“MITIGATION OF HARMONICS USING SVPWM FOR 3-LEVEL INVERTER DRIVEN INDUCTION MOTOR”

B.TECH. PROJECT REPORT

Submitted by

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to

The APJ Abdul Kalam Technological University in partial fulfillment of the requirements for the award of the Degree

of

Department of Electrical & Electronics Engineering

CARMEL COLLEGE OF ENGINEERING & TECHNOLOGY
PUNNAPRA, ALAPPUZHA, KERALA INDIA

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DECLARATION

I undersigned at this moment declare that the project report "**Mitigation of Harmonics using Sector based SVPWM for a 3 Level Inverter driven Induction Motor**", submitted for partial fulfillment of the requirements for the award of the degree of Bachelor of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of **Ms. Shani S J, Asst. Professor**. This submission represents my ideas in my own words, and where ideas or words of others have been included, I have adequately and accurately cited and referenced the sources. I also declare that I have adhered to academic honesty and integrity ethics and have not misrepresented or fabricated any data, idea, fact, or source in my submission. I understand that any violation of the above will cause disciplinary action by the institute and/or the university and can also evoke penal action from the sources that have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for awarding any degree,diploma or similar title of any other University.

Place: Alappuzha

Date:07/05/2024

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INDIA

CERTIFICATE

This is to certify that the project report entitled "**Mitigation of Harmonics Using SVPWM for 3-level Inverter Driven Induction Motor**" is a bona fide record of the work done by **SHERIL MARY GEO (**Reg.No. CMA20EE046) under my supervision and guidance, in partial fulfillment of the requirements for the award of Degree of Bachelor of Technology in Electrical & Electronics Engineering from Carmel College of Engineering for the year 2024.

NAME OF GUIDE | **HOD**

13/05/2024

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SHERIL MARY GEO

ABSTRACT

Multilevel inverters (MLIs) are increasingly used in industrial applications due to their advantages over two-level inverters, such as lower total harmonic distortion (THD), higher efficiency, and improved output waveform quality. However, MLIs also have some drawbacks, such as increased complexity and cost. Space vector pulse width modulation (SVPWM) is a popular modulation technique for MLIs that can reduce THD and improve output waveform quality. This project proposes a novel SVPWM technique for 3-level inverters that further reduces THD and switching losses. The proposed technique is based on a sector-based switching pattern that minimizes switching transitions. The performance of the proposed technique is evaluated through simulations and compared to the conventional SVPWM technique. Simulation results show that the proposed technique can significantly reduce THD and switching losses compared to the conventional SVPWM technique.

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CHAPTER 1

INTRODUCTION

Pulse Width Modulation (PWM) is a fundamental technique used in electronics and electrical engineering to control the amount of power delivered to a load by manipulating the duty cycle of a periodic signal. The principle behind PWM involves rapidly switching a signal on and off at a fixed frequency, where the ratio of the on-time (pulse width) to the total period determines the average power delivered to the load. PWM is widely employed due to its efficiency, precision, and versatility in various applications. One of the primary reasons for using PWM is its ability to efficiently control power while minimizing energy loss. By switching the power on and off at a high frequency, PWM allows power transistors to operate in a binary manner either fully on or fully off resulting in reduced heat generation and improved overall efficiency compared to continuous voltage control methods. This efficiency makes PWM particularly suitable for applications where energy conservation and thermal management are critical concerns.

There are several types of PWM techniques, each offering unique characteristics and suitable for different applications. Edge-aligned PWM controls the duty cycle by varying the time between the rising or falling edges of the PWM signal. This method is straightforward to implement and commonly used in motor speed control and lighting systems. Center-aligned PWM, on the other hand, adjusts the duty cycle by varying the time between the rising edge and the midpoint of the pulse. It is often employed in audio amplifiers and power inverters where symmetric waveform generation is essential. Asymmetric PWM allows for different rise and fall times of the pulse, offering flexibility in waveform shaping and harmonic control. This technique finds applications in power electronics and motor drives where precise waveform manipulation is required. Carrier-based PWM involves comparing a high-frequency carrier waveform with a reference signal to generate the PWM output. This method is widely used in switch-mode power supplies and voltage regulators for efficient power conversion and control. The choice of PWM technique depends on the specific requirements of the application, including desired waveform characteristics, complexity of implementation, and efficiency considerations.

Space Vector Pulse Width Modulation (SVPWM) is an advanced PWM technique used primarily in motor control applications to optimize motor performance and efficiency. SVPWM operates by dividing the space of three-phase voltage vectors into sectors and strategically modulating these vectors to achieve precise control over motor operation. SVPWM offers several advantages over traditional PWM techniques, making it increasingly popular in industrial and automotive applications. One of the primary reasons for using SVPWM is its ability to maximize the utilization of available voltage vectors, resulting in higher efficiency and reduced losses in motor control systems. By efficiently distributing voltage vectors, SVPWM minimizes energy wastage and enhances overall system performance, particularly in electric vehicle propulsion systems and industrial motor drives.

Moreover, SVPWM significantly reduces harmonic distortion in the output waveform compared to conventional PWM methods. This reduction in harmonic content leads to smoother motor operation, reduced motor heating, and enhanced system reliability. The precise control afforded by SVPWM over motor speed and torque makes it ideal for applications where dynamic performance and accuracy are critical, such as robotics and industrial automation. In electric vehicles (EVs), SVPWM plays a crucial role in achieving efficient and precise control over motor speed and torque, thereby enhancing vehicle performance and range. SVPWM is also widely employed in renewable energy systems, such as grid-tied inverters for solar and wind power, where it improves the efficiency and stability of power conversion. In home appliances like washing machines, air conditioners, and refrigerators, SVPWM enhances motor efficiency and energy conservation, contributing to overall energy savings and user comfort.

CHAPTER 2

LITERATURE SURVEY

2.1 MITIGATION OF HARMONICS USING NOVEL SECTOR-BASED SWITCHING PATTERN SPACE VECTOR PULSE WIDTH MODULATION

The paper presents a significant advancement in the field of power electronics, specifically addressing the challenge of harmonic distortions in three-phase inverters. Harmonics can lead to various issues such as decreased efficiency, increased heating, and interference in electrical systems, making their mitigation crucial for enhancing system performance and reliability. This study introduces a novel sector-based switching pattern within Space Vector Pulse Width Modulation to effectively reduce harmonic content in the output voltage waveform.

The proposed sector-based switching pattern divides the voltage space into distinct sectors based on the position of the desired output voltage vector. Within each sector, a tailored switching strategy is employed to generate optimized PWM signals. By dynamically adjusting the switching patterns according to system conditions and load requirements, the novel approach aims to minimize switching losses and high-frequency components, resulting in improved power quality.

2.2 PWM SCHEME FOR A 3-LEVEL INVERTER CASCADING TWO 2-LEVEL INVERTERS.

The research focuses on developing effective pulse width modulation techniques tailored specifically for a configuration involving two cascaded two-level inverters to achieve a three-level voltage output. Such an arrangement offers advantages in terms of reduced switching losses, improved efficiency, and enhanced control over the output waveform compared to traditional inverters. By investigating novel PWM strategies suitable for this topology, the research aims to optimize performance and address key challenges related to harmonic distortion and voltage quality in power conversion systems.

The proposed PWM scheme for the cascaded 3-level inverter involves designing and implementing control strategies that capitalize on the unique capabilities of the two-level inverters in tandem. This approach leverages the ability to synthesize a three-level voltage waveform, which is desirable for applications requiring higher voltage resolution and improved efficiency. By carefully orchestrating the switching patterns and modulation techniques, the research seeks to achieve precise control over the inverter's output while minimizing losses and enhancing overall system performance. The investigation delves into theoretical analysis, simulation studies, and experimental validation to demonstrate the effectiveness and practicality of the proposed PWM scheme.

2.3 SPACE VECTOR PULSE WIDTH MODULATION APPLIED TO THE THREE-LEVEL VOLTAGE INVERTER.

The research represents a significant contribution to the field of power electronics. This study explores the implementation and optimization of SVPWM techniques specifically tailored for three-level inverters, which are increasingly used in various industrial and renewable energy applications. The focus is to achieve precise control over the output voltage of three-level inverters while minimizing harmonic distortions and improving overall efficiency. By leveraging the capabilities of SVPWM, which is known for its effectiveness in producing high-quality voltage waveforms with reduced harmonic content, this study aims to enhance the performance and reliability of three-level voltage inverters.

The application of SVPWM to three-level voltage inverters involves developing advanced modulation strategies that optimize the switching patterns of semiconductor devices to synthesize desired output voltages. By utilizing SVPWM techniques tailored for three-level inverters, the study seeks to address key challenges such as harmonic mitigation, voltage regulation, and efficiency enhancement in power conversion systems. The findings from this research hold promise for practical implementations in motor drives, renewable energy systems, and other critical applications where precise voltage control and harmonic reduction are essential.

2.4 A NOVEL VOLTAGE MODULATION TECHNIQUE OF THE SPACE VECTOR PWM.

The research represents an important contribution to the field of power electronics. This study explores innovative techniques for voltage modulation within Space Vector Pulse Width Modulation systems, aiming to enhance the performance and efficiency of power converters and motor drives. The focus of this research is to develop and optimize novel voltage modulation strategies that can effectively control the output voltage waveform while minimizing harmonic distortions and switching losses. By leveraging advanced modulation techniques within the framework of SVPWM, this study seeks to push the boundaries of power electronics technology, offering new avenues for improving the quality and reliability of electrical power systems.

The proposed novel voltage modulation technique within SVPWM involves the design and implementation of innovative control strategies that exploit the unique characteristics of space vector modulation. This approach aims to optimize the switching patterns of semiconductor devices to achieve precise control over the output voltage of power converters and motor drives. By dynamically adjusting the modulation technique according to load conditions and system requirements, the research aims to improve efficiency, reduce electromagnetic interference, and enhance overall system performance. The theoretical analyses, simulation studies, and experimental validations conducted in this research provide insights into the effectiveness and practicality of the novel voltage modulation technique proposed.

2.5 POWER ELECTRONICS FOR MODERN SUSTAINABLE POWER SYSTEMS: DISTRIBUTED GENERATION, MICROGRIDS AND SMART GRIDS—A REVIEW.

The article provides a comprehensive review of the role of power electronics in advancing modern sustainable power systems. The study delves into key technologies such as distributed generation, microgrids, and smart grids, highlighting the pivotal role of power electronics in enabling their integration and operation. By synthesizing current research and advancements in the field, the article aims to offer insights into the challenges, opportunities, and emerging trends shaping the transformation of conventional power systems towards more sustainable and resilient architectures.

CHAPTER 3

METHODOLOGY

3.1 CONVENTIONAL 2 LEVEL SVPWM

Space Vector Pulse Width Modulation (SVPWM) controls inverter output voltage in power electronics by generating and synthesizing reference voltages in a 2D space (α-β). It determines active voltage vectors and their durations to approximate desired voltages, optimizing motor control efficiency. SVPWM reduces harmonic distortion, improves efficiency, and maximizes DC bus voltage utilization compared to other PWM techniques.

3.1.1 abc to Alpha-Beta Transformation

In an alternating current (AC) electrical system, the input voltage and current waveforms fluctuate over time between positive and negative values. These waveforms are typically represented in three-phase coordinates, denoted as abc, where a, b, and c are the three-phase voltages. It is useful to transform these three-phase coordinates into two-phase coordinates, denoted as alpha-beta . Clark's transformation maps a three-phase input waveform into a two-dimensional space as it reduces complexity, that is three-phase systems require complex calculations and control strategies. Converting them to αβ simplifies the math and control algorithms by representing the three phases in a two-dimensional rotating reference frame.

$$\alpha = (Va - (0.5 \times Vb) - (0.5) \times Vc)$$
$$\beta = 0.866 \times (Vb - Vc)$$

3.1.2 Reference Vector Calculation

The reference vector calculation involves determining the magnitude and angle of the desired output voltage waveform. The magnitude is determined by taking the square root of the sum of the squares of the alpha and beta coordinates. The angle is determined by taking the inverse tangent of the beta coordinate divided by the alpha coordinate.

$$V_{ref} = \sqrt{\alpha^2 + \beta^2}$$

3.1.3 Sector Identification

Sector identification is a key step in Space Vector Pulse Width Modulation (SVPWM), which involves determining the sector in which the reference vector lies in the complex plane. This sector information is used to generate the PWM signals for the inverter's output waveform.The sector identification process involves comparing the magnitudes of the three-phase voltages (Va, Vb, and Vc) to determine which phase has the highest value. Depending on the relative magnitudes of the three-phase voltages, the reference vector can occupy one of six sectors in the complex plane.

Table 1: Sector identification for 2 level SVPWM

Sector	Instantaneous reference vector amplitude
1	Va>Vb>Vc
2	Vb>Va>Vc
3	Vb>Vc>Va
4	Vc>Vb>Va
5	Vc>Va>Vb
6	Va>Vc>Vb

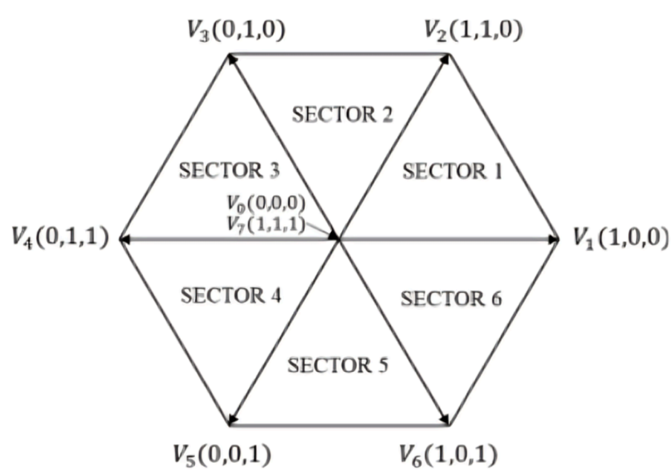


Fig 3.1.1: Space vector diagram of a 2 level Inverter

3.1.4 Dwell Time Calculation

Dwell time is defined as the duration for which the voltage vectors in a three-phase inverter remain constant during each switching cycle.

$$t1 = \frac{\sqrt{3} \times tz \times Vref}{Vdc} \times sin(sector \times \frac{\pi}{3}) - angle$$

$$t2 = \frac{\sqrt{3} \times tz \times Vref}{Vdc} \times sin((angle - ((sector - 1) \times \frac{\pi}{3})$$

$$t0 = tz - t1 - t2$$

Where , t1 represents the dwell time for one of the active vectors in the SVPWM .

t2 represents the dwell time for another active vector in the SVPWM .

t0 represents the dwell time for the zero vector in the SVPWM .

tz is the Sampling time.

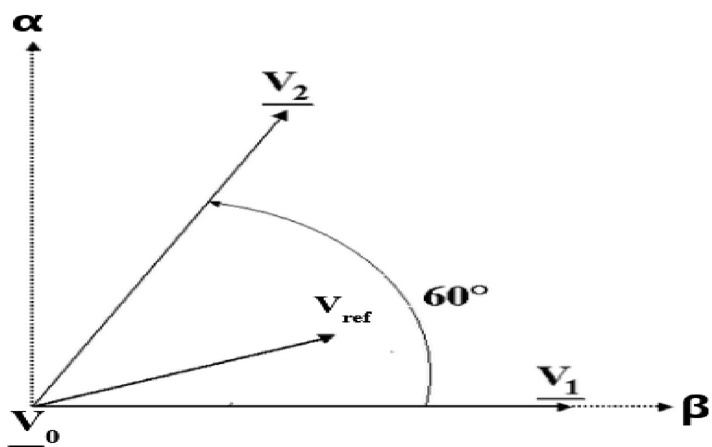
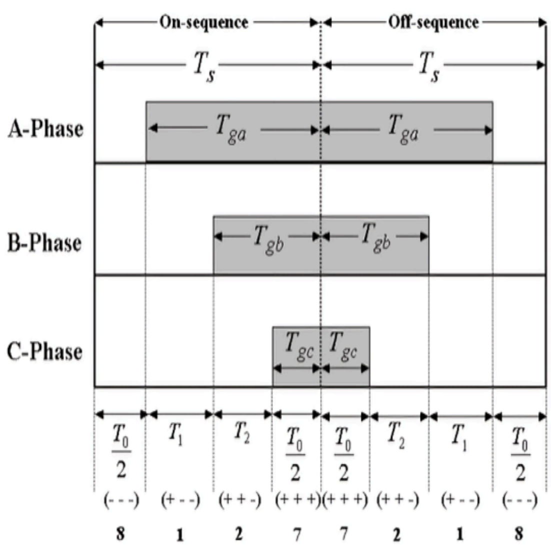


Fig 3.1.2:Sector-1 of 2 Level SVPWM hexagon

3.1.5 Switching Signal Generation

Following sector identification and dwell time calculation in Space Vector Pulse Width Modulation (SVPWM), the subsequent crucial step involves generating switching signals for the inverter's output waveform. These signals control the activation and deactivation of the inverter's switches, determining the exact timing and duration of each switch's operation. The dwell time, computed previously for each sector based on the modulation index and sector angle, guides this process. By allocating specific time intervals to each switch within a given sector, the switching signals ensure that the output voltage closely tracks the desired reference waveform. This meticulous synchronization between the calculated dwell times and the generation of switching signals enables precise control over the inverter's output, facilitating the generation of high-quality voltage waveforms with minimal distortion. Consequently, this step plays a pivotal role in ensuring the efficiency and accuracy of the SVPWM technique, crucial for various applications requiring precise voltage control, such as motor drives and renewable energy systems.



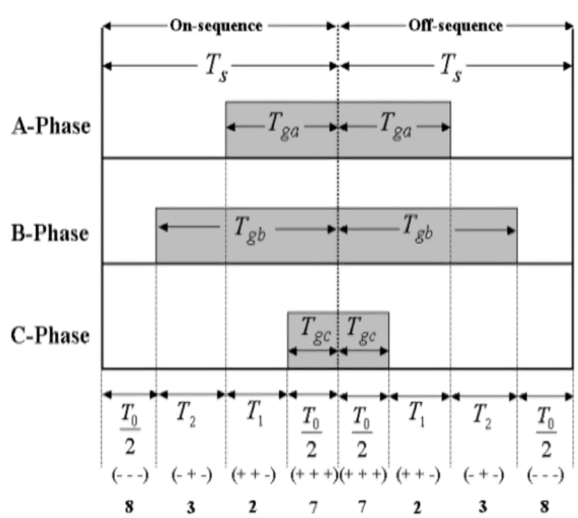


Fig 3.1.3: The Gating pulses for the A, B and C phases when the tip of reference voltage space phasor is situated in sector 1 and sector 2

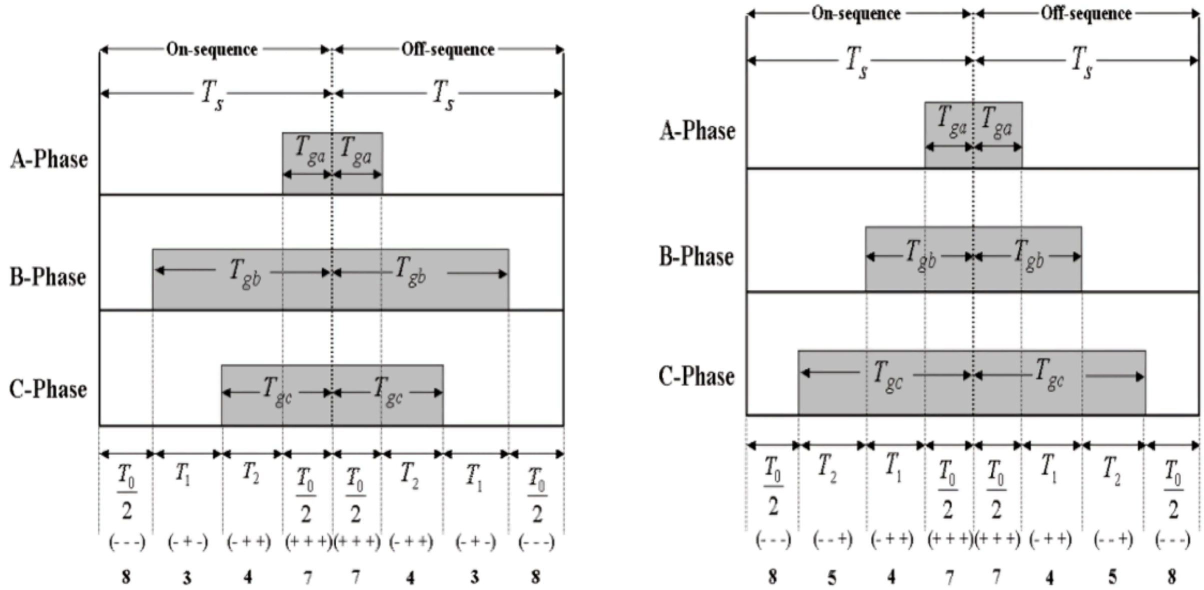


Fig 3.1.4: The Gating pulses for the A, B and C phases when the tip of reference voltage space phasor is situated in sector 3 and sector 4

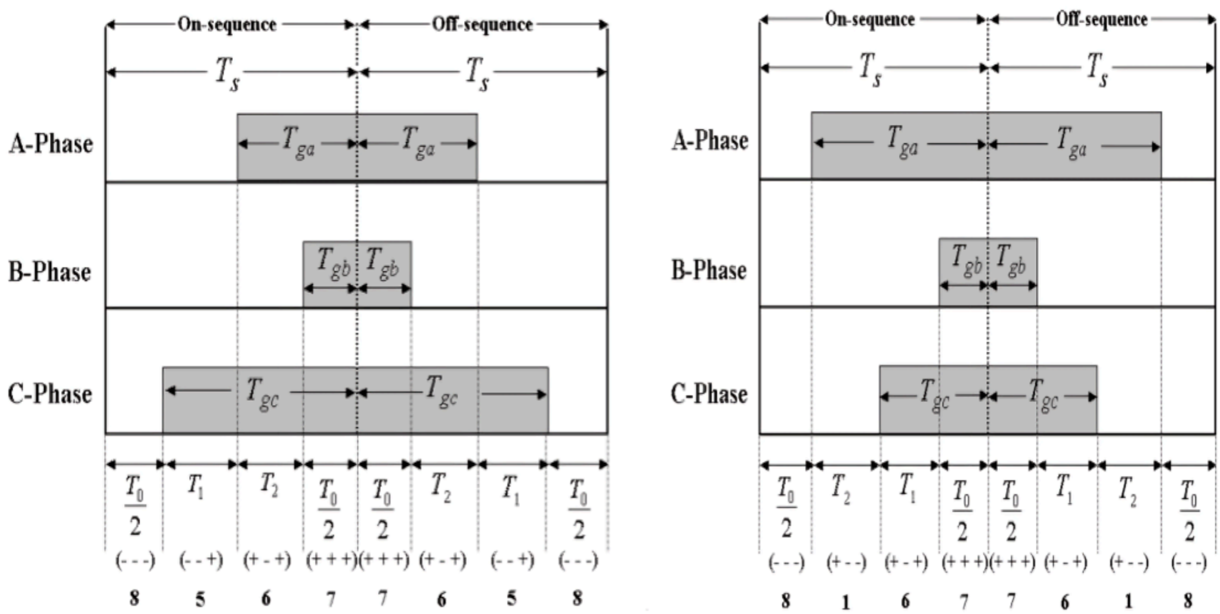


Fig 3.1.5: The Gating pulses for the A, B and C phases when the tip of reference voltage space phasor is situated in sector 5 and sector 6

3.2 PROPOSED 2 LEVEL SVPWM

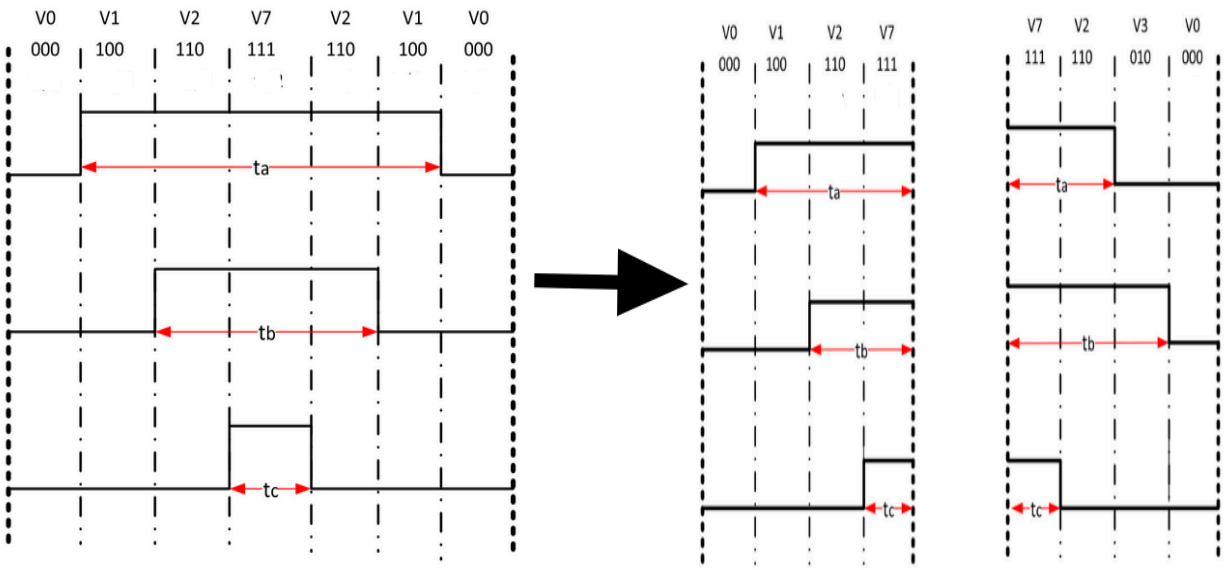


Fig 3.2.1:Difference between ON OFF sequence of conventional and proposed SVPWM

In the proposed two-level system, the operational steps closely resemble those of the conventional two-level Space Vector Pulse Width Modulation (SVPWM). Initially, the process entails converting the abc signals to Alpha-Beta coordinates, followed by computing the reference vector and identifying the sector, all of which adhere to the standard procedure. However, a notable departure arises when addressing dwell times.In the conventional system, the dwell time dictates a specific switching sequence, as exemplified by V0-V1-V2-V7-V2-V1-V0 for sector 1. Conversely, in the proposed system, there's a distinct switching sequence. For sector 1, it follows V0-V1-V2-V7, while for sector 2, it's V7-V2-V3-V0. This alteration necessitates recalculating dwell times to align with the modified switching sequence.Subsequently, the system recalibrates the dwell times accordingly. Then, utilizing these adjusted dwell times, the system generates switching signals. This meticulous adjustment ensures seamless transition and effective operation within the proposed system's unique switching paradigm.

3.3 CONVENTIONAL 3 LEVEL SVPWM

Conventional three-level Space Vector Pulse Width Modulation (SVPWM) is a technique used in power electronics to control the switching of inverters in three-phase systems.This additional voltage level allows for finer control of the output voltage waveform, reducing harmonic distortion and improving overall efficiency. In two-level SVPWM, only eight possible voltage vectors are available, limiting the resolution of the output waveform. However, three-level SVPWM offers 27 possible voltage vectors, resulting in smoother output waveforms with reduced total harmonic distortion (THD). Additionally, the increased number of available voltage vectors allows for better utilization of the DC link voltage, reducing the required voltage stress on the power semiconductors. Consequently, three-level SVPWM is often favored in high-power applications where minimizing harmonic distortion and maximizing efficiency are critical.

3.3.1 abc to Alpha-Beta Transformation

Clark's transformation converts the three-phase components of a system into two-phase alpha-beta components. This simplifies analysis by reducing the complexity of three-phase circuits to that of two-phase circuits, making it easier to analyze and design control strategies for power electronic systems and machines.

$$\alpha = (Va - (0.5 \times Vb) - (0.5) \times Vc)$$

$$\beta = 0.866 \times (Vb - Vc)$$

3.3.2 Reference Vector Calculation

Using the alpha beta values the reference vector is calculated by the equation,

$$V_{ref} = \sqrt{\alpha^2 + \beta^2}$$

3.3.3 Level Identification

In the conventional SVPWM level identification involves identifying whether the reference vector lies in 2 level or 3 level SVPWM.

$$Vref < \frac{\sqrt{3}}{4} Vdc \text{ for 2 level}$$

$$Vref > \frac{\sqrt{3}}{4} Vdc \text{ for 3 level}$$

As the above equations , if $Vref$ is less than $\frac{\sqrt{3}}{4} Vdc$, then it is 2 level

and if $Vref$ is more than $\frac{\sqrt{3}}{4} Vdc$, then it is 3 level

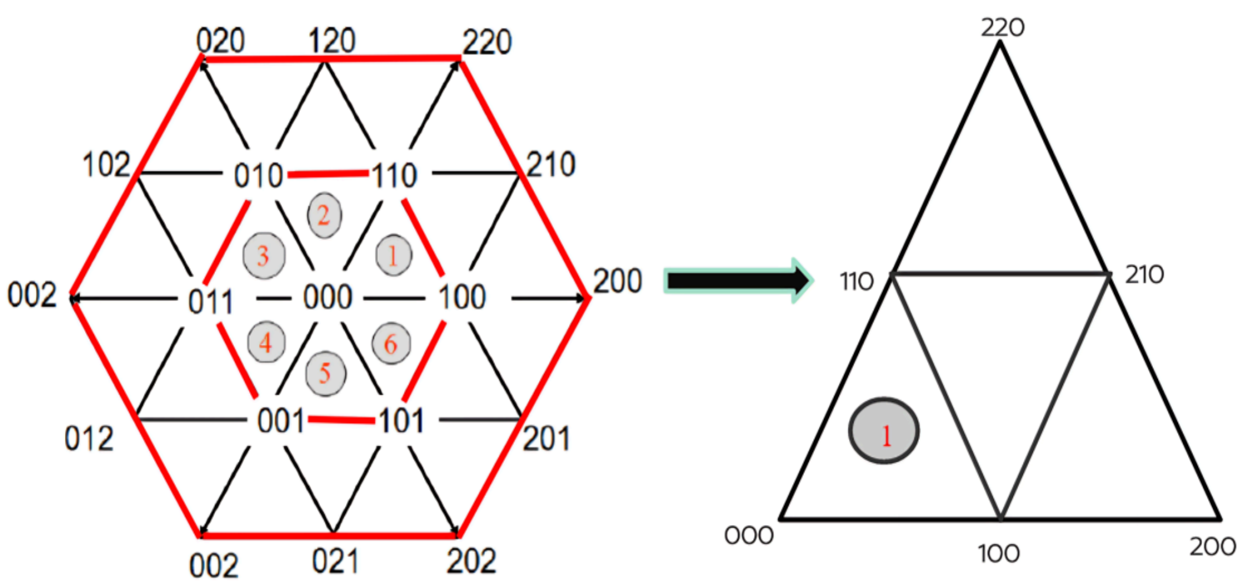


Fig.3.3.1: Space vector diagram of a 3 level Inverter

3.3.4 Sub Hexagon Centre Determination

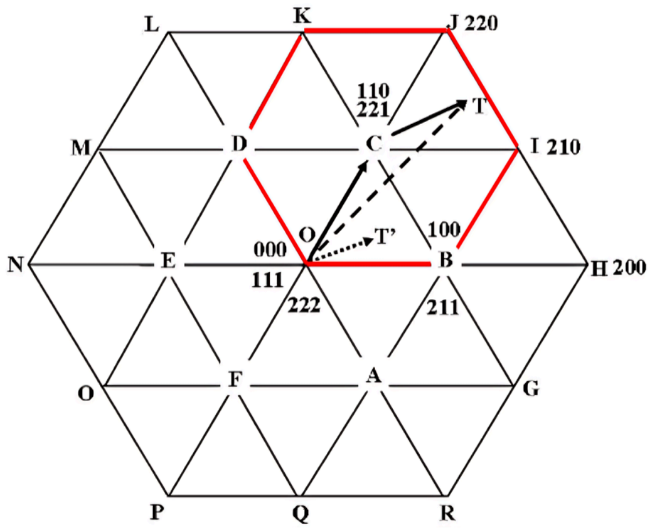


Fig 3.3.2: Reference vector OT split into vectors OC and CT . Small vector CT is mapped to the inner sub hexagon. The mapped vector is shown as OT'

Three phase components are compared inorder to determine the sub hexagon center. Finding the sub-hexagon centers is crucial for determining the switching states of the inverter. If the $Vref$ lies in 3 level , sub hexagon center is determined . The vector OT' is the vector sum of CT and OC . OC lies in the 2 level whereas the CT is outside the 2 level . Therefore CT has to be mapped into the 2 level.

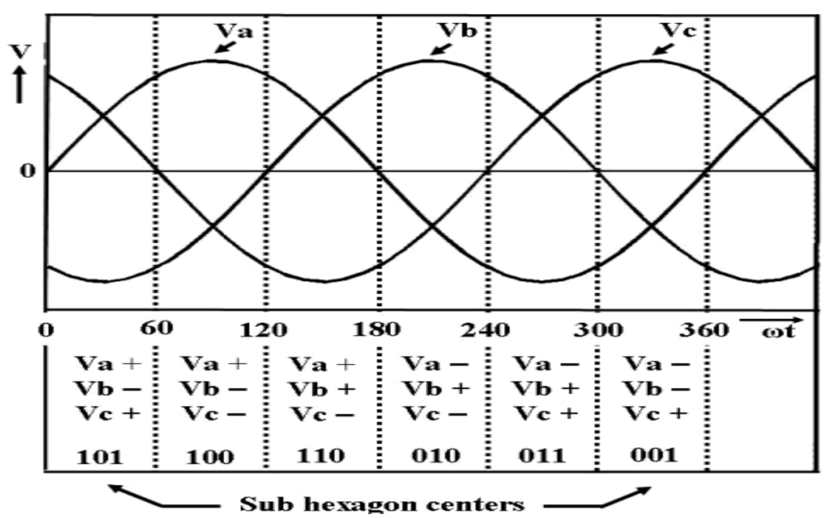


Fig 3.3.3:- Phase reference signal and sub hexagon centers

3.3.5 Mapped Values Calculation

In conventional three-level Space Vector Pulse Width Modulation (SVPWM), the reference vector OT, depicted in figure 3.3.2, is formed by the vector sum of OC and CT. Here, OC represents one of the standard voltage vectors available in the three-level inverter, while CT lies within the space covered by the three-level inverter's voltage levels.The process of mapping the vector CT to the two-level representation, OT'.

$$\alpha_{mapped} = \alpha - \alpha_s$$

$$\beta_{mapped} = \beta - \beta_s$$

where, α_{mapped} and β_{mapped} are the alpha and beta components of the vector OT' and α_s and β_s are the alpha and beta components of the vector OC.

3.3.6 Inverse Clarke Transformation

Inorder to identify the sectors , the alpha and beta components of the OT' vector is transformed to 3 phase components using inverse clarke transformation using the below equations .

$$V_{am} = \alpha_{mapped}$$

$$V_{bm} = -\frac{\alpha}{2} + \frac{\sqrt{3}}{2}\beta_{mapped}$$

$$V_{cm} = -\frac{\alpha}{2} - \frac{\sqrt{3}}{2}\beta_{mapped}$$

where V_{am} , V_{bm} and V_{cm} are the 3 phase components .

3.3.7 Sector Identification

By comparing the 3 phase components , V_{am} , V_{bm} and V_{cm} , sectors can be identified **.**

Table 2 : Sector identification for 3 level SVPWM

Sector	Instantaneous reference vector amplitude
1	$V_{am}>V_{bm}>V_{cm}$
2	$V_{bm}>V_{am}>V_{cm}$
3	$V_{bm}>V_{cm}>V_{am}$
4	$V_{cm}>V_{bm}>V_{am}$
5	$V_{cm}>V_{am}>V_{bm}$
6	$V_{am}>V_{cm}>V_{bm}$

3.3.8 Dwell Time Calculation

Dwell time of every sector is calculated .

$$t1 = \frac{\sqrt{3}\times tz\times Vref}{Vdc} \times sin(sector \times \frac{\pi}{3}) - angle$$

$$t2 = \frac{\sqrt{3}\times tz\times Vref}{Vdc} \times sin((angle - ((sector - 1) \times \frac{\pi}{3})$$

$$t0 = tz - t1 - t2$$

Where , t1 represents the dwell time for one of the active vectors in the SVPWM

t2 represents the dwell time for another active vector in the SVPWM

t0 represents the dwell time for the null vector in the SVPWM .

tz is the Sampling time.

3.3.9 Switching Signal Generation

Once the dwell times for each sector are determined based on the positions of the sub-hexagon centers, switching signals are generated accordingly.

3.3.10 Reverse Mapping

In the reverse mapping process of Space Vector Pulse Width Modulation (SVPWM), adding the durations of gate pulses of vector OC to the duration of vector CT involves determining the total duration of the switching signals required to approximate the desired reference vector OT.

3.4 PROPOSED 3 LEVEL SVPWM

The implementation process of the proposed 3-level SVPWM mirrors that of the conventional 3-level SVPWM. However, the distinguishing factor lies in the values of dwell time for generating switching signals in each sector.This tweak is aimed at reducing Total Harmonic Distortion (THD) further.Thus, we can more precisely control how long each switch remains in a particular state, which can lead to smoother transitions and ultimately lower harmonic distortions in the output voltage waveform.

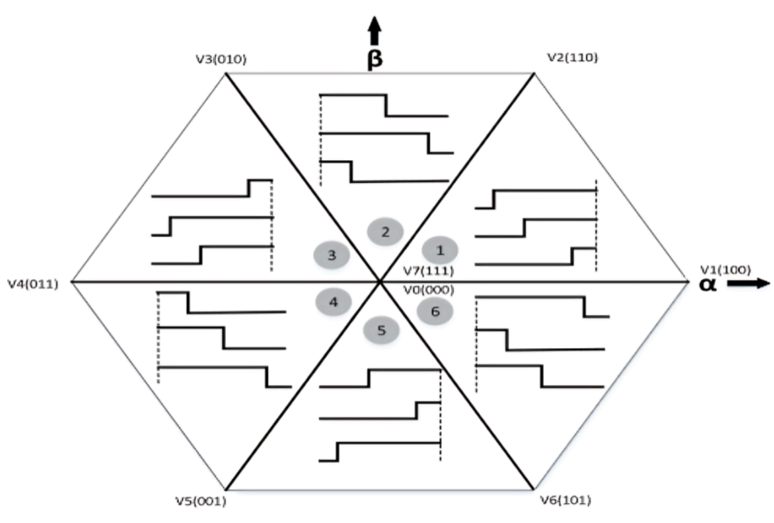


Fig 3.4.1: Gate pulse of all 3-phases in each sector of the proposed SVPWM

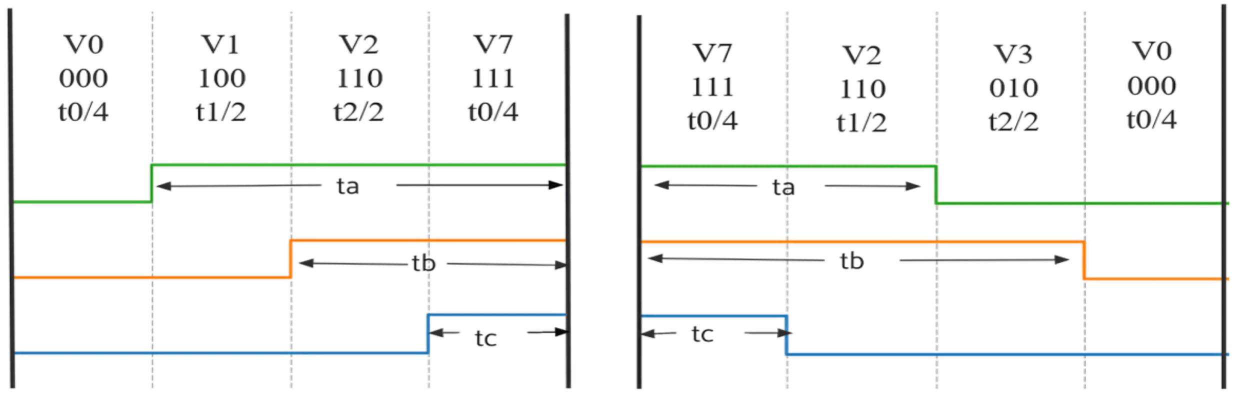


Fig 3.4.2:Gate pulses for all 3-phases in sector 1 and sector 2

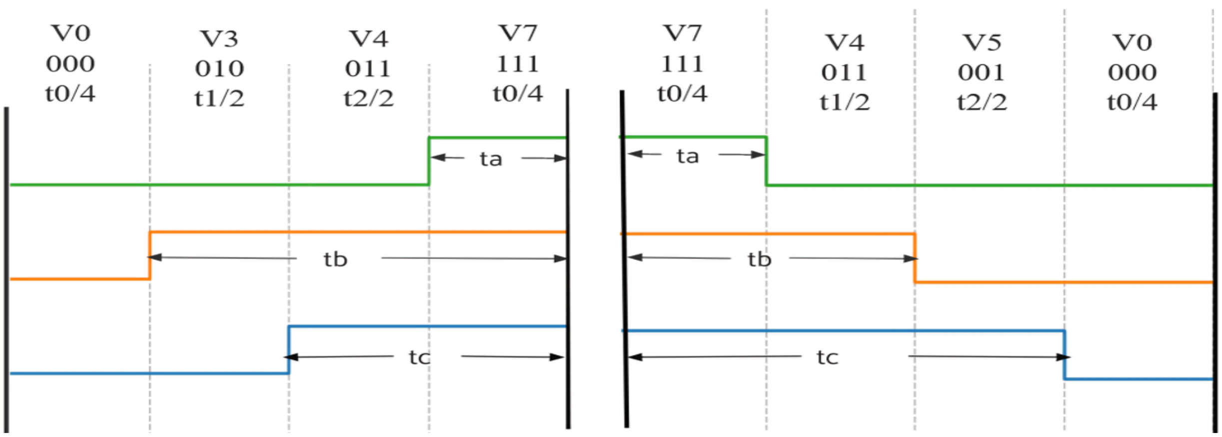


Fig 3.4.3:Gate pulses for all 3-phases in sector 3 and sector 4

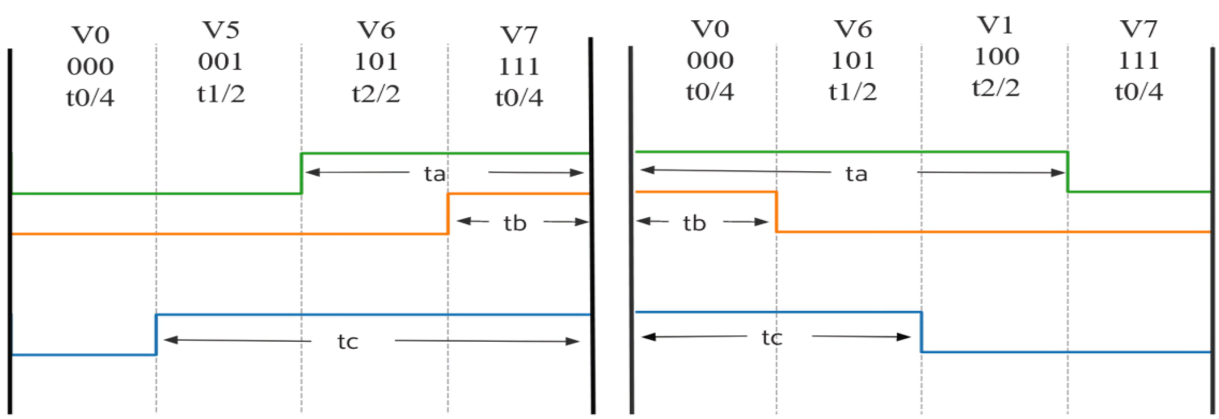


Fig 3.4.4:Gate pulses for all 3-phases in sector 5 and sector 6

CHAPTER 4

SIMULATION

4.1 PROPOSED 2 LEVEL SVPWM

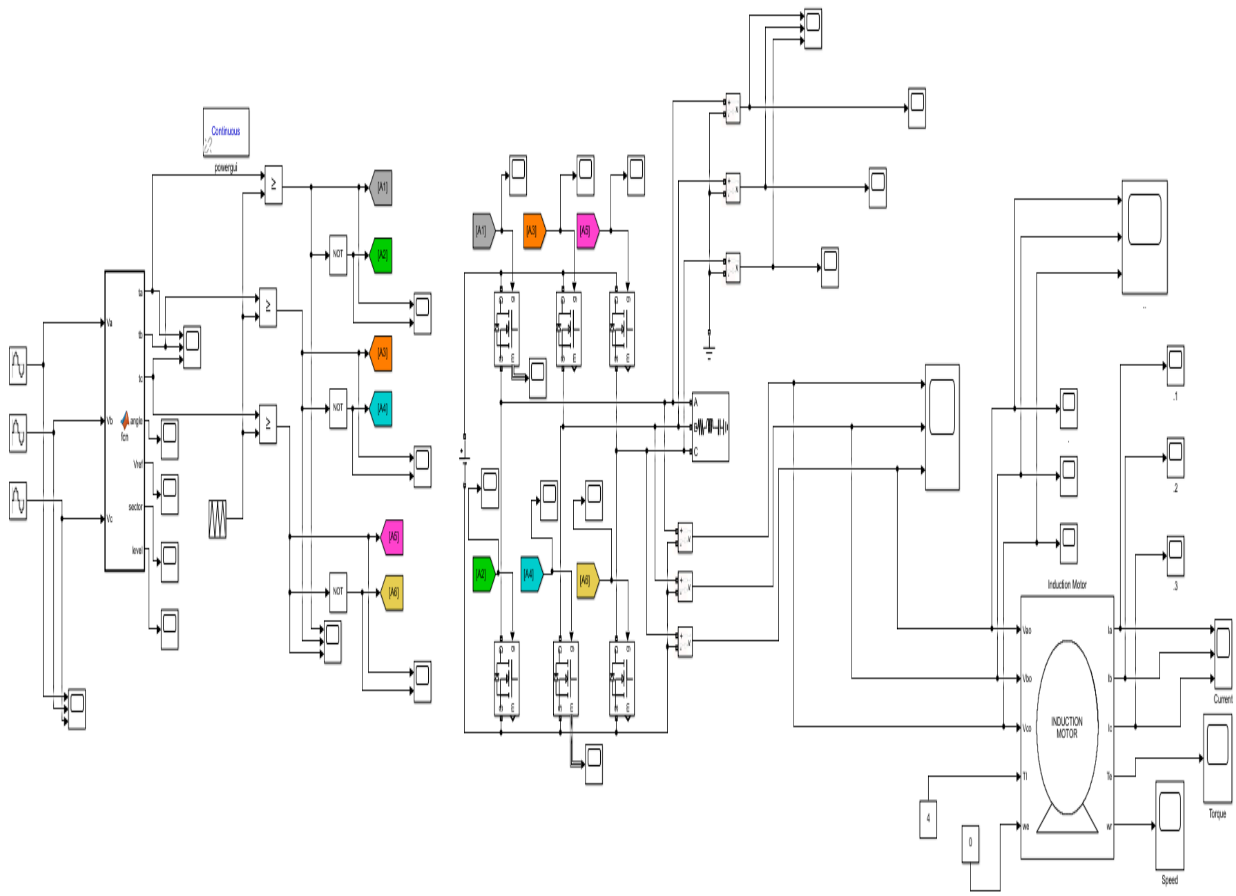


Fig 4.1.1: Simulation of proposed 2 level SVPWM

In the simulation setup of the proposed two-level Space Vector Pulse Width Modulation scheme, sinusoidal waveform blocks are connected to a MATLAB function block. Within this MATLAB function block, the algorithm for the SVPWM scheme is implemented, generating switching signals based on the reference sinusoidal waveforms. These switching signals are crucial as they dictate the on and off states of the power switches in the inverter.The generated switching signals are then compared with a repeating sequence to accurately generate the required pulse patterns. This comparison ensures that the pulses precisely align with the desired waveform characteristics. Once the pulses are generated, they are distributed to the inverter, which typically consists of six switches arranged in three pairs, forming the three-phase output.Each leg of the inverter, representing one phase of the motor, comprises two switches, of MOSFETs. These switches control the flow of current through the motor windings, allowing for precise modulation of voltage and frequency.

The generated pulses are distributed to the respective switches of the inverter according to the SVPWM scheme's logic. By appropriately turning on and off the switches in the inverter, the desired voltage waveform is synthesized, mimicking the behavior of a sinusoidal waveform. Finally, the inverter output is connected to a three-phase induction motor. The synthesized voltage waveform generated by the inverter drives the motor, controlling its speed and torque output. Through this process, the SVPWM scheme enables efficient and precise control of the induction motor, making it suitable for various industrial applications requiring accurate speed and torque regulation.

4.2 PROPOSED 3 LEVEL SVPWM

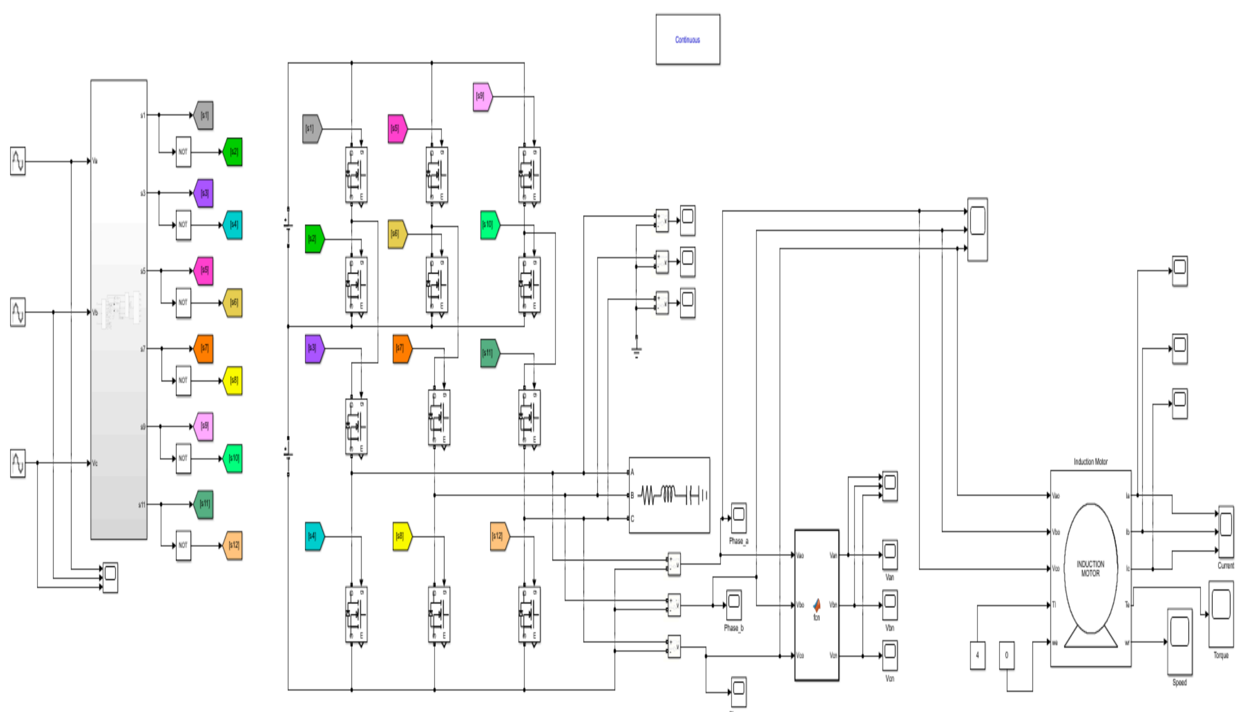


Fig 4.1.2: Simulation of proposed 3 level SVPWM

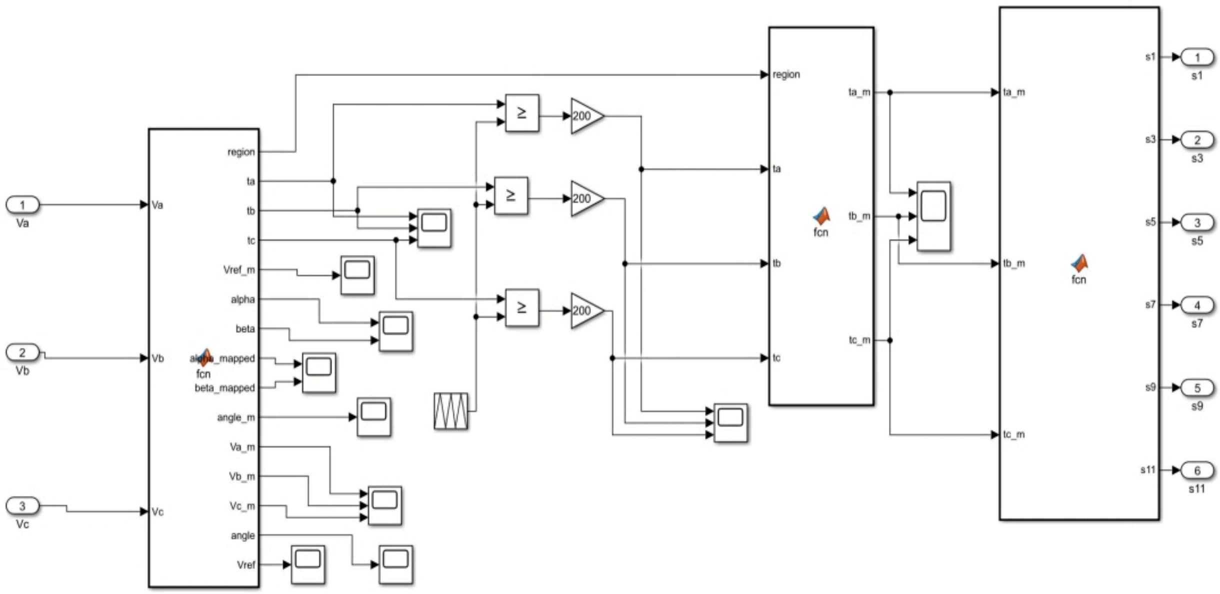


Fig 4.1.3: Subsystem Simulation of proposed 3 level SVPWM

In the proposed simulation of a three-level Space Vector Pulse Width Modulation (SVPWM) scheme, the initial process mirrors that of the two-level setup. Sinusoidal waveform blocks are still utilized and connected to a MATLAB function block, where the SVPWM algorithm generates switching signals based on these reference waveforms. These signals are then compared with a repeating sequence to produce the required pulse patterns, ensuring precise alignment with the desired waveform characteristics.Here,two inverters are cascaded, meaning there are now four switches (MOSFETs) in each leg. Consequently, the total number of switches in the setup increases to twelve. Each leg of the cascaded inverter represents one phase of the motor and contains four switches for precise control over current flow through the motor windings.

Similar to the two-level setup, the generated pulses are appropriately distributed to all twelve switches according to the logic of the SVPWM scheme. This ensures that the desired voltage waveform is synthesized accurately, mimicking sinusoidal behavior. Finally, the output of the cascaded inverters is connected to the three-phase induction motor, where the synthesized voltage waveform drives the motor, controlling its speed and torque output. Through this process, the three-level SVPWM scheme enables efficient and precise control of the induction motor, suitable for various industrial applications requiring accurate speed and torque regulation.

4.3 MOTOR MODEL

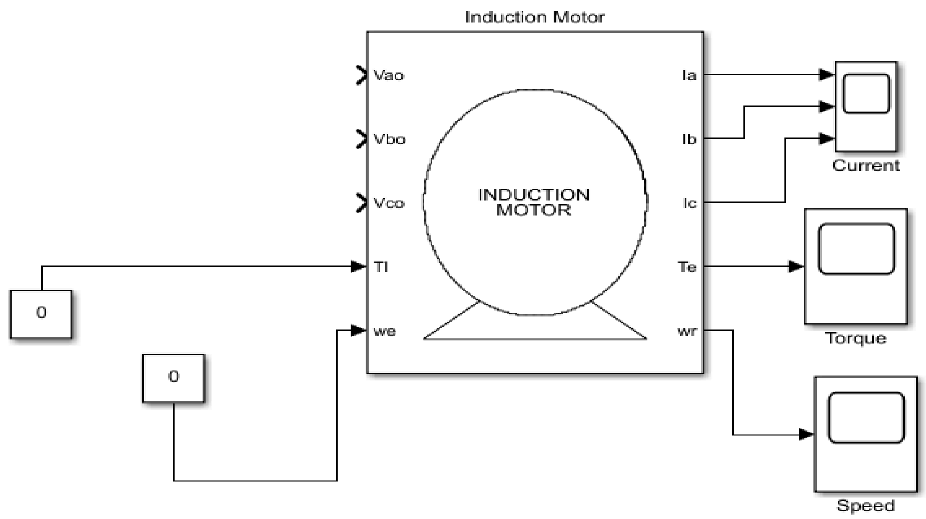


Fig 4.1.4: Induction Motor Model

Table 3: Motor Model Specifications

Motor Model Specification	Value
Rotor Resistance	0.8160 Ω
Stator Resistance	0.4350 Ω
Rotor Inductance	0.0020 H
Voltage	311.1240 volts (RMS value)
Frequency	60 Hz
Number of Poles	4
Base Speed	377 radians per second
Base Torque	11.9000 Nm
Stator Leakage Reactance	0.7540 Ω
Rotor Leakage Reactance	0.7540 Ω
Magnetizing Reactance	26.1300 Ω

CHAPTER 5

SIMULATION RESULTS

5.1 2 LEVEL SVPWM SIMULATION RESULTS

5.1.1 Conventional 2 level SVPWM

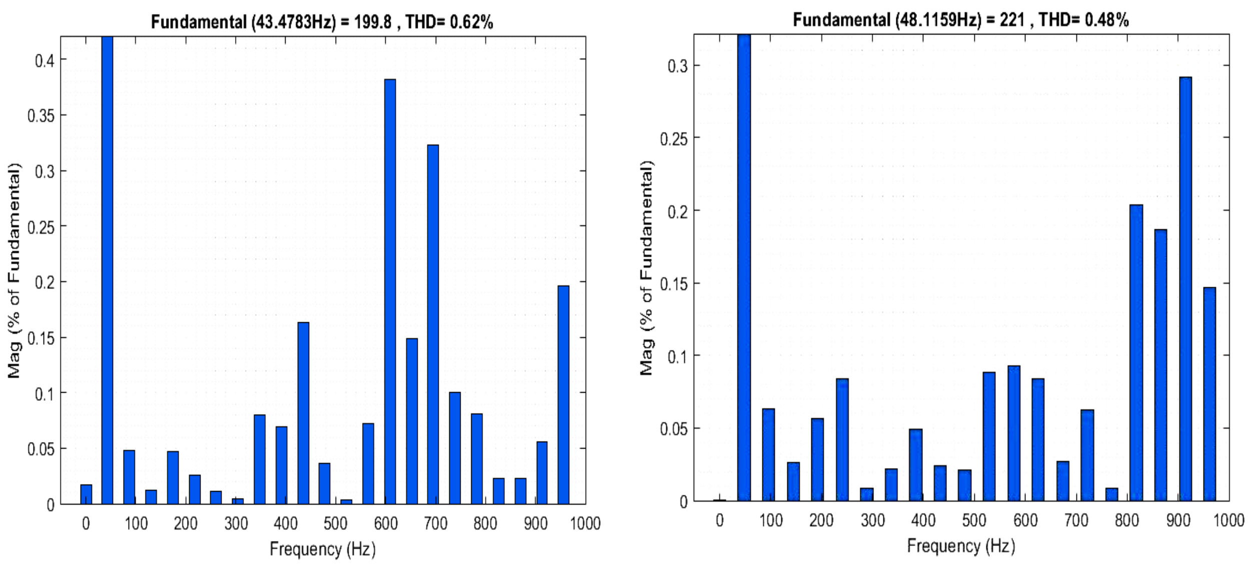


Fig 5.1.1 Harmonic spectrum of phase-a voltage of 3 phase Induction Motor of MI 0.75 and 0.8

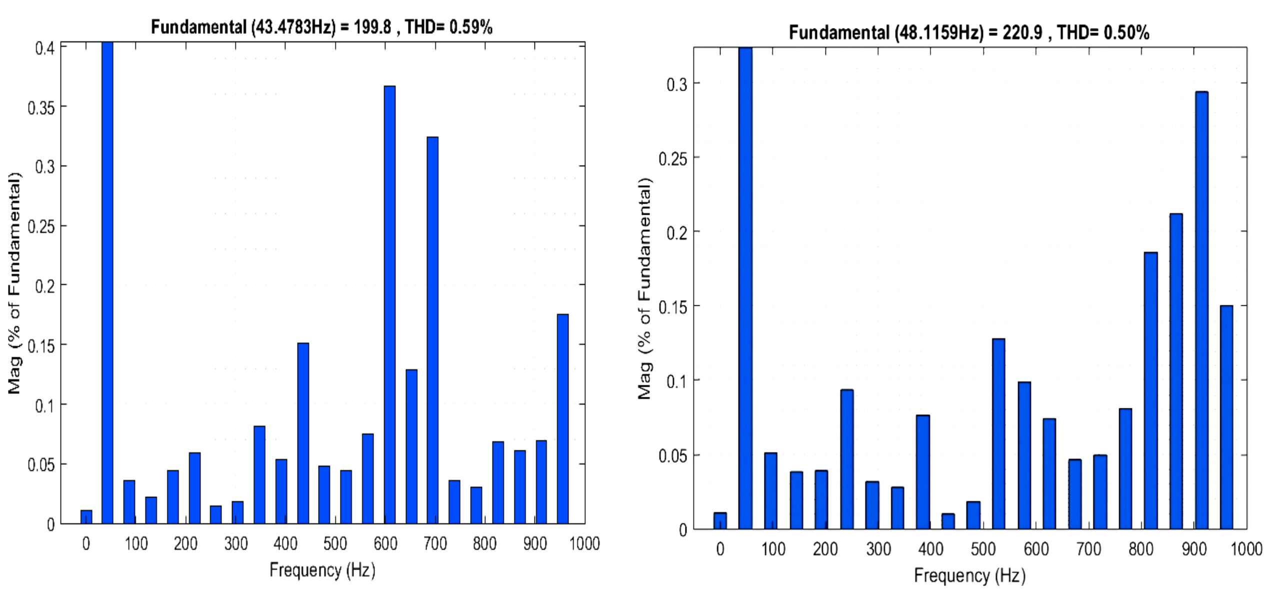
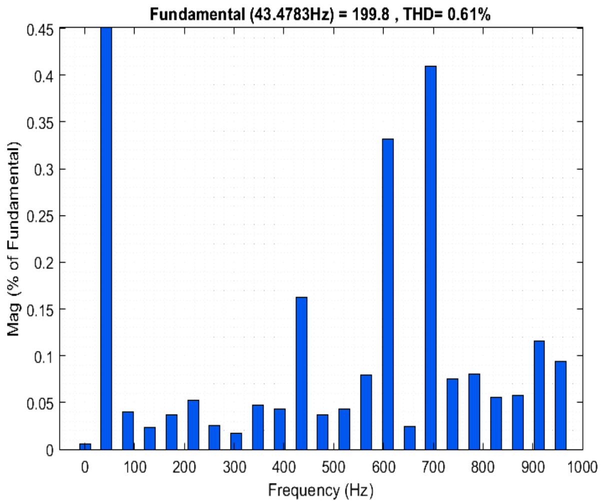


Fig 5.1.2 Harmonic spectrum of phase-b voltage of 3 phase Induction Motor of MI 0.75 and 0.8



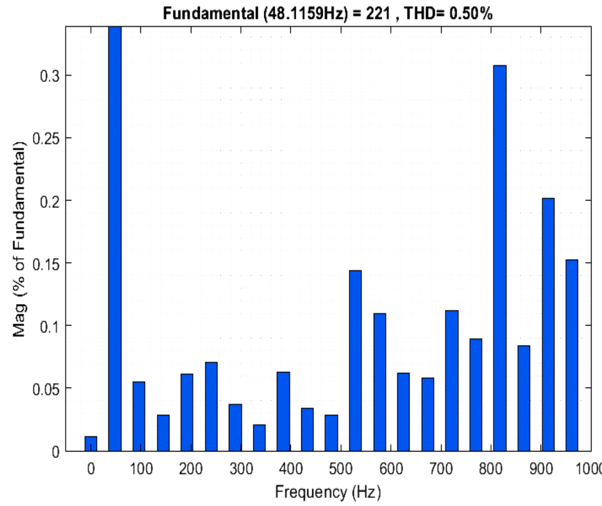
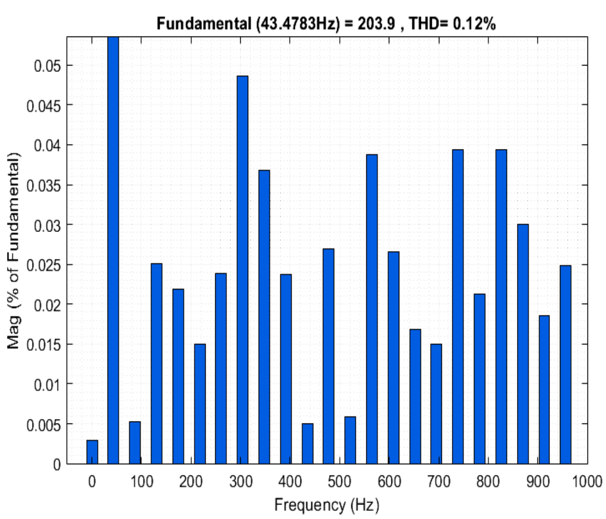


Fig 5.1.3 Harmonic spectrum of phase-c voltage of 3 phase Induction Motor of MI 0.75 and 0.8

The analysis of the harmonic spectrum of phase voltages for a three-phase induction motor employing FFT analysis under the conventional two-level Space Vector Pulse Width Modulation (SVPWM) scheme revealed valuable insights. With a modulation index (MI) of 0.75, the examination unveiled harmonic distortion levels of 0.62%, 0.59%, and 0.61% for phase-a, phase-b, and phase-c voltages respectively. Subsequently, under an increased modulation index of 0.8, the harmonic distortion levels improved to 0.48%, 0.50%, and 0.50% for phase-a, phase-b, and phase-c voltages respectively.

5.1.2 Proposed 2 level SVPWM



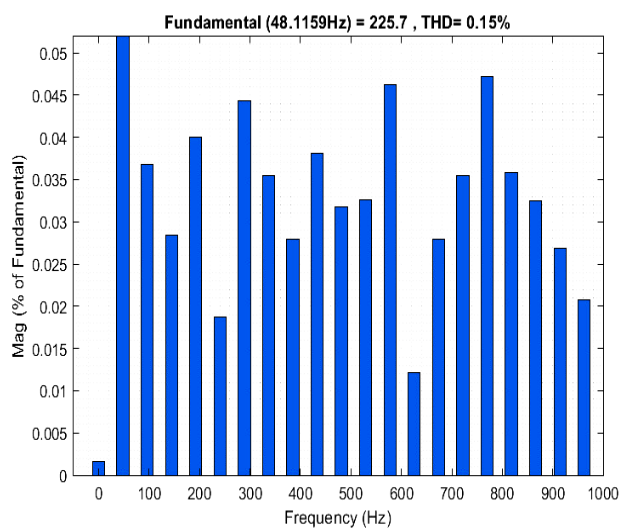


Fig 5.1.4 Harmonic spectrum of phase-a voltage of 3 phase Induction Motor of MI 0.75 and 0.8

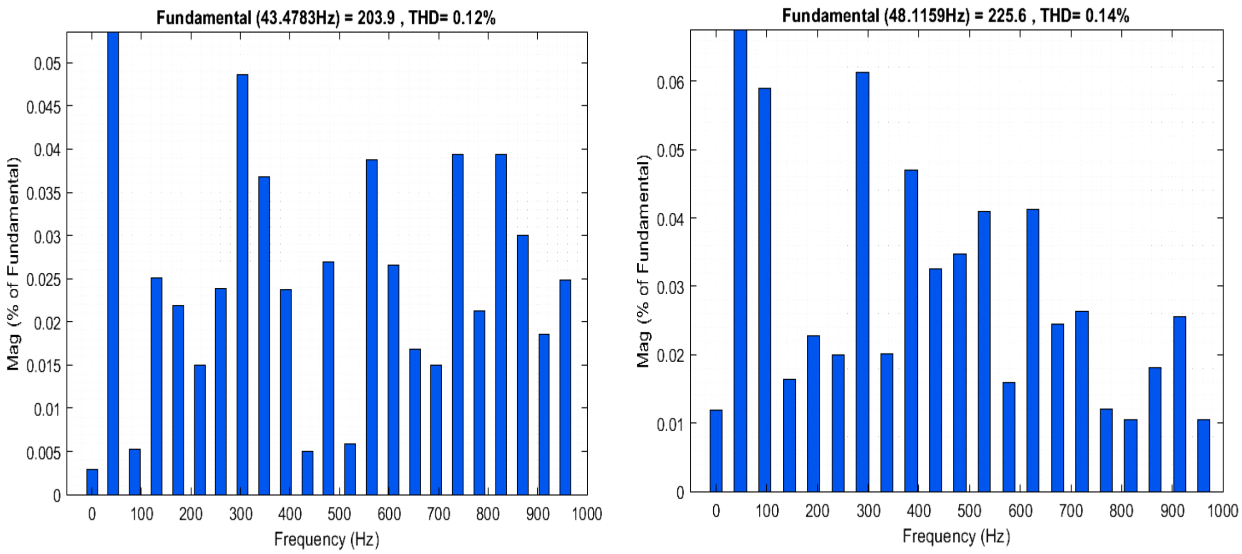


Fig 5.1.5 Harmonic spectrum of phase-b voltage of 3 phase Induction Motor for MI 0.75 and 0.8

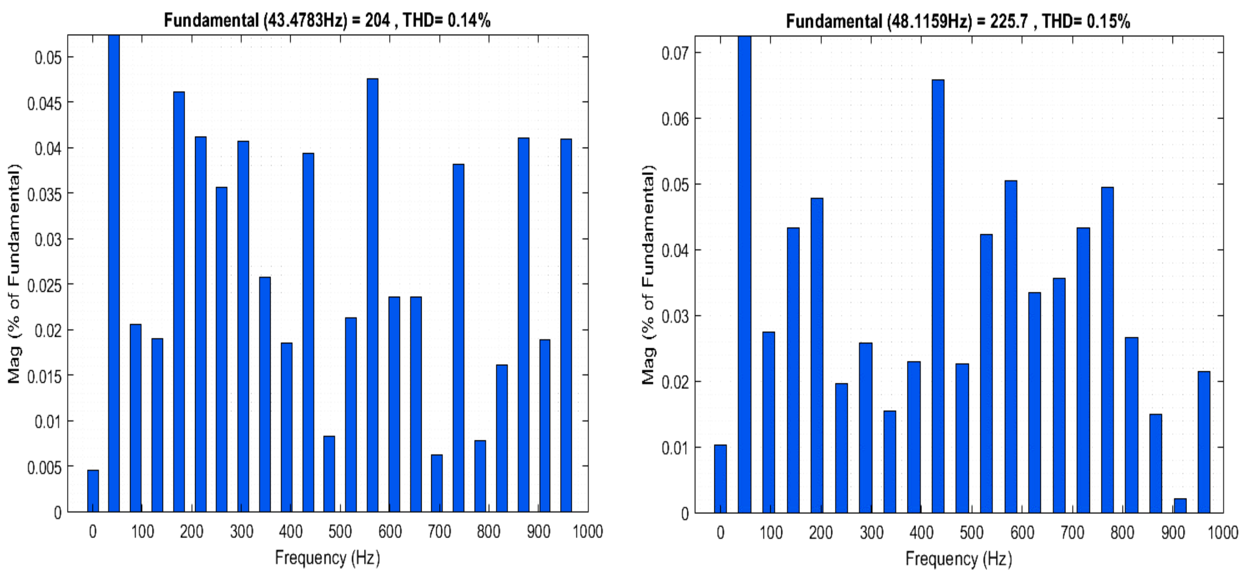


Fig 5.1.6 Harmonic spectrum of phase-c voltage of 3 phase Induction Motor for MI 0.75 and 0.8

The analysis of the harmonic spectrum of phase voltages for a three-phase induction motor, conducted using FFT analysis in conjunction with the proposed two-level Space Vector Pulse Width Modulation (SVPWM) scheme, revealed insightful findings. Under a modulation index (MI) of 0.75, the examination unveiled harmonic distortion levels of 0.12%, 0.12%, and 0.14% for phase-a, phase-b, and phase-c voltages respectively. Similarly, at a modulation index of 0.8, the harmonic distortion levels were measured at 0.15%, 0.14%, and 0.15% for phase-a, phase-b, and phase-c voltages respectively. These results illustrate the impact of modulation index variations on harmonic distortion levels, indicating the effectiveness of the proposed SVPWM scheme in mitigating harmonics and ensuring relatively low distortion levels in the induction motor's phase voltages.

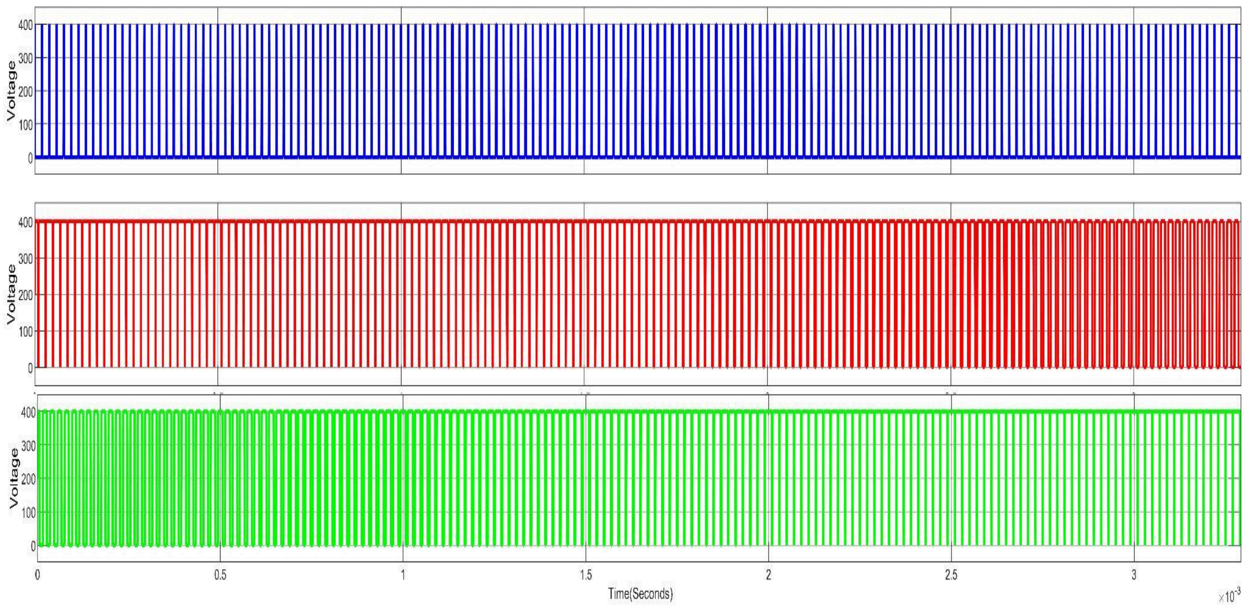


Fig 5.1.7 Pole Voltages of a 3 phase Induction Motor of the 2 level Proposed SVPWM.

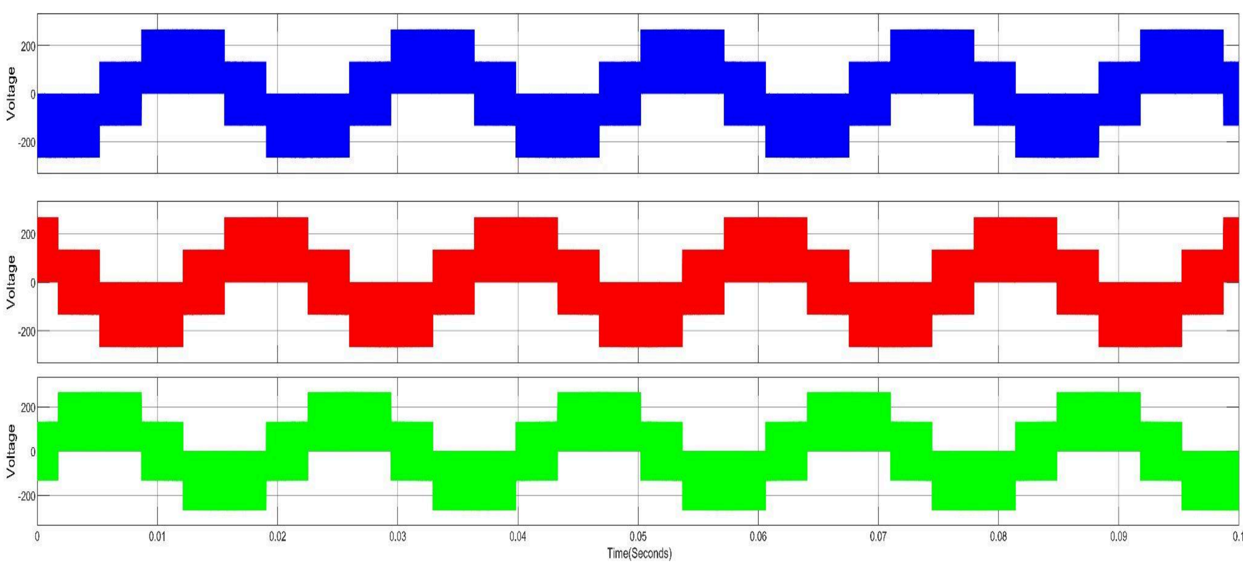


Fig 5.1.8 Phase Voltages of a 3 phase Induction Motor of the 2 level Proposed SVPWM.

The phase voltage and pole voltage waveforms obtained from a three-phase induction motor offer critical insights into its operational behavior and performance characteristics. Phase voltage waveforms depict the instantaneous voltage across each phase of the motor, providing essential information about the voltage supplied to individual windings during operation.Where,pole voltage waveforms represent the voltage across the motor's poles, reflecting the magnetic flux distribution within the motor's core. These waveforms are vital for assessing the motor's magnetic saturation, core losses, and overall magnetic performance.

5.2 3 LEVEL SVPWM SIMULATION RESULTS

5.2.1 Conventional 3 level SVPWM

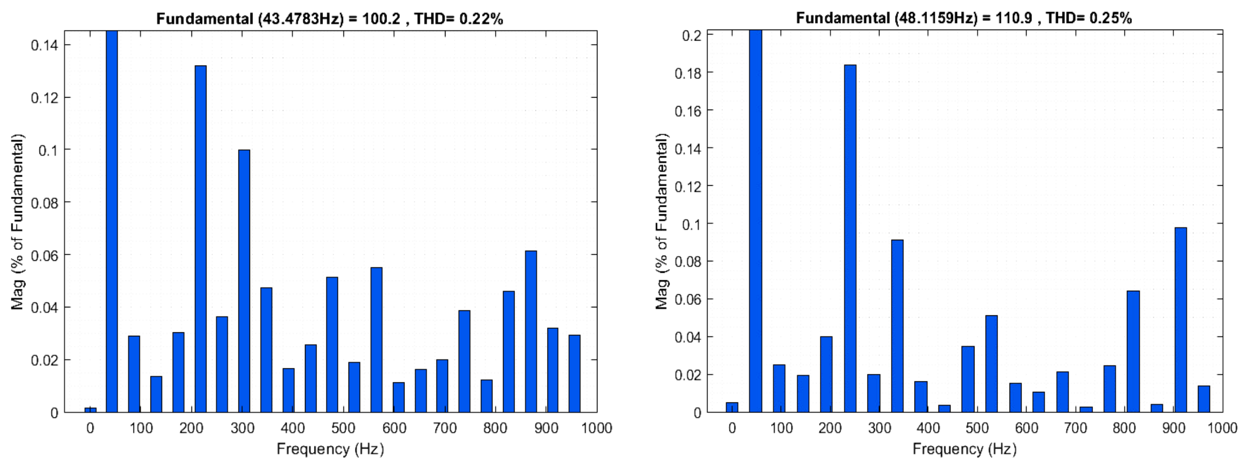


Fig 5.2.1 Harmonic spectrum of phase-a voltage of 3 phase Induction Motor of MI 0.75 and 0.8

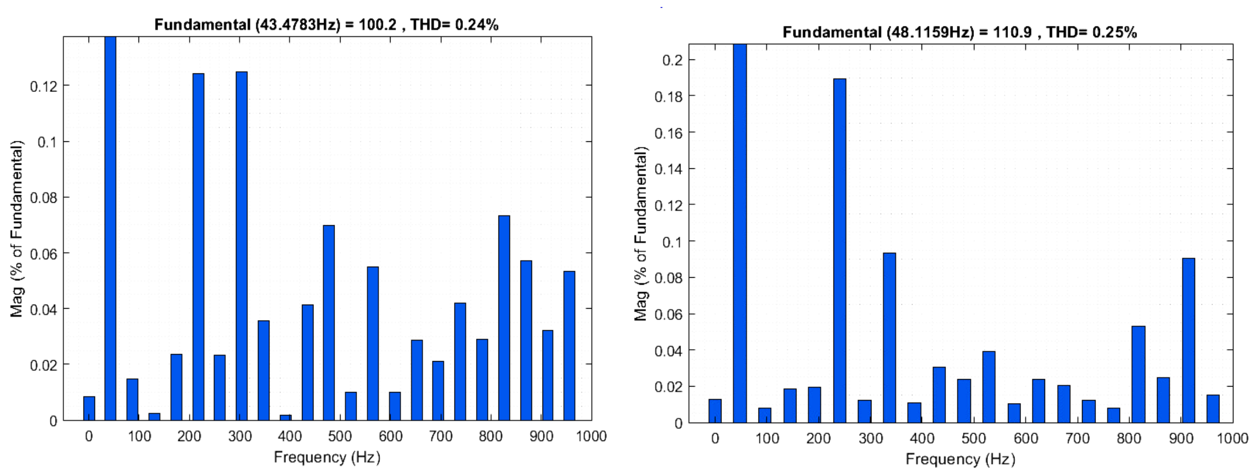


Fig 5.2.2 Harmonic spectrum of phase-b voltage of 3 phase Induction Motor of MI 0.75 and 0.8

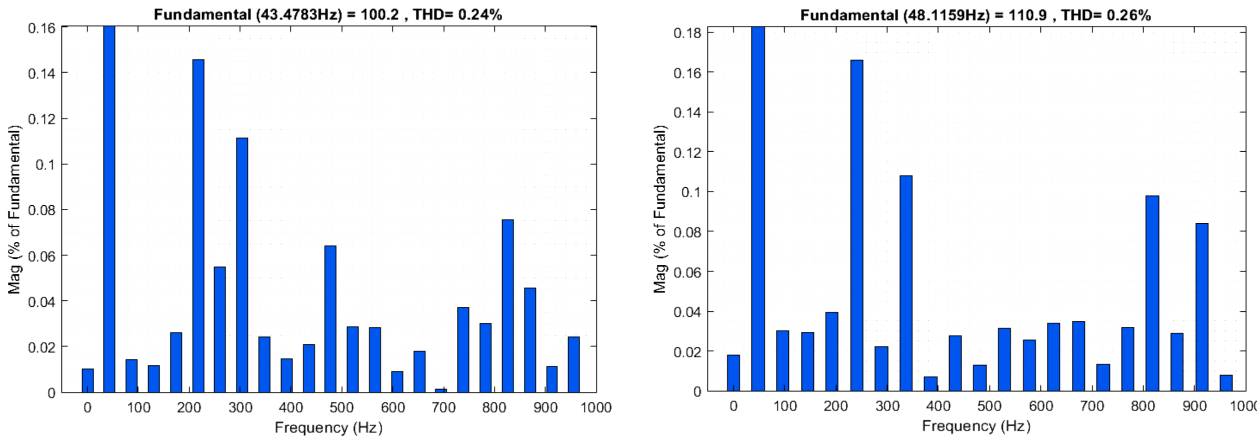


Fig 5.2.3 Harmonic spectrum of phase-c voltage of 3 phase Induction Motor of MI 0.75 and 0.8

The analysis of the harmonic spectrum of phase voltages for a three-phase induction motor employing FFT analysis, and utilizing the conventional three-level SVPWM scheme, revealed insightful findings. With a modulation index of 0.75, the examination unveiled harmonic distortion levels of 0.22%, 0.24%, and 0.24% and under a modulation index of 0.8, these distortion levels slightly increased to 0.25%, 0.26%, and 0.25% for phase-a, b and c voltages respectively.

5.2.2 Proposed 3 level SVPWM

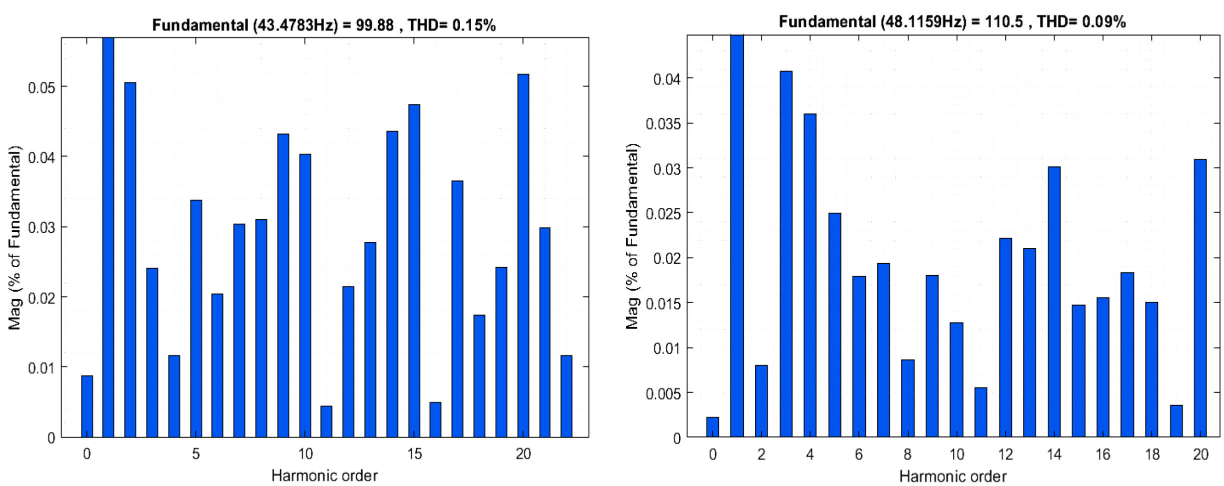


Fig 5.2.4 Harmonic spectrum of phase-a voltage of 3 phase Induction Motor of MI 0.75 and 0.8

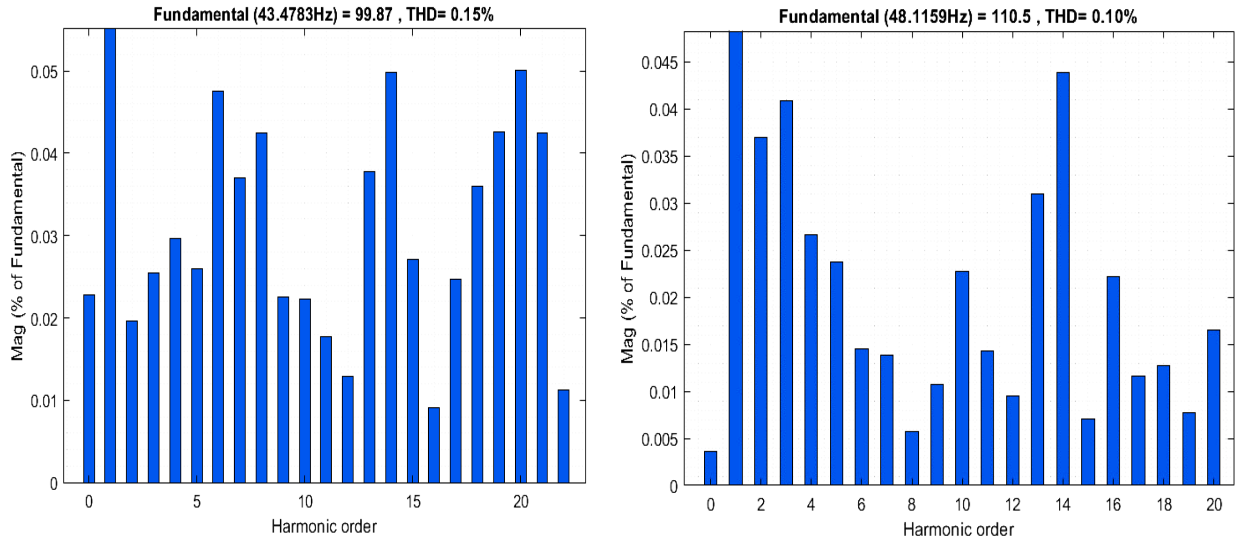


Fig 5.2.5 Harmonic spectrum of phase-b voltage of 3 phase Induction Motor of MI 0.75 and 0.8

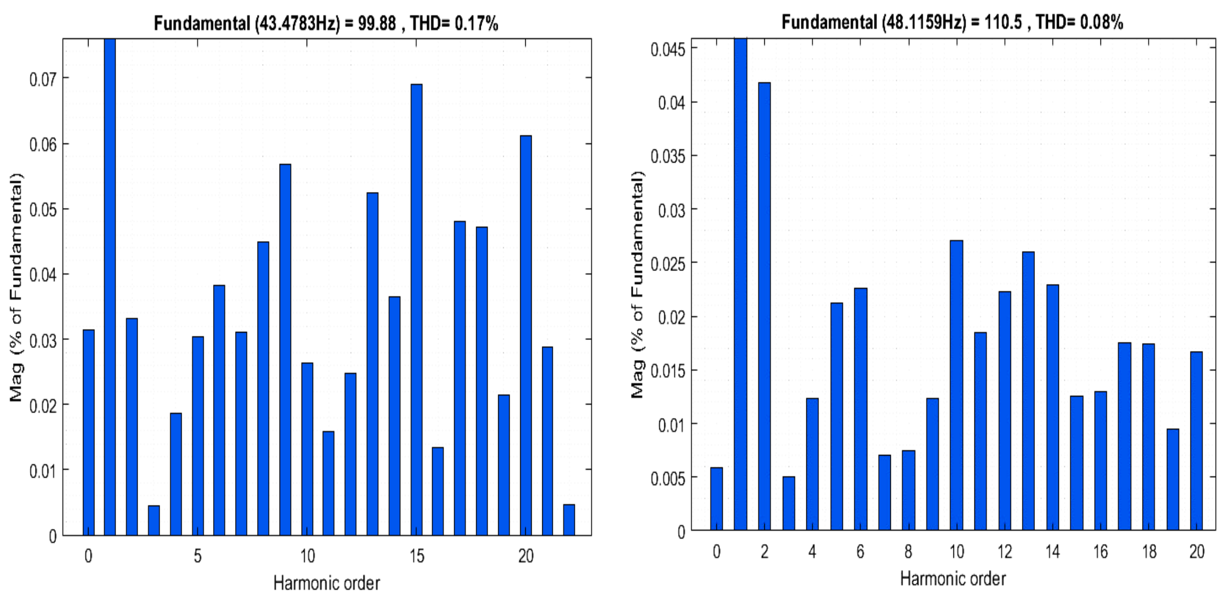


Fig 5.2.6 Harmonic spectrum of phase-c voltage of 3 phase Induction Motor of MI 0.75 and 0.8

The analysis of the harmonic spectrum of phase voltages for a three-phase induction motor, employing FFT analysis alongside the proposed three-level Space Vector Pulse Width Modulation (SVPWM) scheme, unveiled compelling results. At a modulation index (MI) of 0.75, the examination revealed harmonic distortion levels of 0.15%, 0.15%, and 0.17% for phase-a, phase-b, and phase-c voltages respectively. Upon increasing the modulation index to 0.8, the distortion levels exhibited a notable decrease, with values of 0.09%, 0.10%, and 0.08% observed for phase-a, phase-b, and phase-c voltages respectively.

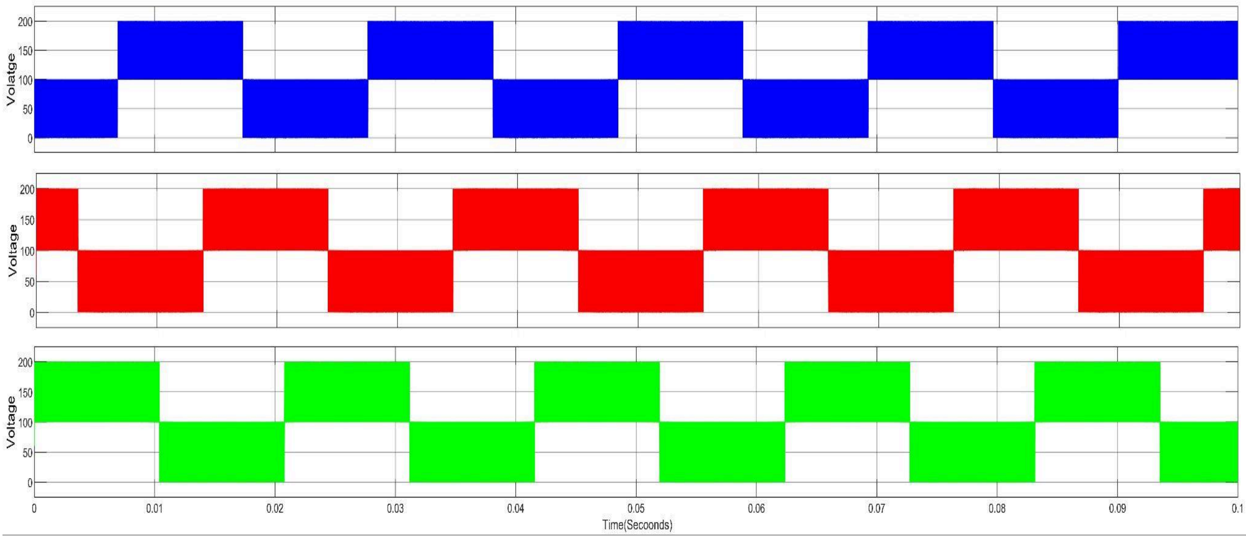


Fig 5.2.7 Pole Voltages of a 3 phase Induction Motor 3 level Proposed SVPWM

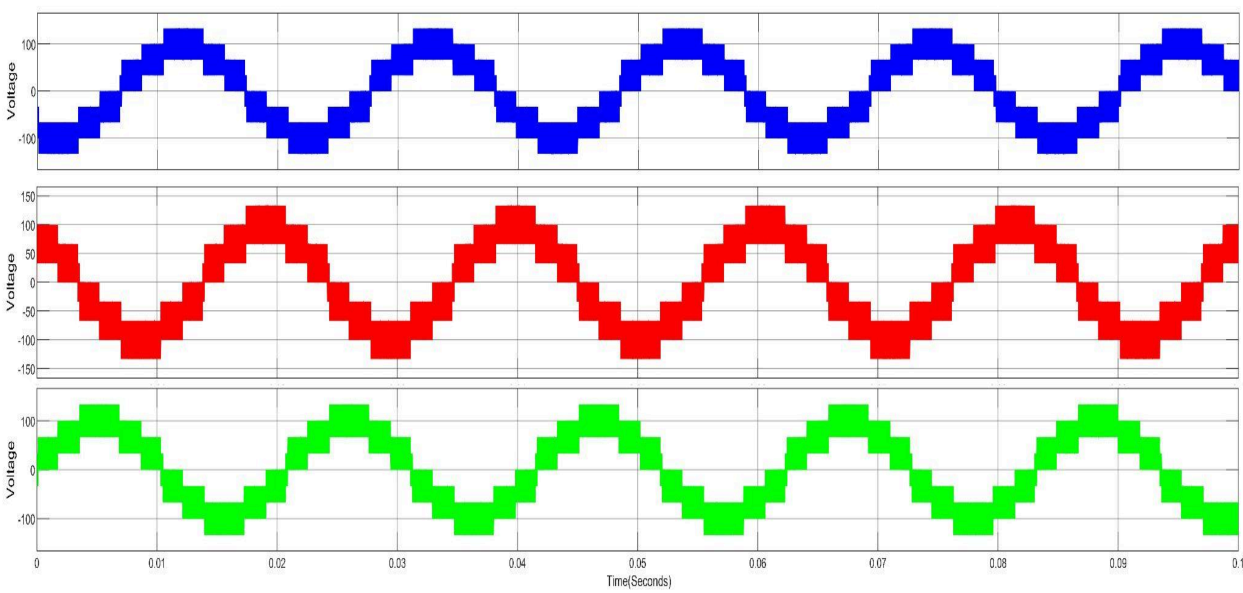


Fig 5.2.8 Phase Voltages of a 3 phase Induction Motor 3 level Proposed SVPWM

The phase voltage and pole voltage waveforms obtained from the three-phase induction motor connected to the inverter under the proposed three-level Space Vector Pulse Width Modulation (SVPWM) scheme represent a significant advancement in motor control technology. In transitioning from a two-level to a three-level SVPWM scheme, a noticeable improvement in the waveform quality is observed. Specifically, the phase voltage waveform tends towards a more sinusoidal shape as the number of voltage levels increases. This phenomenon is attributed to the enhanced resolution and finer control offered by the three-level SVPWM scheme, allowing for smoother transitions between voltage states and reduced harmonic content in the output waveform. The nearly sinusoidal phase voltage waveform signifies improved motor performance, including reduced torque ripple, minimized electromagnetic interference, and enhanced efficiency.

Table:4 Comparison table for THD for the MI 0.75 and 0.8

Technique	**Conventional**				**Proposed**			
	2 Level		**3 Level**		**2 Level**		**3 Level**	
MI	**0.75**	**0.8**	**0.75**	**0.8**	**0.75**	**0.8**	**0.75**	**0.8**
Phase-a	0.62	0.48	0.12	0.25	0.22	0.15	0.15	0.09
Phase-b	0.59	0.50	0.12	0.26	0.24	0.14	0.15	0.10
Phase-c	0.61	0.50	0.14	0.25	0.24	0.15	0.17	0.08

The comparison of harmonic distortion levels across different modulation indices and SVPWM schemes for the phase voltages of a three-phase induction motor yields insightful observations. In the conventional two-level SVPWM scheme, increasing the modulation index from 0.75 to 0.8 led to a decrease in harmonic distortion levels from 0.62%, 0.59%, and 0.61% to 0.48%, 0.50%, and 0.50% for phase-a, phase-b, and phase-c voltages respectively. However, for both the conventional three-level SVPWM and the proposed two-level SVPWM schemes, an increase in modulation index resulted in higher harmonic distortion levels. Specifically, under the conventional three-level scheme, distortion levels rose from 0.22%, 0.24%, and 0.24% to 0.25%, 0.26%, and 0.25% for phase-a, phase-b, and phase-c voltages respectively, when the modulation index increased from 0.75 to 0.8. Conversely, in the proposed two-level scheme, distortion levels increased from 0.12%, 0.12%, and 0.14% to 0.15%, 0.14%, and 0.15% for phase-a, phase-b, and phase-c voltages respectively.

Further scrutiny reveals a noteworthy trend regarding the proposed three-level SVPWM scheme. Despite the increase in modulation index from 0.75 to 0.8, harmonic distortion levels experienced a significant reduction, showcasing values of 0.15%, 0.15%, and 0.17% decreasing to 0.09%, 0.10%, and 0.08% for phase-a, phase-b, and phase-c voltages respectively. This distinctive reduction in harmonic distortion levels in the proposed three-level scheme compared to both conventional two and three-level schemes underscores its effectiveness in mitigating harmonics and improving waveform quality, particularly at higher modulation indices. Moreover, this comparison elucidates the progressive decrease in harmonic distortion levels with an increase in the number of levels in the SVPWM scheme, highlighting the importance of modulation technique selection in achieving optimal motor performance and efficiency.

5.2.3 Waveform of Induction Motor

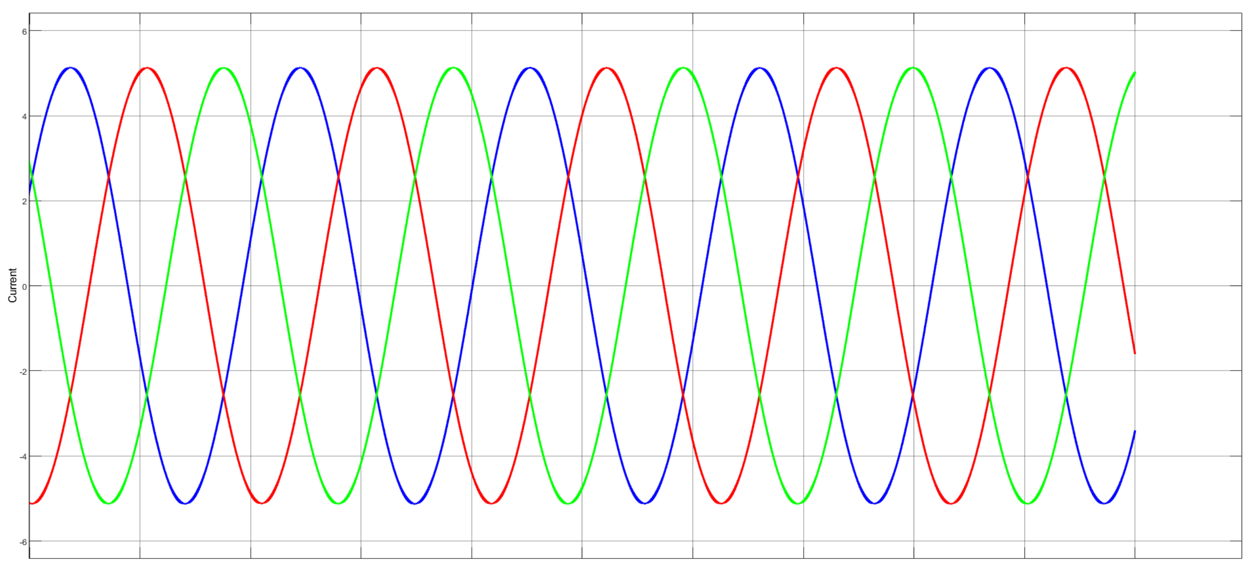


Fig 5.2.9.Current vs time waveform of induction motor

In an induction motor controlled by SVPWM (Space Vector Pulse Width Modulation), the current waveform won't directly exhibit a perfect 120° phase shift. SVPWM is a technique for generating a three-phase AC voltage output from a DC source using rapid switching. This creates a stepped waveform, but the average effect on the motor appears close to a three-phase sine wave with 120° phase displacement between each phase. The actual current waveform will be influenced by motor parameters and load conditions, but SVPWM aims to achieve smooth control and near-sinusoidal currents for efficient motor operation.

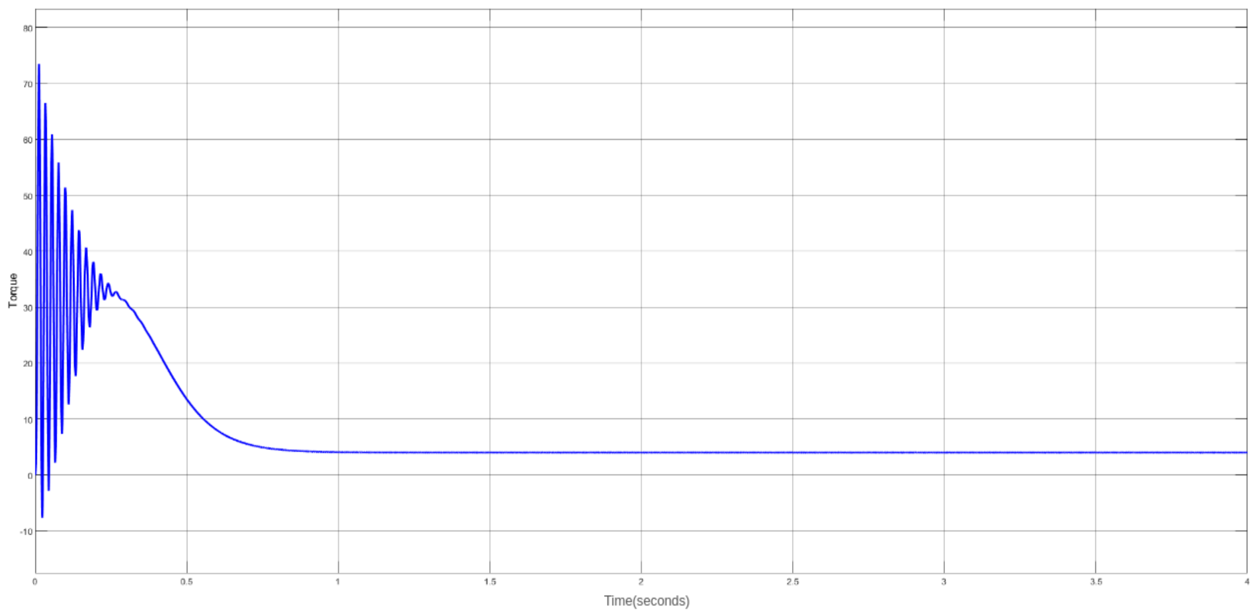


Fig 5.2.10 Torque vs time waveform of induction motor

In an induction motor controlled by SVPWM (Space Vector Pulse Width Modulation), the torque waveform can be significantly improved to minimize ripples. SVPWM achieves this by strategically applying voltage vectors to the motor windings. Unlike simpler PWM techniques, SVPWM creates a more sinusoidal voltage output, resulting in a smoother torque waveform. This translates to reduced torque pulsations, leading to quieter operation and less mechanical stress on the motor.

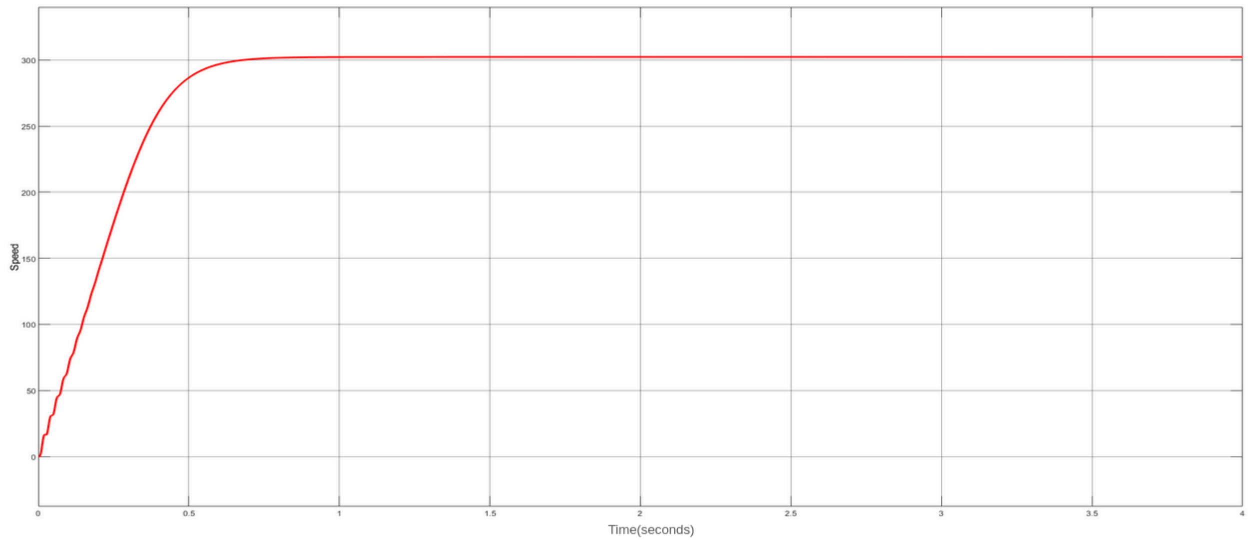


Fig 5.2.11 Speed vs time waveform of induction motor

In an induction motor, precise speed control is often achieved using SVPWM (Space Vector Pulse Width Modulation). SVPWM translates a desired sinusoidal reference voltage into switching patterns for the inverter that drives the motor. This switching creates a stepped approximation of the smooth sine wave.

The resulting motor speed waveform reflects this stepping pattern. While not perfectly sinusoidal, SVPWM offers significant advantages. Compared to simpler techniques, SVPWM reduces harmonic distortion in the output voltage, leading to smoother motor operation and improved efficiency. Additionally, SVPWM allows for better utilization of the DC bus voltage, enabling higher achievable motor speeds.

CHAPTER 6
CONCLUSION

In this study, I have investigated and compared different SVPWM strategies conventional 2-level SVPWM, conventional 3-level SVPWM, and a proposed 2-level SVPWM along with the implementation of the proposed scheme in a 3-level configuration. My primary goal was to evaluate the performance of these modulation techniques in terms of Total Harmonic Distortion (THD) reduction when applied to drive a 3-phase induction motor.

Firstly, I have implemented the conventional 2-level SVPWM technique. This method, although widely used, exhibited limitations in terms of harmonic reduction due to its inherent modulation characteristics. I have observed significant THD levels under varying load conditions, which prompted us to explore alternative approaches.

Subsequently, I have tested the conventional 3-level SVPWM technique. This method inherently provides better harmonic performance compared to the 2-level counterpart by utilizing additional voltage levels. However, challenges such as increased complexity and switching losses were encountered, motivating us to explore further refinements.

The study then introduced a novel 2-level SVPWM scheme, proposed with the aim of addressing the shortcomings observed in the conventional methods. This new approach leveraged innovative modulation strategies to optimize harmonic performance while maintaining simplicity in implementation.

The proposed 2-level SVPWM was further extended and adapted for a 3-level topology, offering a balance between complexity and harmonic mitigation. This configuration was then implemented in motor drive setup for practical validation.

Upon implementation and comparative analysis, I have observed a substantial reduction in THD levels when employing the proposed 3-level SVPWM compared to the other schemes investigated. This outcome validated the effectiveness of this proposed method in achieving superior harmonic performance under load.

The key advantage of this proposed approach lies in its ability to efficiently reduce THD levels while preserving implementation simplicity, crucial for practical industrial applications. By optimizing the voltage space vector switching and modulation techniques, I was able to achieve cleaner waveforms and enhanced motor performance.

In conclusion, my study underscores the importance of selecting an appropriate SVPWM strategy tailored to specific motor drive requirements. The proposed 2-level and extended 3-level SVPWM techniques offer promising solutions for enhancing motor drive performance by minimizing harmonic distortions, thereby improving efficiency and reducing operational costs in industrial applications.

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