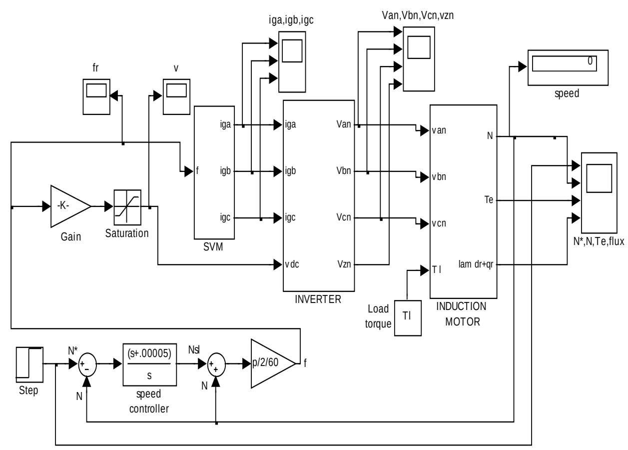


Fig.7. Simulation block diagram of closed loop SVM

f) Closed loop v/f control when the motor is accelerating

Fig. 9 &10 shows ref speed, actual speed, torque developed and flux for closed loop control of SVM inverter fed IM when motor is accelerating and decelerating respectively.

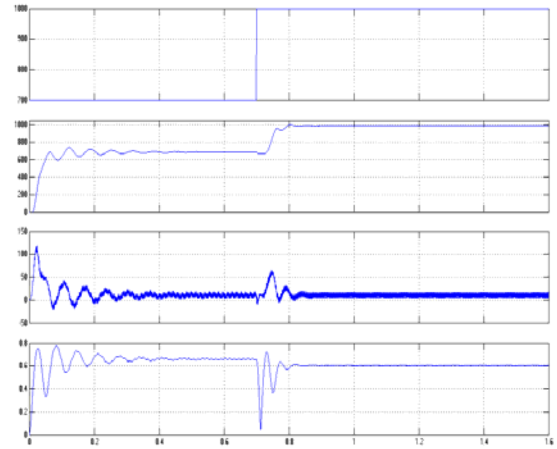


Fig.9. Ref Speed N*, Actual Speed N (rpm), Torque developed, Flux

g) Closed loop v/f control when the motor is decelerating

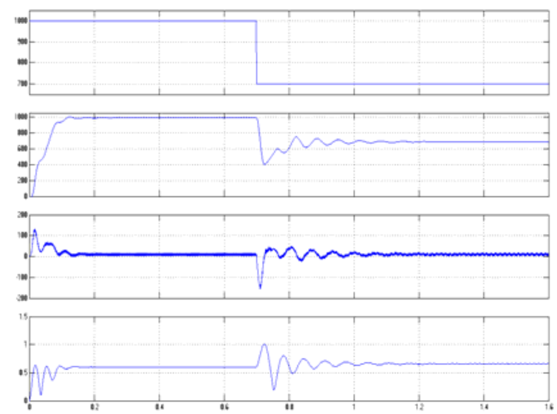
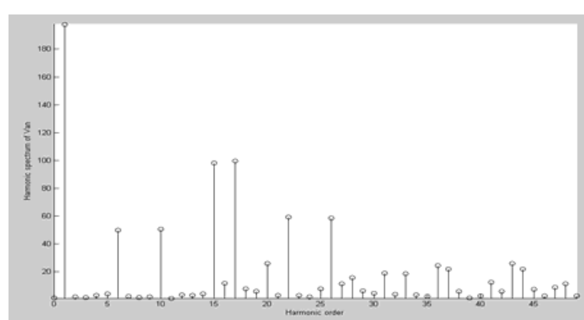


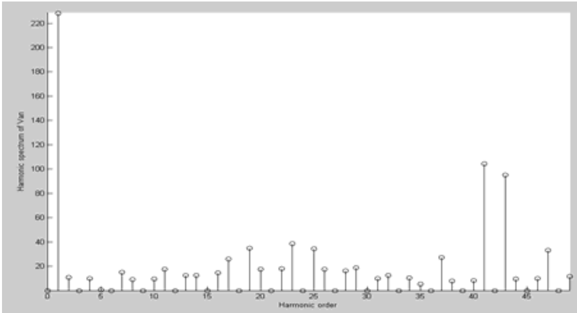
Fig.10. Ref Speed N*, Actual Speed N (rpm), Torque developed, Flux

h) Harmonic Spectrum

Fig 11a & 11b shows the harmonic spectrum of output phase voltages obtained using Fast Fourier Transform technique for SPWM and SVM inverter respectively. It can be observed that all the lower order harmonics are reduced for SVM when compared to SPWM.



(a)



(b)

Fig.11. (a) Harmonic Spectrum of Phase Voltages with SPWM
(b) Harmonic Spectrum of Phase Voltage with SVM

i) Comparison table of SPWM and SVM

Table-1 compares the various performance details of SPWM /SVM inverter fed IM. Input Dc voltage to inverter is 282.84BV.

TABLE-1

Control Strategy	R.M.S. Phase voltage	R.M.S. Line Voltage	Fundamental Phase Voltage	Fundamental Line Voltage	THD	Speed (RPM)
SPWM	203	352	197.6	342.3	1.80	1467
SVM	218	382	228.4	395.6	1.60	1475

VI. CONCLUSIONS

Simulation of space vector modulation (SVM) technique and sinusoidal PWM (SPWM) technique has been done using MATLAB. The v/f control of Induction motor drive for both open loop and closed loop system has been simulated. The transient behavior of the same motor operated with fixed supply voltage and no feedback control is compared with the closed loop control. It is observed that SVM generates less harmonics distortion in the output voltage and more efficient use of supply voltage in comparison with SPWM and hence Motor performance is improved.

REFERENCES

[1] Joohn-sheok Kim, seung-ki sul "A novel voltage Modulation Technique of the pace vector PWM", IPEC-Yokohama'95.

[2] S.R.Bowes,"New sinusoidal pulse width modulation inverter," Proc.Inst. Elect. Eng., vol. 122,pp. 1279-1285,1975.

[3] K.Zhou, D. Wang "Relationshi between Space Vector Modulation and three phase carrier-based PWM: Acomprehensive analysis," IEEE Trans. Ind. Elec. Vol. 49,pp 186-196.feb.2002

[4] D.C Lee.G-M.Lee," A Novel over modulation technique for space vector PWM inverters," IEEE Trans. 1997

[5] J.Holtz, "Pulse width modulation for electronic power conversion ", Proc.IEEE, vol.82,pp 1194- 1214, Aug. 1994.

[6] J.Holtz,"Pulsewidth modulation-a Survey," in Proc. IEEE PESC'92,1992, pp.11-18.

R.Linga Swamy obtained the B.Tech degree in Electrical and Electronics engineering from Gokaraju Rangaraju institute of Engineering and Technology, Hyderabad in 2002 and the M.Tech degree in power electronics and drives from NIT, Warangal in 2004. Presently he is working as an Assistant Professor in department of electrical engineering, University College of Engineering (Autonomous), Osmania University, Hyderabad, Andhra Pradesh, India.

P. Satish Kumar obtained the B.Tech degree in electrical and electronics engineering from JNTU College of Engineering, Kakinada, A.P., India in 1996 and the M.Tech degree in power electronics from JNTU College of Engineering, Hyderabad in 2003. He worked in various Private Engineering Colleges in Andhra Pradesh for more than 11 years as Associate Professor in the Department of Electrical and Electronics Engineering. Presently he is Assistant Professor in department of electrical engineering, University College of Engineering (Autonomous), Osmania University, Hyderabad, Andhra Pradesh, India