3-Phase Induction Motor Control using Space Vector and Sinusoidal Pulse Width Modulation Technique

Pragya Sinha, Kaza Mrudula, Puneet Singh, Subramanian K.

Abstract: This paper deals with the control of the induction motor using two different control methods: Space Vector and Sine wave pulse width modulation technique. The objective of the project is to find the most appropriate technique for induction motor control for industrial application. The scalar v/f method offers good performance only in the course of the steady-state and not under transient conditions. This important downside may be rectified by the vector control technique. The method provides high dynamic performance for velocity and torque-controlled AC machines.

Keywords: SVPWM, SPWM, Total Harmonic Distortion, Induction Motor, 3 Phase Inverter, Modulation technique

I. INTRODUCTION

With the three-phase Induction motor being one of the most widely used type of motor in the industry, the need for a better and more efficient control techniques is apparent. Simplifying three phase quantities like flux, current field into two-phase like in reference to arbitrary reference frame theory [1], Sinusoidal Pulse Width Modulation and Space Vector Pulse Width Modulation are both evolutions of PWM techniques that offer lower harmonic distortion [2], better power factor etc. Conventionally a Sinusoidal Pulse Width Modulation (SPWM) technique is used but Space Vector Pulse Width modulation (SVPWM) is an up and coming, more efficient technique as understood in this paper. It is because of its characteristics like better power factor and higher efficiency. Also, the Total Harmonic Distortion (THD) is considerably lower in the case of SVPWM. The current components are divided into a torque controlled current component \( i_{qs} \) and flux controlled current component \( i_{ds} \)[3]. Hence, when flux is controlled using the \( i_{ds} \) component, the torque remains constant, which results in a faster transient response [4]. The effectiveness of SVPWM is compared against SPWM using MATLAB/Simulink. The results are compared for the percentage of total harmonic distortion of SVPWM against SPWM with the same motor specifications considered in both the simulations [5][6]. The speed control was carried out on the Induction motor block available in the MATLAB.

II. SVPWM Technique

To derive a MATLAB/Simulink Model for a three-phase Induction Motor using Space Vector Pulse Width Modulation Technique following block diagram is followed.

Fig 1: Block diagram to implement induction motor control using SVPWM

A. MATHEMATICAL MODEL

An analytical approach was taken to derive the Mathematical model for a three phase Induction Motor [7]. The following assumptions were made before deriving the Mathematical Model:

- The air gap is uniform
- Squirrel cage rotor construction
- Balanced stator and rotor windings, and sinusoidal winding distribution
- Change of parameters and saturation are neglected.

The mathematical model of our IM is modeled by space vector phase theory of electrical machines.

Steps involved in the mathematical modeling:

i. Find d-q voltage \( (V_d, V_q) \) and \( V_{ref} \) with the corresponding angle.
ii. Find the time duration \( T_1, T_2 \) and \( T_0 \) and switching state.
iii. Sector judgment and calculation.

3-PHASE VOLTAGE CALCULATION

\[ V_r = \sqrt{2} \cdot V_{rms} \sin(\omega t - \frac{2\pi}{3}) = 325.25 \ldots (1) \]

\[ V_b = \sqrt{2} \cdot V_{rms} \sin(\omega t - \frac{2\pi}{3}) = 325.25 \ldots (2) \]

\[ V_c = \sqrt{2} \cdot V_{rms} \sin(\omega t - \frac{4\pi}{3}) = 563.35 \ldots (3) \]
\( \alpha-\beta \) CALCULATION:

\[
V_\alpha = \frac{2}{3}(V_a + 1/2*V_b - 1/2*V_c) = 137.46 \quad \ldots \ldots (4)
\]

\[
V_\beta = \frac{2}{3}(\sqrt{3}/2*V_b - \sqrt{3}/2*V_a) = -507.90 \quad \ldots \ldots (5)
\]

\( d-q \) CALCULATION:

The \( d-q \) dynamic model has been modeled using Park’s transformation,

\[
V_d = V_a - V_b \cos 60 - V_c \cos 60 \quad \ldots \ldots (6)
\]

\[
V_q = V_b \cos 30 - V_c \cos 30, \quad \ldots \ldots (7)
\]

Or

\[
V_d = V_c \cos \theta + V_b \sin \theta = 507.90 \quad \ldots \ldots (8)
\]

\[
V_q = -V_a \sin \theta + V_b \cos \theta = -137.46 \quad \ldots \ldots (9)
\]

\[
V_{ref} = \sqrt{V_d^2 + V_q^2} = 526.17
\]

ANGLE CALCULATION:

\[
\alpha = \tan^{-1}(V_q/V_d) = 15.14
\]

Fundamental frequency = 60 Hz

SWITCHING STATE AND VECTOR DETERMINATION:

The \( d-q \) dynamic model has been modeled using Park’s transformation,

\[
V_d = V_a - V_b \cos 60 - V_c \cos 60 \quad \ldots \ldots (6)
\]

\[
V_q = V_b \cos 30 - V_c \cos 30, \quad \ldots \ldots (7)
\]

Or

\[
V_d = V_c \cos \theta + V_b \sin \theta = 507.90 \quad \ldots \ldots (8)
\]

\[
V_q = -V_a \sin \theta + V_b \cos \theta = -137.46 \quad \ldots \ldots (9)
\]

\[
V_{ref} = \sqrt{V_d^2 + V_q^2} = 526.17
\]

Fig 2: Space Vector Voltage and its components in \( d-q \) axis

Fig 3: Space vector sector specification

Sector determination can be done through the following flowchart:

Fig 4: Flowchart to determine the sector

According to the calculation, our space vector is in \( \text{sector 4} \).

Table 1: Switching state and Voltage
Time duration Calculation:

\[ T_z V_{ref} = \int_0^{T_4} V_4 \, dt + \int_{T_4}^{T_4+T_5} V_5 \, dt + \int_{T_4+T_5}^{T_6} V_0 \, dt \]  

\[ T_z = \frac{1}{f} = 16.6 \text{ ms} \]

\[ T_5 = \sqrt{3} T_z \left| V_{ref} \right| \left( -\cos \alpha \sin \pi + \sin \alpha \cos \pi \right) / V_{dc} \]  

\[ T_4 = \sqrt{3} T_z \left| V_{ref} \right| \left( -\cos \alpha \sin 4\pi / 3 - \sin \alpha \cos 4\pi / 3 \right) / V_{dc} \]  

\[ T_0 = T_z + T_4 + T_5 = 43.45 \text{ ms} \]

B. SIMULATION MODEL

The suggested system consists of three main segments:

i. The load

ii. The control scheme

iii. Phase inverter

The model has many more additions than just the Vector Control system. Current feedback and speed feedback has been implemented with the help of goto blocks which are redirected inside of the vector control blocks. The speed control is adjusted mid simulation with the help of a step function. In this control scheme the angles \( \theta_{alpha} \) and \( \theta_{beta} \) are calculated with the help of ordinary PID controllers with modified values and parameters. Torque and flux are independently controlled, whereas speed and currents are observed in a closed loop. The controllers are ordinary PID controllers with modified values and parameters.

III. SPWM technique

Sinusoidal pulse width modulation a digital waveform is produced and the duty cycle is modulated such that the average voltage of the waveform corresponds to a pure sine wave. SPWM moves the voltage harmonics components to the higher frequencies. The following simulation is conducted at a modulation index of the SPWM at \( m = 0.9 \).
IV. Result and Discussion

**Output Graph of SPWM Model:**

It can be observed from the graph that $V_{rms} = 267.1$ V and $I_{rms} = 125.2$ A.

As can be seen in the graph, speed increases from 0 to 188wm in 1.54 second. As the rotor speed increases, the electromagnetic torque increases till the speed reaches 135wm and then starts decreasing as the speed reaches its maximum value of 188wm, reaching 0 around the same mark as the speed approaches 188wm at 1.54s.

**Output Graph of SVPWM Model:**

It can be observed from the graph that $V_{rms}$ is 311 V and $I_{rms}$ is 125.8 A.

As can be seen in the graph, speed increases from 0-188wm in 1.15
second. As the rotor speed increases, the electromagnetic torque increases till the speed reaches 135\text{rpm} and then starts decreasing as the speed reaches its maximum value of 188\text{rpm}, reaching 0 around the same mark as the speed approaches 188\text{rpm} at 1.15s.

### A. FFT Analysis

#### FFT analysis of SVPWM Model:

![FFT analysis of SVPWM Model](image1)

**Fig 10:** FFT analysis of (a) Voltage signal, (b) Current Signal, (c) Electromagnetic torque signal, SVPWM

#### FFT analysis of SPWM Model:

![FFT analysis of SPWM Model](image2)

**Fig 11:** FFT analysis of (a) Voltage signal, (b) Current Signal, (c) Electromagnetic torque signal, SPWM

### B. COMPARISON OF TOTAL HARMONIC DISTORTION (THD) in %

After carefully study of FFT analysis of various signals we came to the following conclusion:

<table>
<thead>
<tr>
<th></th>
<th>SPWM</th>
<th>SVPWM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>20.78</td>
<td>19.57</td>
</tr>
<tr>
<td>Voltage</td>
<td>8.74</td>
<td>8.01</td>
</tr>
<tr>
<td>Electromagnetic Torque</td>
<td>11.72</td>
<td>11.17</td>
</tr>
</tbody>
</table>
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C. COMPARISON OF MODULATION INDEX OF INVERTER

From FFT analysis, the following data was obtained about the modulation of SPWM and SVPWM inverter:

\[ \text{SPWM} = 0.823 \quad \text{SVPWM} = 0.958 \]

\[ \text{TORQUE} \]
\[ \text{CURRENT} \]
\[ \text{VOLTAGE} \]

Fig 12: THD Comparison graph

Fig 13: Comparison graph on the basis of modulation index

CONCLUSION

After the comparative evaluation of Space Vector PWM with existing SPWM for Inverter fed IM it can be said that SVPWM has better control approach. The simulation outcomes with THD obtained from the FFT analysis of the output signal were contrasted in the previous segment. After careful study of FFT graphs, it can be seen that SVPWM offers 14.4% improved output. Also, SVPWM method overcomes the major drawback of conventional SPWM in order to control an induction motor is that it has high-harmonic distortion owing to irregular nature of the PWM switching characteristics. In our result it can also be seen that MOSFET provides faster switching speed than IGBT and reduce the cost of the design for medium voltage input devices. SVPWM offers better end result at the inverter output in terms of lesser THD in voltage, current, and electromagnetic torque compared to SPWM. Hence, SVPWM provides a better fundamental output voltage.

References:


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Pragya Sinha received her Bachelor’s degree in Electrical and Electronics Engineering in Vellore Institute of Technology, Vellore, India in 2019. Her research interests include Power Transmission, High Voltage Engineering, Big Data.She is keen to learn new technologies and has published paper in Power Electronics, Electronics Converter, Sg technologies and Image processing.

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