Speed Control of an Induction Motor Fed by an Inverter Using dSPACE Controller

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Abstract. This paper presents the design and implementation of Inverter system for driving three phase Induction motor using DS1104 controller with the controlling objective space vector pulse width modulation (SVPWM) technique. AC motor drives are commonly used over DC motor drives because of their more advantages. Induction motor is the most commonly used AC motor drive for various industrial and domestic applications. The project will be commenced by a basic understanding of SVPWM inverter, components used in the design and study the mathematical equations of the Induction motor. The performance of SVPWM based Induction motor (IM) in open loop is presented with simulation. Here the hardware implementation of the three phase inverter which is fed to a three phase induction motor driven by DS1104 is been implemented.

1 Introduction

AC motor drives are commonly used over DC motor drives because of their more advantages. Induction motor is the most commonly used AC motor drive for various industrial and domestic applications. Generally Pulse Width Modulation (PWM) technique is used for driving a motor drive. In this paper design of variable speed induction motor drive using Space Vector Pulse Width Modulation (SVPWM) inverter is explained. PWM signals are generated using a DSPACE Controller.

1.1 Open loop Block diagram

Block diagram of single phase or three phase induction motor drive fed by an inverter driving in open loop is given below.

![Fig. 1. Open Loop Block Diagram](image)

2 Inverter

Depending on the supply inverters are classified in to two types. They are

- Single-phase Inverter
- Three-phase Inverter

2.1 Space vector pulse width modulation

Space vector pulse width modulation (SVPWM) is a pulse width modulation (PWM) technique which is used to apply to a three phase induction motor. The main objective of this technique is to use a dc voltage source and by means of six IGBT switches produce a three phase sine waveform in which frequency and amplitude is adjustable.

To implement space vector pulse width modulation, the voltages equations in abc reference frame can be transformed in to the stationary d-q reference frame that consists of horizontal and vertical axis.
In space vector pulse width modulation six non-zero vectors (V1, V2, V3, V4, V5, V6) and two zero vectors (V0, V7) are formed. These are called the space vectors. The objective of space vector pulse width modulation technique is to approximate the reference voltage vector Vref using the eight switching patterns.

**Fig. 2. Transformation of three axis to two axis reference frame**

\[
\begin{align*}
V_d &= V_{an} - \frac{V_{bn}}{2}\cos(60) - \frac{V_{cn}}{2}\cos(60) \\
&= V_{an} - \frac{1}{2}V_{bn} - \frac{1}{2}V_{cn} \\
V_q &= 0 + \frac{V_{bn}}{2}\cos(30) - \frac{V_{cn}}{2}\cos(30) \\
&= 0 - \frac{\sqrt{3}}{2}V_{bn} - \frac{\sqrt{3}}{2}V_{cn}
\end{align*}
\]

\[
\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}
\]

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

\[
\alpha = \tan^{-1}\left(\frac{V_q}{V_d}\right) = \omega t = 2\pi f t
\]

Where f = fundamental frequency

**Fig. 3. Basic switching vectors and sectors**

Therefore, space vector pulse width modulation can be implemented by the following steps:

**Step 1. Determine Vd, Vq, Vref, and angle (\(\alpha\))**

Step 2. Determine time duration T1, T2, T0

Step 3. Determine the switching time of each transistor (S1 to S6)

**Step 1: Determine the Vd, Vq, Vref, and an angle (\(\alpha\))**

From figure 4, the Vd, Vq, Vref, and angle (\(\alpha\)) can be determined as follows:

\[
V_d = V_{an} - V_{bn}\cos(60) - V_{cn}\cos(60)
\]

\[
V_q = 0 + V_{bn}\cos(30) - V_{cn}\cos(30)
\]

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

\[
\alpha = \tan^{-1}\left(\frac{V_q}{V_d}\right) = \omega t = 2\pi f t
\]

Where f = fundamental frequency

**Fig. 4. Voltage Space Vectors and its components in d-q axis**

**Step 2: Determine time duration of T1, T2, T0**

From figure 5, the switching time duration can be calculated as follows:

Switching time duration at Sector 1

\[
T_z = T_1 + T_2 + T_3
\]

\[
V_{ref} = V_1 + V_2 + V_3
\]

\[
T_z \left[ \begin{array}{c} V_{ref} \\ \cos(\alpha) \\ \sin(\alpha) \end{array} \right] = T_1 \left[ \begin{array}{c} 1 \\ -\frac{2}{3} V_d \cos(60) \\ 0 \end{array} \right] + T_2 \left[ \begin{array}{c} 1 \\ -\frac{2}{3} V_d \cos(30) \\ 0 \end{array} \right] + T_3 \left[ \begin{array}{c} 1 \\ -\frac{2}{3} V_d \cos(0) \\ 0 \end{array} \right]
\]

(Where, 0 \(\leq\) \(\alpha\) \(\leq\) 60)

\[
T_1 = T_z \frac{\sin(\pi/3 - \alpha)}{\sin(\pi/3)}
\]

\[
T_2 = T_z \frac{\sin(\pi/3)}{\sin(\pi/3)}
\]

\[
T_3 = T_z \frac{V_d}{V_d}
\]
Step 3: Determine the switching time of each transistor (S1 to S6)

Table 1. Switching time at each sector

| Sector | Upper Switches (S1, S3, S5) | Lower Switches (S4, S6, S2) |
|--------|-----------------------------|-----------------------------|
| 1      | S1=T1+T2+T0/2/S3=T2+T0/2/S5=T0/2 | S4=T0/2/S6=T1+T0/2/S2=T1+T2+T0/2 |
| 2      | S1=T1+T0/2/S3=T1+T2+T0/2/S5=T0/2 | S4=T2+T0/2/S6=T0/2/S2=T1+T0/2 |
| 3      | S1=T0/2/S3=T1+T2+T0/2/S5=T2+T0/2 | S4=T1+T2+T0/2/S6=T0/2/S2=T1+T0/2 |

3 Induction motor

An Induction motor works on the principle of Electro Magnetic Induction (EMI). Stator and rotor are the two parts of induction motor which are separated by an air gap. When a three phase supply is given to an induction motor, it produces a constant amplitude and rotating magnetic field (RMF). This field cuts the rotor conductor and induces an Electro Magnetic Force (emf) which drives current in short circuited rotor conductor.

3.1 Dynamic Modelling of Induction Motor

Dynamic model of an induction motor can be obtained from two-axis theory of electrical machines. The following assumptions are made for dynamic model of induction motor.

1. Space harmonics are negligible.
2. The slotting in stator and rotor produces negligible variations in respective inductances.
3. Mutual Inductances are equal.
4. Voltage and Current harmonics are neglected.
5. Saturation, hysteresis and eddy current losses are negligible.

![Fig.5. Reference vector from combination of adjacent vectors](image_url)

![Fig.6. Two axis representation of IM](image_url)
Through the above analysis speed, torque of an Induction Motor can be controlled by voltage current parameters.

4 Simulation

Matlab is an interactive software program for numerical computations and graphics. In this paper three phase SVPWM inverter is explained in open loop.

Open loop three phase inverter:

$$V_{ds} = P(L_{d}d'_{q}q_{s}) + R_{d}d_{s} + P(L_{d}d'd_{s}) + P(L_{d}d'd_{d}) + P(L_{d}d'b_{d})$$

$$V_{a} = P(L_{a}q_{i}s) + P(L_{a}q_{i}d_{s}) + R_{a}i_{a}$$

$$V_{p} = P(L_{p}q_{i}s) + P(L_{p}q_{i}d_{s}) + P(L_{p}i_{p})$$

$$L_{a}a_{a} = L_{p}d_{p} = L_{q}d_{r}$$

$$L_{d}d_{r} = L_{q}d_{q} = 0$$

$$L_{d}d_{q} = L_{q}d_{q} = 0$$

$$L_{q}d_{q} = L_{q}d_{q} = 0$$

With respect to the fictitious rotor

$$i_{a} = i_{dr} \cos \theta_{r} + i_{qr} \sin \theta_{r}$$

$$i_{p} = i_{dr} \sin \theta_{r} + i_{qr} \cos \theta_{r}$$

With respect to the arbitrary reference frame

$$i_{ds} = i_{dr} \cos \theta_{e} - i_{qr} \sin \theta_{e}$$

$$i_{qs} = i_{dr} \sin \theta_{e} + i_{qr} \cos \theta_{e}$$

Torque:

$$V = [R]i + [L]i + [G]c$$

$$i^{T}[R]i = i^{T}[L]i + i^{T}[G]c$$

where $i$ is the current vector and $V$ is the voltage vector.

$$i^{T}[L]i = \frac{i^{T}[G]c}{2}$$

Air gap power = Mech Rot speed x Air gap

$$w_{a}T_{e} = P_{a} = i^{T}[G]c$$

$$T_{e} = \frac{P}{2}i^{T}[G]$$

$$[G] = i^{T}$$

$$i^{T}[G] = L_{m}i_{dr}c_{dr} - i_{ds}c_{qr}$$

$$T_{e} = \frac{3}{2} P \frac{E_{m}}{2} \left( i_{dr}c_{dr} - i_{ds}c_{qr} \right)$$

$$T_{e} = \frac{3}{2} P \frac{L_{m}}{2} \left( i_{dr}c_{dr} - i_{ds}c_{qr} \right)$$

$$T_{e} = \frac{3}{2} \frac{P}{w_{b}} \left( \psi_{ds}^{c} i_{qs} - \psi_{qs}^{c} i_{ds} \right)$$

Fig.7. Simulink of three phase inverter driving IM in open loop

Fig.8. Gate pulses

Fig.9. Output phase Voltages
5 DSPACE DS1104 Controller

The hardware unit comprises of the DSPACE unit installed to a desktop where in the MATLAB files can be interfaced through the DSPACE package software. Three phase Inverter is been designed with an isolation circuit to protect the controller board from the sudden voltage fluctuations feeding back to the controller board. Pulses from the controller board reaches the switches through the isolation circuit through opto-couplers EL817, pulses passes through the EL817 by light manner.

Inverter feeds the induction motor. And it is well suited for drive control. DSPACE unit operates for 250MHz and the pulse width generated is of 2k frequency. DSPACE unit comprises of 8 analog and 8 digital pins. 20 input and output signals can be interchanged randomly. Input to the Inverter unit is 440volts where the output of the Inverter received is 400 Volts 2 A

6 Experimentation Results
inverter fed induction motor in open loop operation is explained and its respective output waveforms are shown.

**References**

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**Fig.17. Output Voltage of Inverter**

**Fig.18. Speed of Induction motor**

**Practical Results:**

**Table 2. Output Voltage and Speed**

| S.N O | DC InputVoltage (V) | Modulation Index | AC Output Voltage (V) | Speed (rpm) |
|------|---------------------|------------------|-----------------------|-------------|
| 1    | 330                 | 0.8              | 164.6                 | 1128        |
| 2    | 330                 | 0.85             | 164.0                 | 1189        |
| 3    | 330                 | 0.9              | 163.5                 | 1250        |
| 4    | 330                 | 0.95             | 162.1                 | 1309        |
| 5    | 330                 | 1.0              | 162.0                 | 1410        |
| 6    | 330                 | 1.1              | 161.9                 | 1427        |

By varying the width of the PWM pulse in slider control display of the DSPACE desk speed of induction motor is varying accordingly.

**7 Conclusion**

In this paper, Induction motor speed drive is designed using DSPACE DS1104 Controller. Speed, output voltage and current of induction motor at different duty cycles are obtained. The pulse width modulation (PWM) technique used here is space vector pulse width modulation (SVPWM). Simulation of three phase