International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 13 Issue 4 ǁ April 2025 ǁ PP. 16-19

Enhancing Three-Phase Induction Motor Speed Control Using Space Vector Pwm

Rajendra Kumar[1] Mithilesh Singh[2] Kirti Jain[3]
PG student Department of Electrical Engineering, Shri Rawatpura Sarkar University, Raipur[1]
Professor Department of Electrical Engineering, Shri Rawatpura Sarkar University, Raipur[2]
Asst. Professor Department of Electrical Engineering, Shri Rawatpura Sarkar University, Raipr[3]

Abstract
This paper presents an advanced approach to enhancing the speed control of a three-phase induction motor (IM) using ***Space Vector Pulse Width Modulation (SVPWM)****. The SVPWM technique optimizes the voltage utilization of the inverter, reducing harmonic distortion and improving efficiency compared to conventional PWM methods. The proposed system integrates* ***vector control*** *with SVPWM to achieve precise speed regulation and dynamic performance under varying load conditions. Simulation and experimental results demonstrate improved* ***torque response****, lower* ***total harmonic distortion (THD)****, and better efficiency, making it a viable solution for industrial motor drive applications.*

Keywords: *Three-phase induction motor, Space Vector PWM, speed control, vector control, total harmonic distortion, inverter, torque response.*

Date of Submission: 27-03-2025 Date of acceptance: 07-04-2025

I. INTRODUCTION

Three-phase induction motors (IMs) are widely used in industrial applications due to their robustness, reliability, and cost-effectiveness. However, precise speed control remains a critical challenge, especially in dynamic and high-performance environments. Traditional control methods, such as scalar control and sinusoidal PWM, suffer from limitations such as poor dynamic response, increased harmonic distortion, and lower efficiency.

To address these issues, **Space Vector Pulse Width Modulation (SVPWM)** has emerged as an advanced modulation technique that optimally utilizes the DC bus voltage, reduces total harmonic distortion (THD), and enhances the overall performance of the motor drive system. When integrated with **vector control**, SVPWM enables precise torque and speed regulation by efficiently controlling the voltage and frequency applied to the motor.

This paper explores the implementation of SVPWM for improving the speed control of three-phase induction motors. The proposed approach enhances dynamic response, reduces switching losses, and improves motor efficiency, making it suitable for high-performance industrial applications. Simulation and experimental results validate the effectiveness of this method in achieving superior motor performance compared to conventional PWM techniques.

II. PRINCIPLE OF SPACE VECTOR PULSE WIDTH MODULATION

Principle of SVPWM

SVPWM is based on the representation of three-phase voltages as a space vector in a two-dimensional plane (α-β plane). The main idea is to approximate a rotating reference voltage vector using discrete switching states of the inverter.

Space Vector Representation A three-phase voltage system (Va, Vb, Vc) is transformed into an equivalent space vector using Clarke’s transformation:

$$V_\alpha = V_a - \frac{V_b + V_c}{2}$$

$$V_\beta = \frac{\sqrt{3}}{2}(V_b - V_c)$$

These vectors are plotted in a hexagonal structure divided into six sectors.

Inverter Switching States

- A three-phase inverter has eight possible switching states (000 to 111), out of which six produce active voltage vectors, and two (000 and 111) are zero vectors.
- The goal is to approximate the reference vector (V_{ref}) using a combination of these vectors.

Sector Identification

- The reference vector (V_{ref}) is located within one of the six sectors.
- The two adjacent active vectors and zero vectors are used to synthesize (V_{ref}) by controlling the switching time of each state.

Time Calculation for Switching

- The dwell times for the two active vectors (T1 and T2) are calculated using:

$$T1 = \frac{T_s}{V_{dc}} |V_{ref}| \cos(\pi/3 - \theta)$$

$$T2 = \frac{T_s}{V_{dc}} |V_{ref}| \sin(\pi/3 - \theta)$$

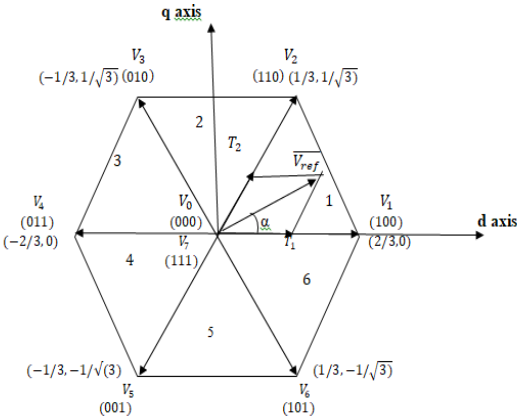


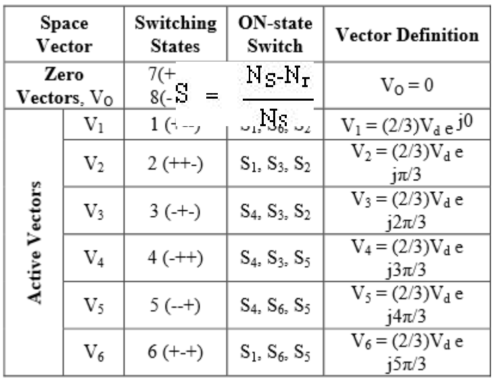
Figure1.1: Space Vector Diagram

Switching Sequence

- The optimal switching sequence minimizes switching losses and ensures smooth voltage transitions.

Table -1: Space Vector **Switching States**

III.THREE PHASE INDUCTION MOTOR



Space Vector		**Switching States**	**ON-state Switch**	**Vector Definition**
Zero Vectors, V_O		7(+ 8(-	[illegible]	$V_O = 0$
Active Vectors	V_1	1 (+--)	S_1, S_6, S_2	$V_1 = (2/3)V_d e^{j0}$
	V_2	2 (++-)	S_1, S_3, S_2	$V_2 = (2/3)V_d e^{j\pi/3}$
	V_3	3 (-+-)	S_4, S_3, S_2	$V_3 = (2/3)V_d e^{j2\pi/3}$
	V_4	4 (-++)	S_4, S_3, S_5	$V_4 = (2/3)V_d e^{j3\pi/3}$
	V_5	5 (--+)	S_4, S_6, S_5	$V_5 = (2/3)V_d e^{j4\pi/3}$
	V_6	6 (+-+)	S_1, S_6, S_5	$V_6 = (2/3)V_d e^{j5\pi/3}$

The relationship between synchronous speed, rotor speed and the slip is given by

$$S = \frac{N_s - N_r}{N_s}$$

Or, $Nr = Ns (1-S)$

□ Rotor speed $N_r = 120f/P(1-s)$

Thus, the speed of an induction motor depends on slip S, frequency of the stator supply f and the number of poles for which the windings are wound. The ability of varying any one of the above three quantities will provide methods of speed control of an induction motor. Constant V/F method is commonly used for constant and variable speed control of induction motor. The torque developed by the motor is directly proportional to the magnetic field produced by the stator. So, the voltage applied to the stator is directly proportional to the product of stator flux and angular velocity. This makes the flux produced by the stator proportional to the ratio of applied voltage and frequency of supply. Therefore, by varying the voltage and frequency by the same ratio, the torque can be kept constant throughout the speed range. The below relations justify the above explanation.

This makes constant V/F is the most common speed control of an induction motor. The torque developed by the induction motor is directly proportional to the V/F ratio. If we vary the voltage and frequency, keeping their ratio constant, then the torque produced by induction motor will remain constant for all the speed range. Since the torque developed by the induction motor is directly proportional to the V/F ratio will not remain constant throughout the speed.

$$\text{Stator Voltage (V)} \propto [\text{Stator Flux}(\phi)] \times [\text{Angular Velocity }(\omega)]$$

$$V \propto \phi \times 2\pi f$$

$$\phi \propto V/f$$

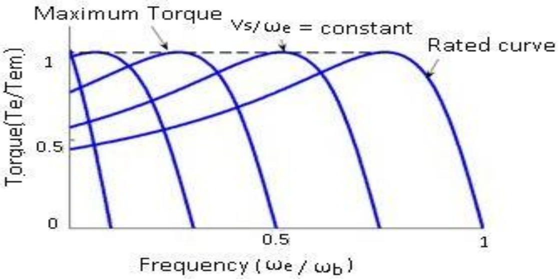


Figure 3.1 Torque-speed characteristics of the induction motor

Other than the variation in speed, the torque-speed characteristics of the V/F control reveal the following:

1) The starting current is low.

2) The stable operating region of the motor is increased. Instead of simply running at its base/ rated speed (NB), the motor can be run typically from 5% of the synchronous speed (NS) up to the base speed. The torque generated by the motor can be kept constant throughout this region.

3) Since almost constant rated torque is available over the entire operating range, the speed range of the motor becomes wider. User can set the speed as per the load requirement, thereby achieving the higher efficiency. Because of above reasons V/F control method is used in this work.

IV SIMULATION RESULT

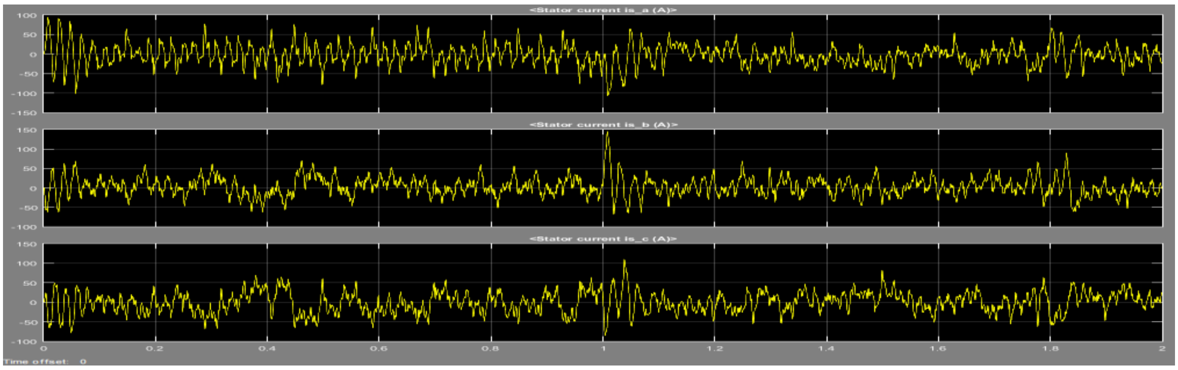


Figure 4.1: Stator Current vs time plot

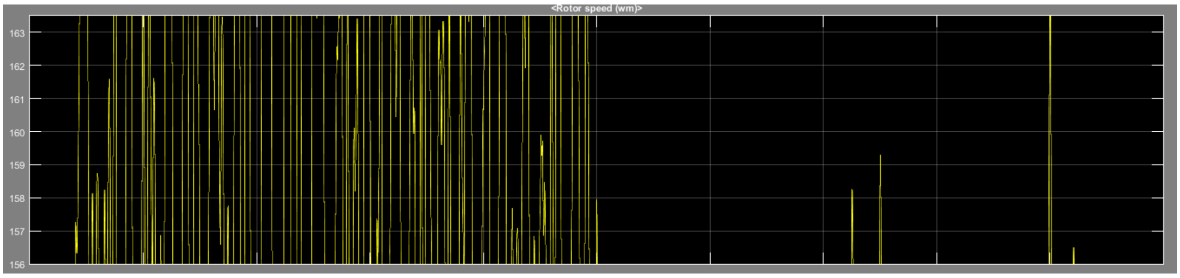


Figure 4.2: Rotor Speed vs time plot

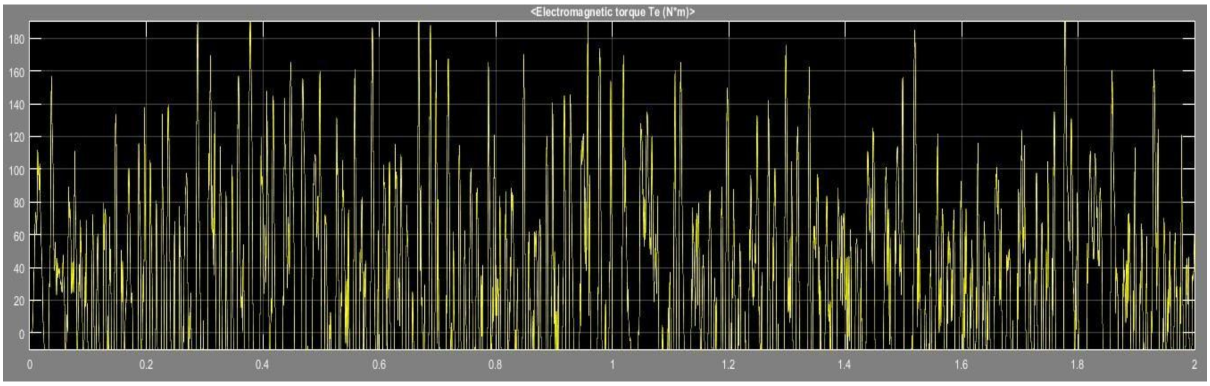


Figure 4.3 Electromagnetic torque vs time plot

V CONCLUSION

Even with non-monotone and non-linearly separable input data, Support Vector Machines (SVMs) can produce classification results that are both extremely accurate and resilient, all while adhering to solid theoretical principles. They make it possible to conveniently evaluate more pertinent information. SVMs eliminate the requirement for expert judgment in selecting the best linearization function for non-linear input data by implicitly linearizing data through the use of kernel transformation. By comparing their input variables with those of the companies in the training sample and looking for comparable constellations of financial statistics, SVMs that operate locally can represent the features of specific organizations. The local linear approximation of SVMs can greatly help in identifying the mechanisms that connect different financial ratios to a company's final score, even though they do not offer a parametric score function. Because of this, SVMs are thought to be useful for enhancing the knowledge obtained from conventional linear classification methods. This study uses MATLAB software to construct and test an induction motor with proportional-integral (PI) control that uses space vector pulse width modulation (SVPWM).

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