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Study of Three Phase Induction Motor with SPWM, THIPWM and SVPWM

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ABSTRACT: This project presents a comprehensive performance analysis of a three phase induction motor for traction applications, utilizing MATLAB Simulink software. The primary objective is to compare the effectiveness of three distinct Pulse Width Modulation (PWM) techniques: Sinusoidal PWM (SPWM), Third Harmonic Injection PWM (THIPWM), and Space Vector PWM (SVPWM). The study focuses on evaluating the motor's steady-state performance in terms of rotational speed (RPM) and the time taken to reach motor's steady state.

KEYWORDS: SPWM, THIPWM, SVPWM.

I. INTRODUCTION

Three-phase induction motors are used in industries due to their robustness, less maintenance, high efficiency, and low cost. These motors were previously used for essentially constant speed applications. But variable speed drive applications for induction motor have increased with the evolution of power electronics The pulse width modulation (PWM) is the most efficient method used to vary both the voltage and frequency within a three-phase inverter. There are semiconductor switches used in the inverter to convert dc signal to ac signal. When dc is converted to ac, it contains some harmonic content, which affects the performance. The performance parameter of an inverter is total harmonic distortion (THD), distortion factor etc. Lower THD value of an inverter output means better efficiency, high power factor, etc. Therefore, THD plays an important role in power electronic systems.

II. THEORY

A three-phase Pulse Width Modulation (PWM) inverter is a critical device in controlling three-phase induction motors, widely used in industrial and traction applications due to their robustness and efficiency. The primary function of the three-phase PWM inverter is to convert DC voltage into a three-phase AC voltage with precise control over its amplitude and frequency, providing a nearly sinusoidal output waveform that is essential for efficient motor operation.

The three-phase PWM inverter consists of six power semiconductor switches, such as IGBTs or MOSFETs, arranged in an H-bridge configuration shown in Fig.1. These switches are controlled to generate three-phase AC voltages (V_a, V_b, and V_c) from a DC input. The key to PWM is modulating the width of the pulses in each phase to approximate a sinusoidal waveform closely.

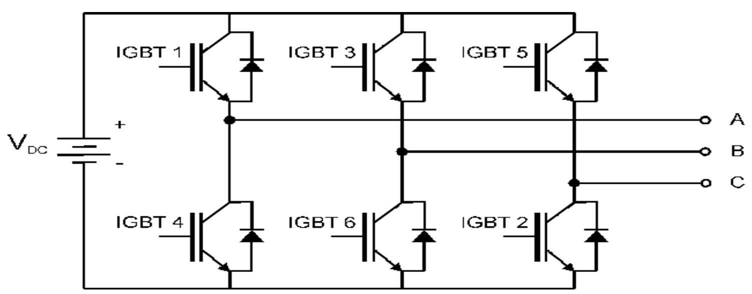

Fig.1: IGBT based three phase inverter.

The frequency of the output AC voltage is determined by the frequency of the reference sinusoidal signals, while the amplitude is controlled by the magnitude of these reference signals. By adjusting these parameters, the PWM inverter

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can precisely control the speed and torque of the induction motor. This is particularly useful in applications requiring variable speed operation, such as in electric vehicles or industrial machinery.

One of the significant advantages of using PWM inverters is their ability to reduce harmonic distortion in the output waveform. Harmonics are undesirable components that cause additional losses and heating in the motor. By using high frequency switching and sophisticated modulation techniques like Space Vector PWM (SVPWM) or Third Harmonic Injection PWM (THIPWM), the inverter can produce a waveform that is very close to a pure sine wave, minimizing harmonic content and improving motor efficiency.

III. SINUSOIDAL PWM

The Sinusoidal Pulse Width Modulation (SPWM) technique is a widely used method in power electronics to control the output voltage of inverters. It works by comparing a reference sinusoidal signal with a high-frequency triangular carrier wave, generating pulse widths proportional to the amplitude of the sine wave. This modulation strategy ensures that the fundamental component of the output voltage closely approximates a sine wave, which is crucial for minimizing harmonic distortion and improving the performance of AC motor drives and other applications. SPWM is particularly valued for its simplicity and effectiveness in producing clean, variable frequency AC outputs, making it a common choice for applications such as variable frequency drives (VFDs), uninterruptible power supplies (UPS), and renewable energy systems. The ability to precisely control the output voltage and frequency with SPWM contributes to the efficient operation and longevity of electrical equipment. Fig. 2 shows a general model generating a Sinusoidal Pulse Width Modulation.

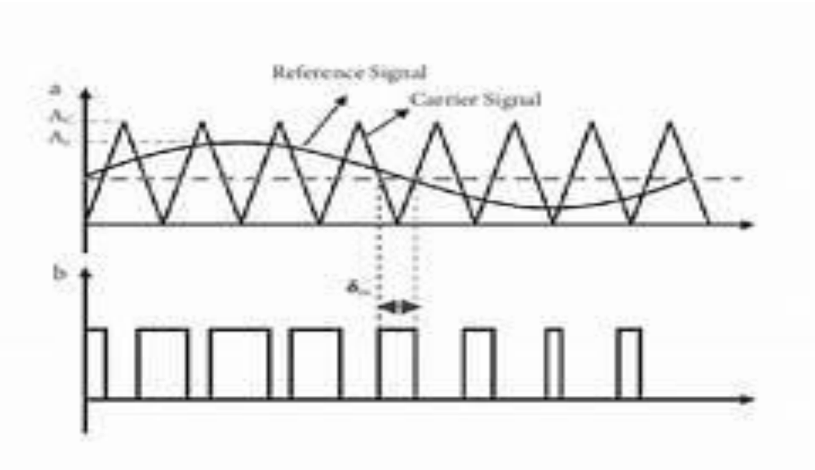

Fig. 2: Sinusoidal Pulse Width Modulation

IV. THIRD HARMONIC INJECTION PWM

The Third Harmonic Injection Pulse Width Modulation (THIPWM) technique is an advanced modulation method used to enhance the performance of power inverters, particularly in applications requiring precise voltage control and high efficiency. Unlike the traditional Sinusoidal PWM (SPWM) technique, THIPWM introduces a third harmonic component into the reference signal, effectively increasing the amplitude of the fundamental output voltage without exceeding the inverter's voltage limits. This results in improved voltage utilization and a significant reduction in total harmonic distortion (THD), leading to a cleaner and more efficient AC output. The injection of the third harmonic allows for better utilization of the DC bus voltage, thereby improving the overall efficiency of the inverter system. THIPWM is especially beneficial in applications such as motor drives and renewable energy systems, where maintaining a high-quality power output is critical. Its ability to optimize the switching sequence and reduce harmonic current ripple makes it a superior choice for achieving enhanced performance and efficiency in modern power electronic systems. Fig. 3 shows reference signal of Third Harmonic Injection Pulse Width Modulation.

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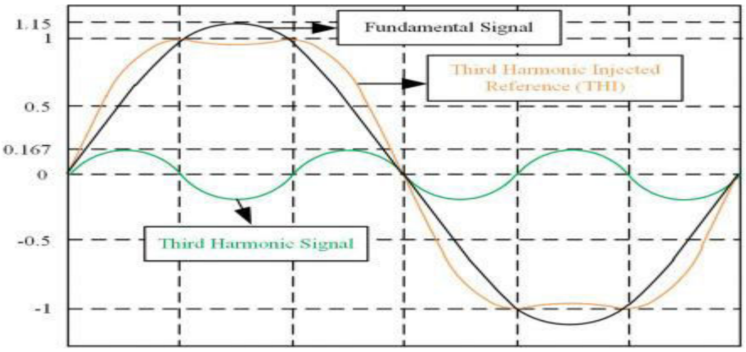

Fig. 3: Third Harmonic Injection Pulse Width Modulation.

IV. SPACE VECTOR PWM

The Space Vector Pulse Width Modulation (SVPWM) technique is a highly efficient and advanced method used to control three-phase inverters, enhancing their performance in various applications. Unlike traditional modulation methods, SVPWM represents the three-phase voltages as vectors in a two-dimensional space, called space vectors. By synthesizing these space vectors, SVPWM generates PWM signals that closely approximate the desired sinusoidal waveforms. This technique maximizes the utilization of the DC bus voltage, resulting in higher output voltage and improved efficiency of the inverter. Additionally, SVPWM significantly reduces harmonic distortion, leading to a cleaner and more stable output. Widely employed in applications such as variable frequency drives (VFDs), renewable energy systems, and electric motor control, SVPWM offers precise control, reduced switching losses, and superior performance, making it a preferred choice for modern power electronic systems.

The formation of Space Vector Pulse Width Modulation (SVPWM) involves representing three-phase voltages as vectors in a two-dimensional space, which simplifies the modulation process. Fig 4 shows the general block representation of SVPWM formation. The core idea is to use these space vectors to generate PWM signals that create a synthesized voltage waveform. The process begins by converting the three-phase AC signals into a complex space vector. This vector is then mapped onto a hexagonal plane, divided into six sectors, each corresponding to a specific combination of inverter switch states. By strategically switching the inverter's power devices, SVPWM generates the desired output waveform by creating an average voltage vector that approximates the reference vector in each sector. This method maximizes the utilization of the DC bus voltage, enhances inverter efficiency, and reduces harmonic distortion, making SVPWM a highly efficient and effective technique for controlling three-phase inverters in various applications, such as motor drives and renewable energy systems. Fig. 5 shows PWM generation of space vector modulation.

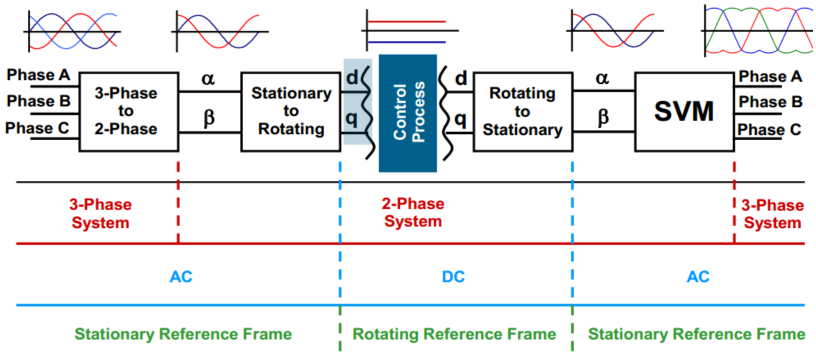

Fig. 4: Block representation of SVPWM formation.

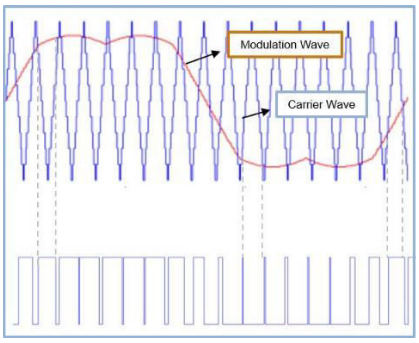

Fig. 5: PWM generation of space vector modulation.

V. SIMULATION AND RESULTS

For Three-phase induction motors Asynchronous Machine SI Units block is used in MATLAB/Simulink software, which has following design parameters: power = 5.4 HP; voltage = 400 V; frequency = 50 Hz; Stator resistance = 1.405Ω; Stator inductance = 0.005839H ; Rotor resistance = 1.395 Ω; Rotor inductance = 0.005839H; Mutual inductance = 0.1722

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Ω : inertia =0.0131 kgm^2 . For the three-phase inverter circuit IGBT switches are used with DC voltage Source with 400V input Voltage. For measuring the voltage, Three-Phase V-I Measurement block is used to measure phase to phase voltage. Bus selector block is used to observe the Mechanical Rotor Speed (w_m) and Electromagnetic torque Te (N m). Scope is used to observe the simulation results.

To Study the performance of Three phase induction motor with Sinusoidal PWM Inverter, Sine pulse is generated by comparing the Triangular Carrier wave of 10KHz frequency and Sinusoidal Reference wave of 50 Hz. Fig.6 Simulation circuit for three phase inverter fed Induction motor.

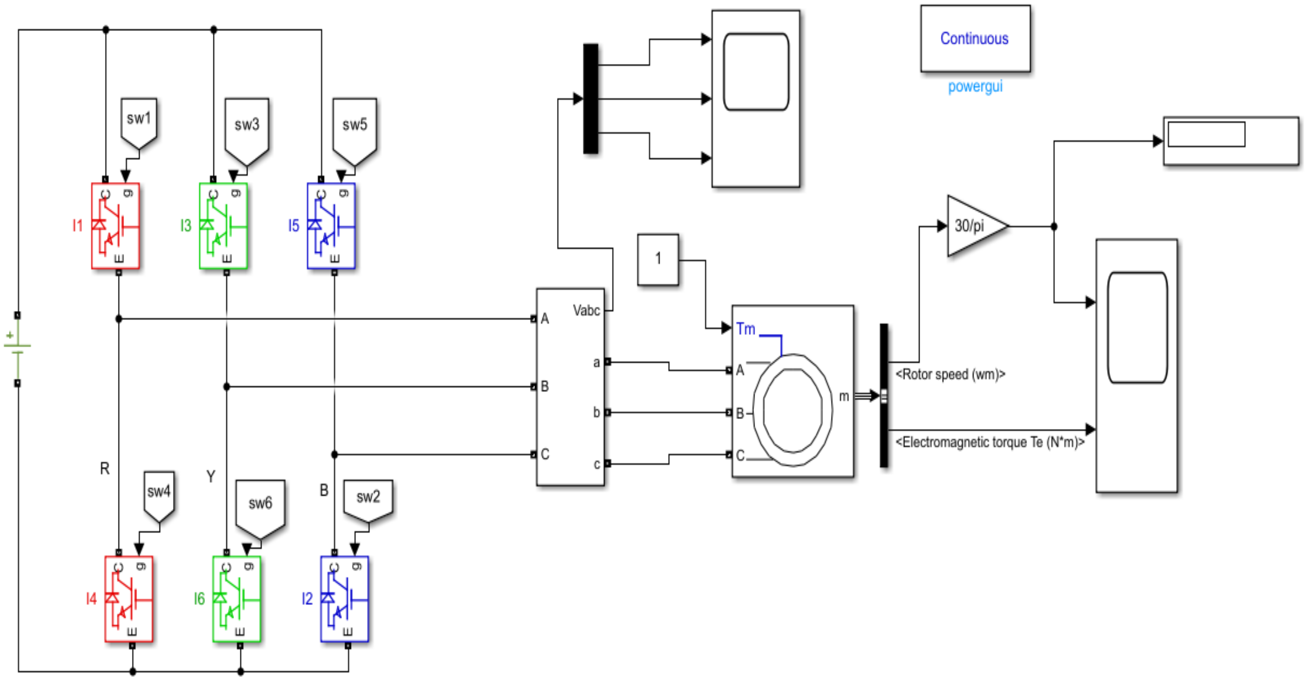

Fig. 6: Simulation Circuit for three phase inverter fed Induction motor.

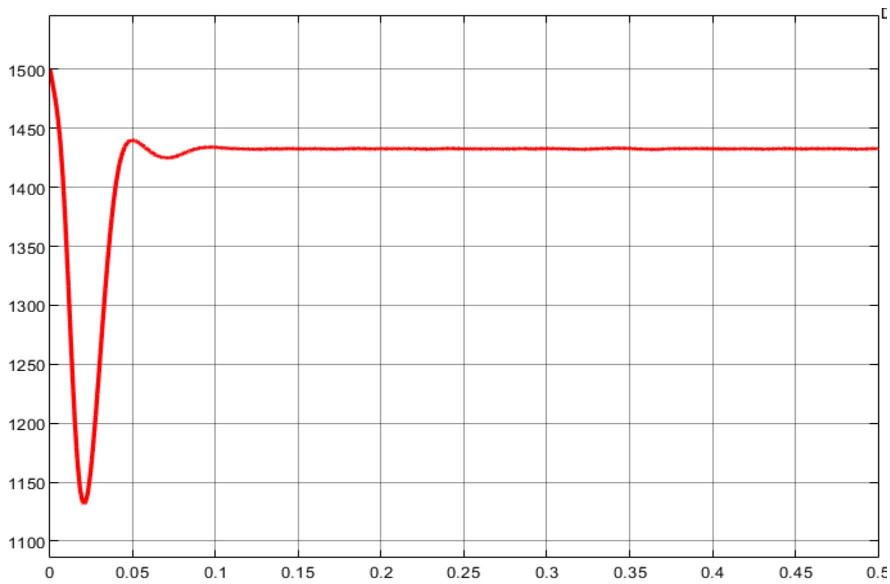

Fig.7: Rotor Speed in Rpm for SPWM fed Induction motor.

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For Studying the performance of Three phase induction motor with Third Harmonics Injected Pulse Width Modulation (THIPWM) Inverter. A Sine wave is injected with 1/3 of another sine wave and the resultant wave is Reference wave. The pulse is generated by comparing the Triangular Carrier wave and Reference wave. Fig. 6 shows simulation circuit third harmonics injected pulse width modulation (THIPWM) inverter. Fig. 8 shows Rotor Speed in Rpm for THIPWM fed Induction motor.

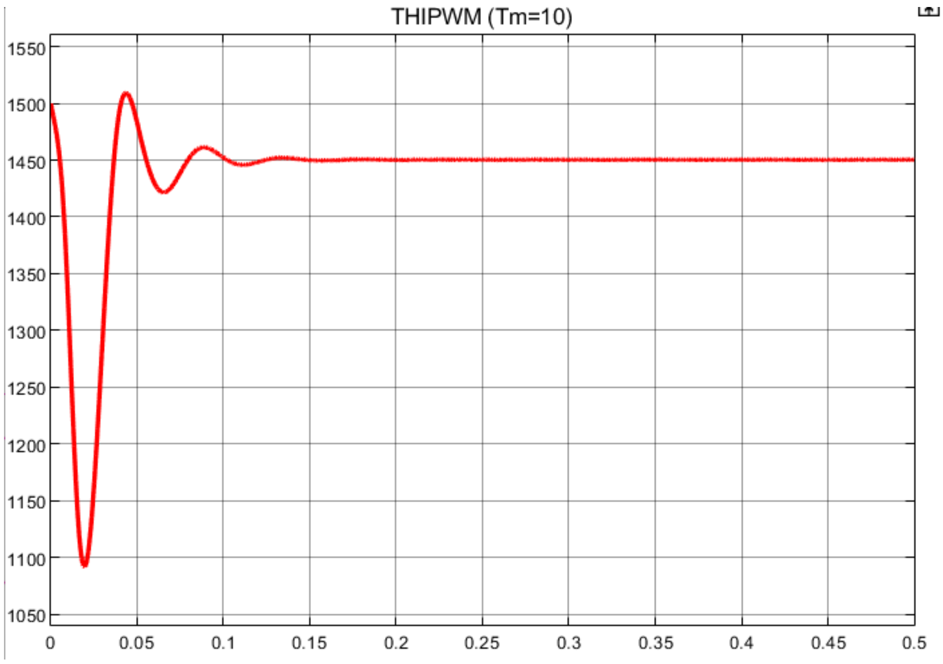

Fig. 8: Rotor Speed in Rpm for THIPWM fed Induction motor.

For Study the performance of three phase induction motor with Space Vector Pulse Width Modulation (SVPWM) Inverter. SVPWM is Implemented by converting three phases in stationary reference frame into two phase rotating reference frame and vice versa. Simulation Circuit is shown in Fig. 6. Fig 9 shows Rotor Speed in Rpm for SVPWM fed Induction motor.

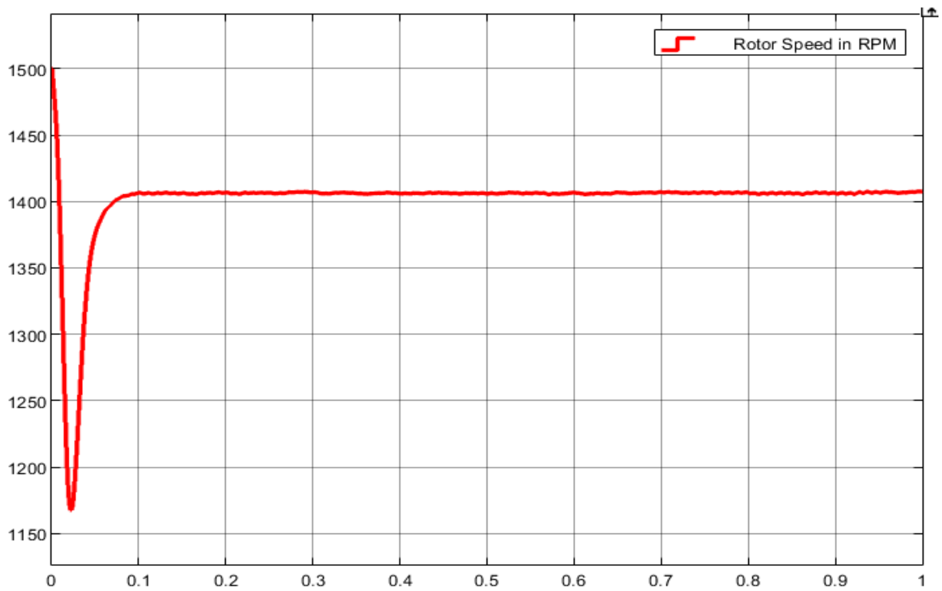

Fig. 5.14 Rotor Speed in Rpm for SVPWM fed Induction motor.

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The results obtained from simulating the three-phase induction with SPWM, THIPWM and SVPWM are observed and recorded in Table 1.

Table 5.1 Motor performance with respect to different PWM Technique

PWM Techniques	Values without using filter		Motor performance		Load Torque Tm (Nm)
	Voltage THD in %	Current THD in %	Steady speed obtaining time (s)	Rotor speed (rpm)	
SPWM	68.58	25.69	0.16	1433	10
THIPWM	52.98	28.70	0.15	1450	10
SVPWM	52.69	14.27	0.1	1407	10

VI. CONCLUSION

In conclusion, the study of three-phase induction motors utilizing SPWM, THIPWM, and SVPWM techniques reveals significant insights into the performance and efficiency of these modulation methods. Each technique plays a critical role in shaping the output waveform, influencing the motor's steady-state speed obtaining time and overall performance. The findings demonstrate that THIPWM and SVPWM techniques, with their ability to produce near-sinusoidal voltage and current waveforms, effectively reduce harmonic distortion and improve the efficiency of the motor drive system. This comparative analysis underscores the importance of selecting the appropriate PWM technique to optimize the performance of three-phase induction motors in various applications, highlighting the superior performance of THIPWM and SVPWM over traditional SPWM.

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