CHAPTER – 4

SPACE VECTOR MODULATION INDUCTION MOTOR DRIVE

4.1 INTRODUCTION

Like most motors, an AC induction motor has a fixed outer portion, called the stator and a rotor that spins inside with a carefully engineered air gap between the two. Virtually all electrical motors use magnetic field rotation to spin their rotors. A three-phase AC induction motor is the only type where the rotating magnetic field is created naturally in the stator because of the nature of the supply. DC motors depend either on mechanical or electronic commutation to create rotating magnetic fields.

There is no direct approach to have the controlled outputs from the commanded inputs. So it is necessary to generate equivalents of the inputs for the output control. This is achieved by three-phase to two-phase transformation where the output equivalent currents for flux and torque respectively are obtained. The per phase equivalent circuit of the machine, is valid only in steady state condition. In adjustable speed drives, the machine normally constituted as element within a feedback loop, and therefore its transient behavior has to be taken into consideration. Besides, high performance over control, such as space vector control is based on the dynamic d-q model of the machine. Therefore, we go for d-q model to understand space vector control principle. The machine model can be described by differential equations with time, requires mutual inductance: but such a model tends to be very complex.

4.2 SPACE VECTOR MODULATION

The block diagram of SVM inverter fed induction motor drive is shown in Fig 4.1. SVM compares a high frequency triangular waveform with modified waveform to generate pulses. Mathematical modeling can be implemented by the following steps.
Step 1: Determine $V_d$, $V_q$, $V_{ref}$ and angle ($\alpha$)

\[
V_d = V_{an} - v_{bn} \cos 60 - V_{cn} \cos 60 \\
= V_{an} - \frac{1}{2} V_{bn} - \frac{1}{2} V_{cn} \quad (4.1)
\]

\[
V_q = 0 + V_{bn} \cos 30 - V_{cn} \cos 30 \\
= 0 + \frac{\sqrt{3}}{2} V_{bn} - \frac{3}{2} V_{cn} \quad (4.2)
\]

Where $f$ = fundamental frequency.

\[
\therefore \begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ \sqrt{3} & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}
\]

\[
\therefore |V_{ref}| = \sqrt{V_d^2 + V_q^2}
\]

\[
\therefore \alpha = \tan^{-1} \left[ \frac{V_q}{V_d} \right] = \cot = 2\pi f t,
\]

Where $f$ = fundamental frequency.

Step 2: Determine time duration $T_1$, $T_2$, $T_0$
The switching time duration can be calculated as follows: Switching time duration at Sector 1

\[
\int_0^{T_z} \overline{V}_{\text{ref}} \, dt = \int_0^{T_z} \overline{V}_1 \, dt + \int_{T_1}^{T_1+T_2} \overline{V}_2 \, dt + \int_{T_1+T_2}^{T_z} \overline{V}_0 \, dt
\]

\[
T_z \cdot \overline{V}_{\text{ref}} = T_1 \overline{V}_1 + T_2 \overline{V}_2
\]

\[
T \cdot |V| \begin{bmatrix} \cos(\alpha) \\ \sin(\alpha) \end{bmatrix} = T_1 \cdot \frac{2}{3} V_{dc} \cdot \begin{bmatrix} 1 \\ 0 \end{bmatrix} + T_2 \cdot \frac{2}{3} V_{dc} \cdot \begin{bmatrix} \cos(\pi/3) \\ \sin(\pi/3) \end{bmatrix}
\]

\[
(\text{where } 0 \leq \alpha \leq 60)
\]

\[
\therefore T_1 = T_z \cdot \frac{\sin(\pi/3 - \alpha)}{\sin(\pi/3)} \quad \therefore T_2 = T_z \cdot a \cdot \frac{\sin(\alpha)}{\sin(\pi/3)} \quad \therefore T_0 = T_z - (T_1 + T_2)
\]

\[
\begin{cases}
\text{where } T_z = \frac{1}{f_s} \text{ and } a = \frac{|V|}{\frac{2}{3} V_{dc}}
\end{cases}
\]

**Step 3: Determine the switching time of each transistor (S_1 to S_6)**

The switching sequence is listed in Table 4.1.
Table 4.1 Switching sequence

The switching sequence tables for the lower and upper thyristors are shown above. The above construction of the symmetrical pulse pattern for two consecutive $T_z$ intervals are shown and $T_z = 2T_s = 1/f_s$ ($f_s$ = switching frequency) is the sampling time. Note that the null time has been conveniently distributed between $V_0$ and $V_7$ vectors to describe the symmetrical pulse width.
4.3 SIMULATION RESULTS

The induction motor drive system is simulated using matlab and the results are presented. From Fig 4.2 the angle $V_{d}, V_{q}, V_{ref}$ and ($\alpha$) can be calculated. From Fig 4.3 the switching time duration can be calculated. The simulink circuit diagram of SVM inverter is shown in Figure 4.4. Inverter circuit alone is shown in Figure 4.5. The details of SVM system is shown in Fig. 4.6. The driving pulses for the MOSFETs 1, 3 and 5 are shown in Fig 4.7. The phase voltages of the inverter are shown in Fig 4.8. They are displaced by 120deg and line voltages are shown in Fig 4.9. They are also displaced by 120deg. The line currents are shown in Fig 4.10.

The simulink diagram of SVM inverter fed induction motor is shown in Fig 4.11. The speed is indicated by using a display block. A scope is connected to display the driving pulses. The phase voltages are shown in Fig 4.12. The line currents are shown in Fig 4.13. The line currents are high at starting and they reduce to the steady state value. The response of the speed is shown in Fig 4.14. The speed settles at 1450 RPM. FFT analysis is done and the spectrum for the current is shown in Fig 4.15. The THD value is 5.6%.

![Fig. 4.4 SVM Based VSI Inverter with resistive load](image-url)
Fig. 4.5 Inverter circuit

Fig. 4.6 Block of SVM
Fig. 4.7 Driving Pulses for M₁, M₂ and M₃

Fig. 4.8 Phase Voltages
Fig. 4.9 Line voltages

Fig. 4.10 Line currents
Fig. 4.11 SVM Inverter fed induction motor Drive

Fig. 4.12 Phase Voltages

Fig. 4.12 Phase Voltages
Fig. 4.13 Line Currents

Fig. 4.14 Rotor speed in rpm.
4.4 COMPARISON OF SINE PWM and SVM CONTROLLED INDUCTION MOTOR DRIVE

The three phase induction motor, which is most widely used AC motor type in the industry, has been favoured because of its self starting capability, simple & rugged structure, low cost, less weight per watt, high reliability and high efficiency. Along with variable frequency AC inverters induction motors are used in many adjustable speed applications, which do not require fast dynamic response. There are many possible PWM techniques like sinusoidal PWM, selected harmonic elimination PWM, space vector PWM etc used for speed control of induction motor. The concept of space vector PWM control has opened a new possibility that induction motors can be controlled to achieve dynamic performance as good as that of DC motors. In sine PWM Inverter the widths of the pole voltage pulses over the output cycle, vary in a sinusoidal manner. By comparing the output, SVPWM is superior as compared to sinusoidal PWM in many aspects like; 1) the modulation index is higher for SVPWM as compared to sinusoidal PWM. 2) The output voltage is about 15% more in case of SVPWM as compared to sinusoidal PWM. 3) The current & torque harmonics produced are much less in the case of SVPWM.
4.4.1 SINE PULSE WIDTH MODULATION

The PWM inverters are very commonly used in adjustable AC motor drive loads, where one needs to feed the motor with variable voltage variable supply frequency. For wide variation in drive speed, the frequency of the applied AC voltage needs to be varied over a wide range. The applied voltage also needs to vary almost linearly with the frequency. The switches of the PWM inverters are turned on and off at significant higher frequencies than the fundamental frequency of the output voltage waveform.

In sine PWM Inverter, the width of the pole voltage pulses over the output cycle, vary in a sinusoidal manner. The scheme, in its simplified form, involves comparison of a high frequency triangular carrier voltage with a sinusoidal modulating signal that represents the desired fundamental component of the pole voltage waveform. The peak magnitude of the modulating signal should remain limited to the peak magnitude of the carrier signal. The comparator output is then used to control the high side and low side switches of the particular pole. Some of the following constraints for slow varying sinusoidal voltage to be considered as the modulating signal are 1) the peak magnitude of the sinusoidal signal is less than or equal to the peak magnitude of the carrier signal. This ensures that the instantaneous magnitude of the modulating signal never exceeds the peak magnitude of the carrier signal. 2) The frequency of the modulating signal is several orders lower than the frequency of the carrier signal. A typical figure will be 50 Hz for the modulating signal and 20 KHZ for the carrier signal. Under such high frequency ratios the magnitude of the modulating signal will be virtually constant over any particular carrier signal time period. 3) A three phase sine-PWM inverter would require a balanced set of three sinusoidal modulating signals along with a triangular carrier signal of high frequency. For a variable voltage- variable frequency (VVVF) type inverter, a typical requirement for adjustable speed drives of AC motor, the magnitude as well as frequency of the fundamental component of the inverters output voltage needs to be controlled. This calls for generation of three phase balanced modulating signals of variable magnitude voltage and frequency which may be emphasized, and need to have identical magnitudes and phase difference of 120 degrees between them at all operation frequencies.
Generating a balanced three phase sinusoidal wave forms of controllable magnitude and frequency is a pretty difficult task for an analog circuit and hence a mixed analog and digital circuits are often preferred.

4.4.2 SPACE VECTOR MODULATION

SVM is a digital modulating technique, where the objective is to generate PWM load line voltages that are in average equal to a given load line voltage. This is done in each sampling period by properly selecting the switch states of the inverter and the calculation of the appropriate time period for each state. The SVM for a three-leg voltage source inverter is obtained by sampling the reference vector at the fixed clock frequency $2f_s$. All the eight possible switching combinations of the switching network are mapped into an orthogonal plane. The results are six non-zero vectors and two zero vectors.

The block diagram of SVM inverter fed induction motor drive is shown in Fig4.4.2a. SVM compares a high frequency triangular waveform with modified waveform to generate pulses.

![Block diagram of SVM fed induction motor drive](image)

Fig. 4.16 Block diagram of SVM fed induction motor drive

4.5 SIMULATION RESULTS

4.5.1 SINE PWM BASED VSI INVERTER FED INDUCTION MOTOR DRIVE.

Induction motor drive is modeled and simulated using matlab simulink. Sine PWM based VSI fed induction motor drive is shown in Fig4.17. Sine PWM generation block is
shown in Fig 4.18. Pulses are generated by comparing sine wave with high frequency triangular wave. Driving pulses are shown in Fig 4.19. Phase voltages are shown in Fig 4.20. The line currents are shown in Fig 4.21. Speed response is shown in Fig 4.22. The speed increases and settles at 1480 RPM. FFT analysis for current is done and the spectrum is shown in Fig 4.23. The THD is 6.01%.

Fig 4.17 VSI fed Induction Motor Drive

Fig 4.18 Sine PWM pulse Generation block
Fig. 4.19 Driving pulses

Fig. 4.20 Phase voltages
Fig 4.21 Line currents

Fig 4.22 Rotor speed in RPM
Fig4.23 FFT analysis for current

Table 4.2 Comparison of Sine PWM and SVM

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>SINE PWM</th>
<th>SVM</th>
</tr>
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<tbody>
<tr>
<td>INPUT VOLTAGE (V)</td>
<td>230</td>
<td>230</td>
</tr>
<tr>
<td>PHASE VOLTAGE (V)</td>
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<td>229</td>
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<tr>
<td>SPEED (RPM)</td>
<td>1469</td>
<td>1480</td>
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<tr>
<td>THD %</td>
<td>6.01</td>
<td>3.87</td>
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</table>

4.6 CONCLUSION

SVM inverter fed induction motor drive is modeled and simulated successfully using matlab simulink & the results are presented. The FFT analysis shows that the current spectrum has reduced harmonics compared to the conventional system. The present work indicates that SVM inverter fed induction motor drive is an economical drive with reduced harmonics. The simulation results are in line with the predictions.