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Simplified PWM Algorithms for three phase Multilevel Inverter

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Abstract: Multilevel inverters have emerged as essential components in modern power electronics systems, offering significant advantages in voltage and waveform quality control for various applications. This paper explores the design, analysis, and implementation of a Multilevel Inverter to address the increasing demand for efficient and flexible power conversion solutions in industries like renewable energy integration, electric transportation, and grid-tied systems. Multilevel inverters are increasingly important in power electronics due to their ability to generate high-quality voltage waveforms with reduced harmonic content. Pulse Width Modulation (PWM) techniques play a pivotal role in controlling multilevel inverters. This paper focuses on the development and evaluation of simplified PWM algorithms tailored to multilevel inverter topologies. The designed PWM algorithms are simulated using MATLAB to assess their performance in terms of voltage quality, harmonic distortion, and switching losses. Comparative analyses with existing PWM techniques are conducted to highlight the advantages of the proposed simplified algorithms.

Index Terms **-** Multilevel inverter, Pulse Width Modulation (PWM), Power electronics, Harmonic distortion, Voltage quality, Switching losses.

I. Introduction

Multilevel inverters have become indispensable components in contemporary power electronics systems, offering significant advancements in voltage and waveform quality control for a myriad of applications. With the ever-increasing demand for efficient and flexible power conversion solutions in industries such as renewable energy integration, electric transportation, and grid-tied systems, the importance of multilevel inverters continues to grow. These inverters excel in generating high-quality voltage waveforms while minimizing harmonic content, thereby enhancing the performance and reliability of power systems. A crucial aspect of controlling multilevel inverters lies in Pulse Width Modulation (PWM) techniques. PWM plays a pivotal role in achieving precise control over the output voltage, ensuring optimal performance across diverse operating conditions. However, the complexity associated with conventional PWM algorithms often presents challenges in practical implementation and real-time control. This paper delves into the design, analysis, and implementation of simplified PWM algorithms tailored specifically to multilevel inverter topologies. The primary objective is to develop PWM techniques that offer enhanced efficiency and ease of implementation while maintaining superior voltage quality and minimizing harmonic distortion. Through comprehensive simulations using MATLAB, the performance of these simplified PWM algorithms is rigorously evaluated, encompassing aspects such as voltage quality, harmonic distortion, and switching losses.

II. Multilevel Inverters

Multilevel inverters are power electronic devices designed to convert DC (direct current) voltage into AC (alternating current) voltage with superior waveform quality. Unlike traditional two-level inverters, which generate output voltage with only two voltage levels (positive and negative), multilevel inverters synthesize output voltage using multiple levels, typically achieved using series-connected power semiconductor devices. This approach results in smoother voltage waveforms with reduced harmonic distortion, making multilevel inverters ideal for applications.

Three most used multilevel inverter topologies are:

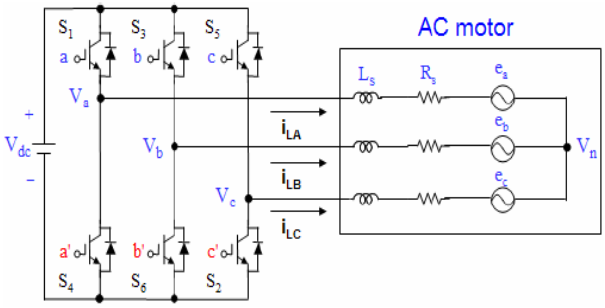
- Cascaded H-bridge multilevel inverters.
- Diode Clamped multilevel inverters.
- Flying Capacitor multilevel inverters.

Diode-clamped topologies are among the most widely used due to their simplicity and effectiveness. This paper presents a comparative study of diode-clamped multilevel inverters with 2, 3, and 5 voltage levels to assess their performance in various industrial applications.

PROPOSED INVERTERS

Two-Level Diode Clamped Multilevel inverter:

The two-level diode-clamped multilevel inverter, utilizing diode-clamped technology to create multiple voltage levels from a DC input, is simpler in design, comprising pairs of power semiconductor switches, typically IGBTs, connected in series with diodes and capacitors. By controlling these switches, different voltage levels can be connected to the output terminals, producing various voltage steps. However, despite its simplicity, it offers fewer voltage levels and lower resolution, which might limit its applicability in scenarios requiring finer voltage control or higher voltage resolution.

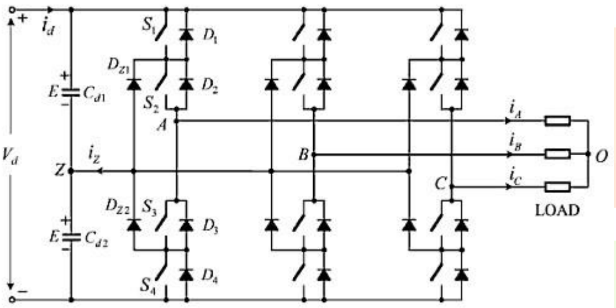


Switching States

S1	S2	S3	Out Phase Voltage
0	0	0	Vdc/2
1	0	0	0
1	1	0	-Vdc/2
0	1	0	0
0	1	1	Vdc/2
0	0	1	0

Three-Level Diode Clamped Multilevel Inverter:

A three-level diode-clamped multilevel inverter operates by generating multiple voltage levels from a DC input, achieved through a series of diode-clamped capacitor modules. Its structure comprises pairs of power semiconductor switches, like IGBTs, connected in series with diodes and capacitors, forming phase legs. Controlled switching of these devices connects corresponding voltage levels to output terminals, creating varied voltage steps. Compared to the two-level counterpart, the three-level version offers finer voltage resolution and improved waveform quality, suitable for applications demanding precise control.

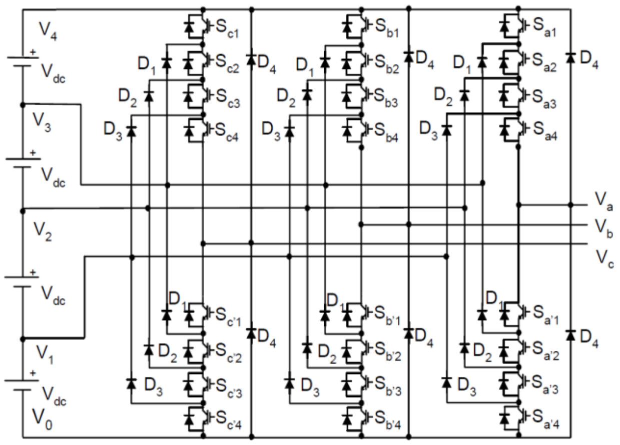


Switching states

Voltage level V_a=	S_{A1}	S_{A2}	S_{A3}	S_{A4}
V_{dc}	1	1	0	0
$V_{dc}/2$	0	1	1	0
zero	0	0	1	1

Five-Level Diode Clamped Multilevel Inverter:

A five-level diode-clamped multilevel inverter converts a single DC input into multiple voltage levels by splitting it into five using diode-clamped capacitor modules. Pairs of power semiconductor switches, such as IGBTs, along with diodes and capacitors, form phase legs. These switches control the connection of specific voltage levels to output terminals, creating various voltage steps. This inverter offers finer voltage resolution and improved waveform quality compared to lower-level versions, suitable for precise control in applications like advanced motor drives or renewable energy systems.



DCMLI VOLTAGE LEVELS AND SWITCHING STATES

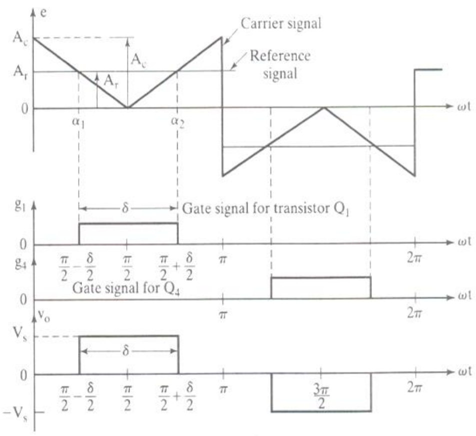
Voltage V_a	SWITCH STATE							
	S_{a1}	S_{a2}	S_{a3}	S_{a4}	$S_{a'1}$	$S_{a'2}$	$S_{a'3}$	$S_{a'4}$
$V_4 = 4Vdc$	1	1	1	1	0	0	0	0
$V_3 = 3Vdc$	0	1	1	1	1	0	0	0
$V_2 = 2Vdc$	0	0	1	1	1	1	0	0
$V_1 = Vdc$	0	0	0	1	1	1	1	0
$V_0 = 0$	0	0	0	0	1	1	1	1

III. PWM TECHNIQUES:

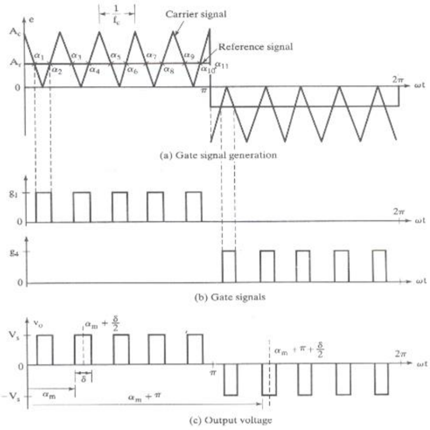
Pulse width modulation is a proven effective technique that is used to control semiconductor devices. PWM involves the generation of square wave pulses to represent analog signals digitally. By distributing signal energy across discrete pulses, PWM effectively controls semiconductor devices, contributing to power efficiency and signal accuracy. The generation of PWM signals typically involves the utilization of comparators. A modulating signal, representing the desired output, is compared with a non-sinusoidal or sawtooth wave. Based on this comparison, the comparator produces a PWM output waveform. When the sawtooth signal exceeds the modulating signal, the output remains in a "High" state, with the pulse width determined by the magnitude difference between the signals.

Basic PWM Techniques:

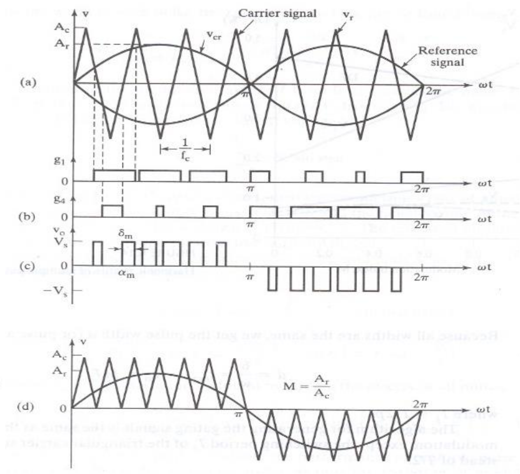
Single PWM



Multiple PWM



Sinusoidal PWM



Sinusoidal pulse width modulation (SPWM) is a technique used to synthesize AC waveforms by modulating the width of pulses in proportion to a sinusoidal reference signal. This method aims to closely mimic the shape of a sinusoidal waveform, resulting in smoother transitions and reduced harmonic distortion compared to other PWM techniques. However, SPWM has limitations, including higher computational complexity and increased switching losses due to the need for high frequency switching to achieve accurate sinusoidal approximation. Additionally, SPWM may suffer from voltage distortion at high modulation indices, impacting the quality of the output waveform.

IV. PROPOSED SVPWM TECHNIQUE:

Space Vector PWM Technique:

- **Application**: Power electronics control for three-phase inverters in motor drives and renewable energy systems.
- **Approach:** Unlike traditional PWM, SVPWM calculates optimal switching states. Aims for minimal harmonic distortion and maximum efficiency.
- **Technique:** Divides modulation period into six or more sectors. Determines appropriate voltage vectors within each sector to get the desired output voltage.

Advantages of Space Vector Modulation:

- Improved Harmonic Performance: SVM generates output waveforms with reduced harmonic distortion, leading to cleaner power conversion and enhanced system reliability.
- Enhanced Efficiency: By optimizing the distribution of voltage vectors, SVM minimizes power losses, resulting in higher overall efficiency in power conversion processes.
- Precise Control Resolution: SVM enables finer control over output voltage and current waveforms, allowing for greater flexibility and accuracy in system operation.
- Reduced Total Harmonic Distortion (THD): The inherent characteristics of SVM result in lower THD levels compared to conventional PWM techniques, contributing to improved power quality.

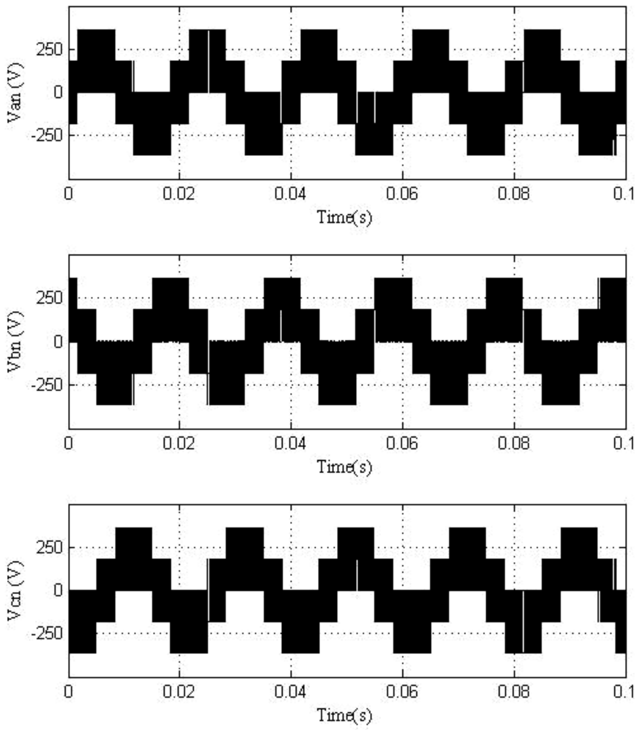
We have conducted a comparative analysis between Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Pulse Width Modulation (SVPWM). This analysis aims to evaluate the performance and efficiency of both techniques in synthesizing AC waveforms from DC sources. SPWM modulates the width of pulses proportionally to a sinusoidal reference signal, aiming for waveform fidelity, while SVPWM calculates voltage vectors to achieve optimized voltage utilization and reduced harmonic content. Through this comparative study, we aimed to discern the advantages and limitations of each technique concerning factors such as waveform quality, switching losses, and computational complexity, thereby informing the selection of the most suitable modulation strategy for specific applications.

V. RESULTS AND DISCUSSIONS

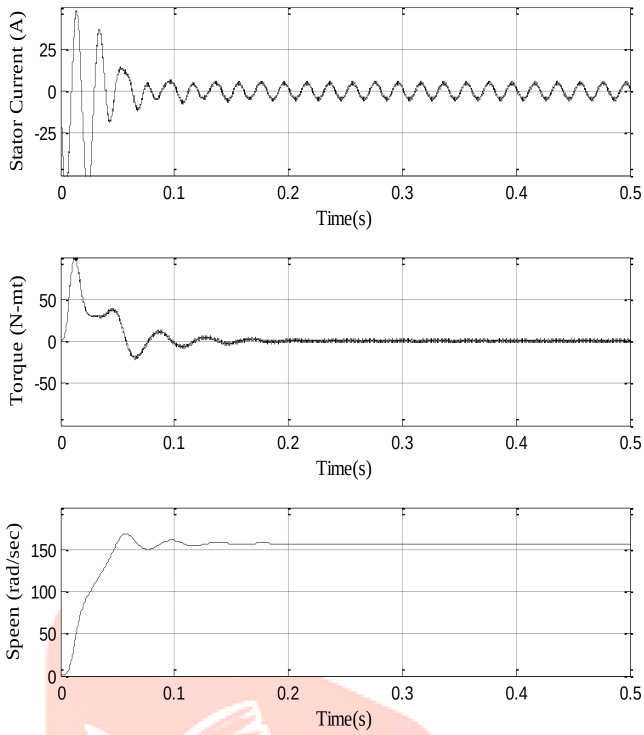
Sinusoidal PWM Technique for Two level Inverter, three level Inverter and Five level Inverter:

Two level Inverter

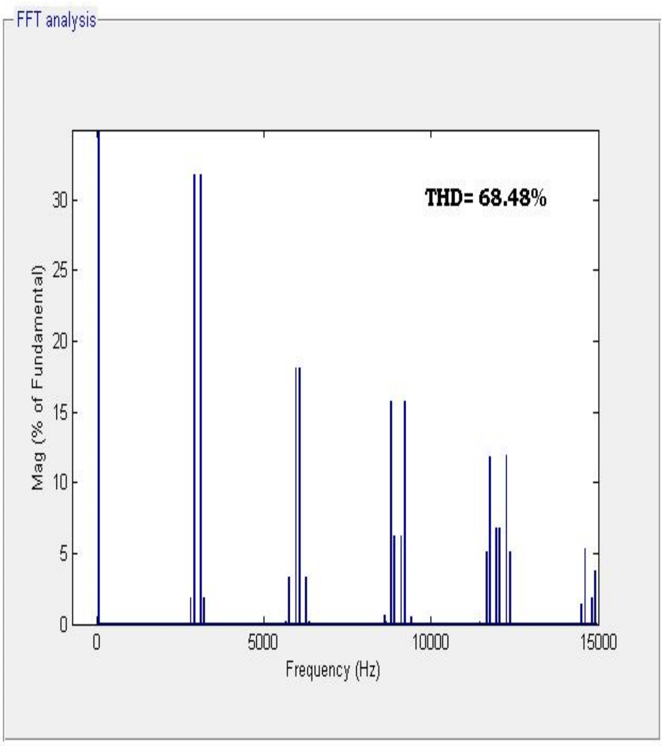
Phase Voltages

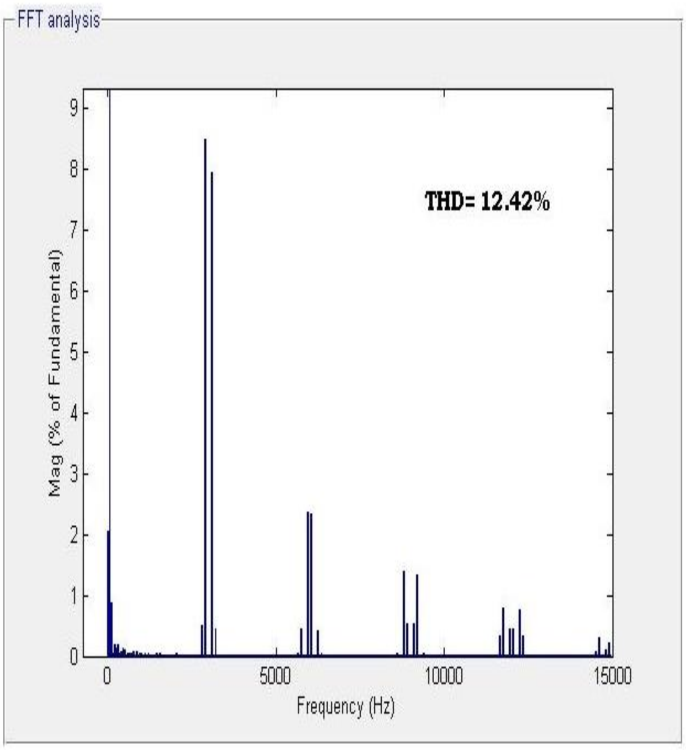


Stator Current, Torque and Speed



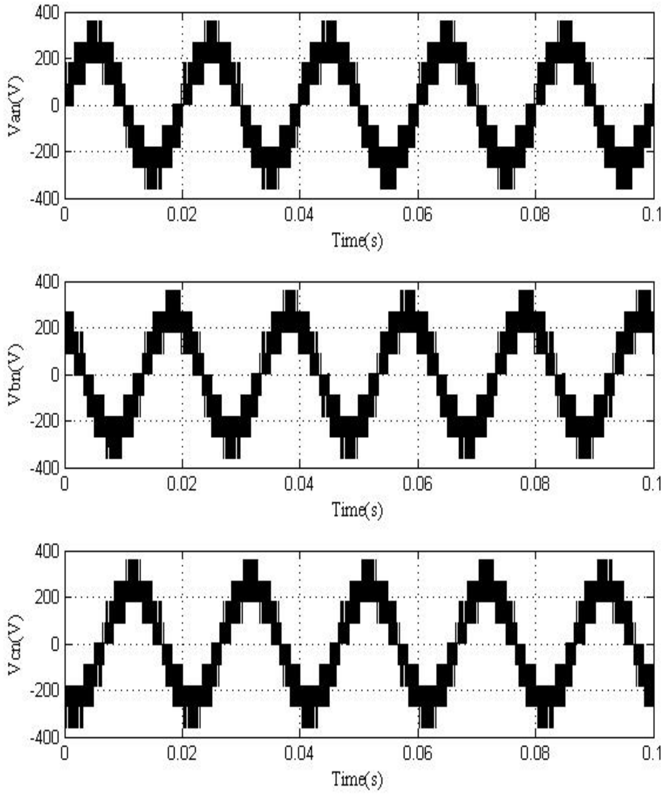
Total Harmonic Distortion (THD) of Phase voltage and Stator Current



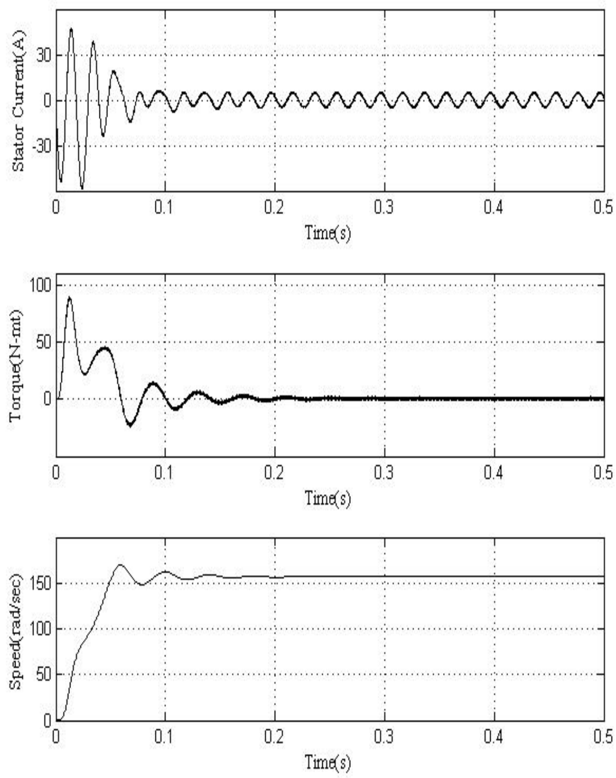


Three level Inverter

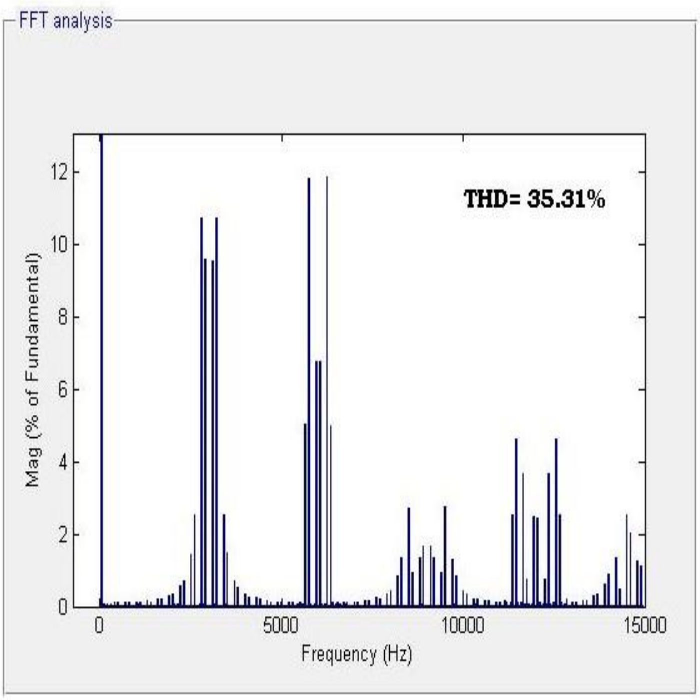
Phase Voltages

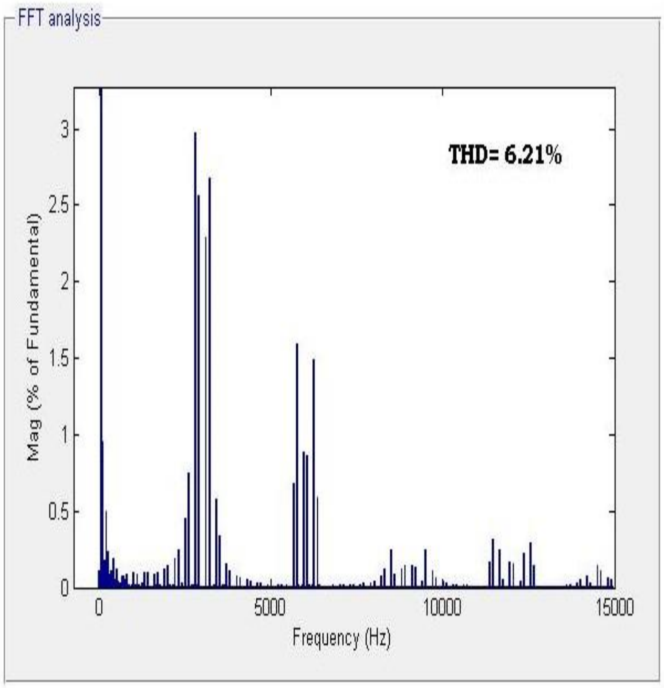


Stator Current, Torque and Speed



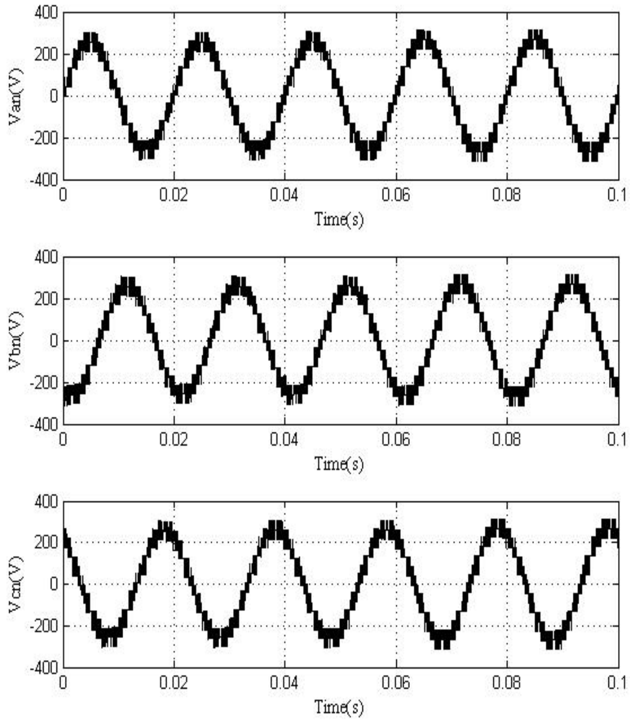
Total Harmonic Distortion (THD) of Phase voltage and Stator Current



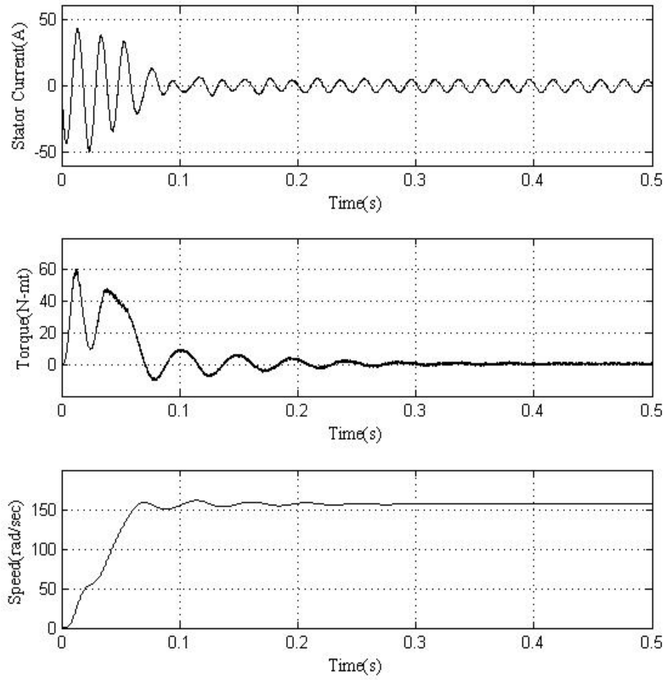


Five level Inverter

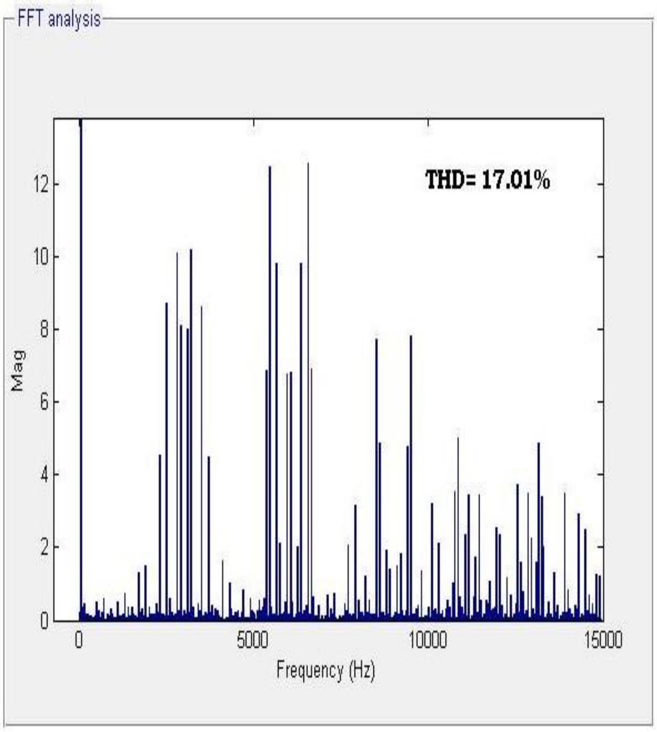
Phase Voltages

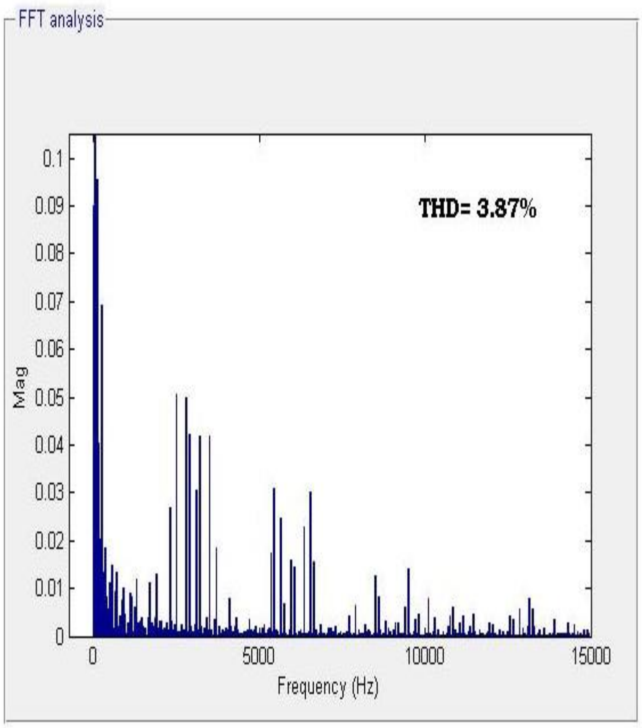


Stator Current, Torque and Speed



Total Harmonic Distortion (THD) of Phase voltage and Stator Current

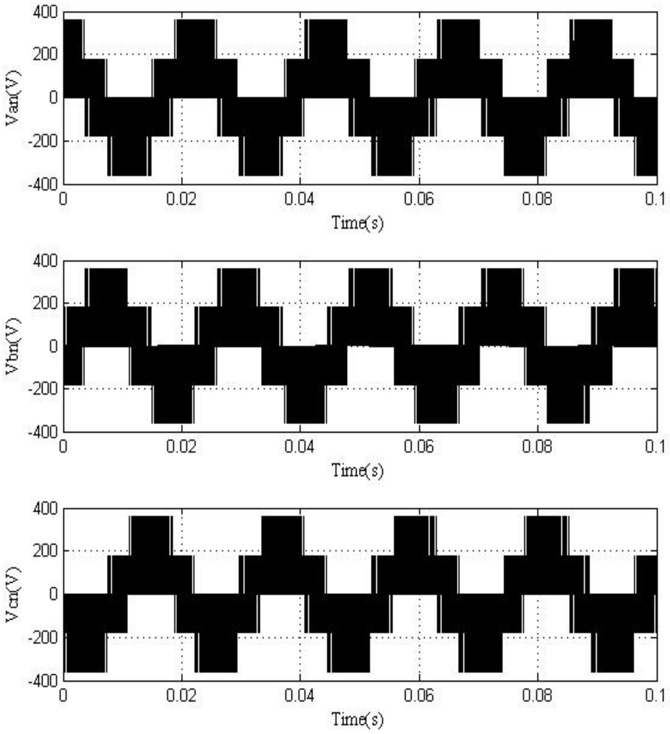




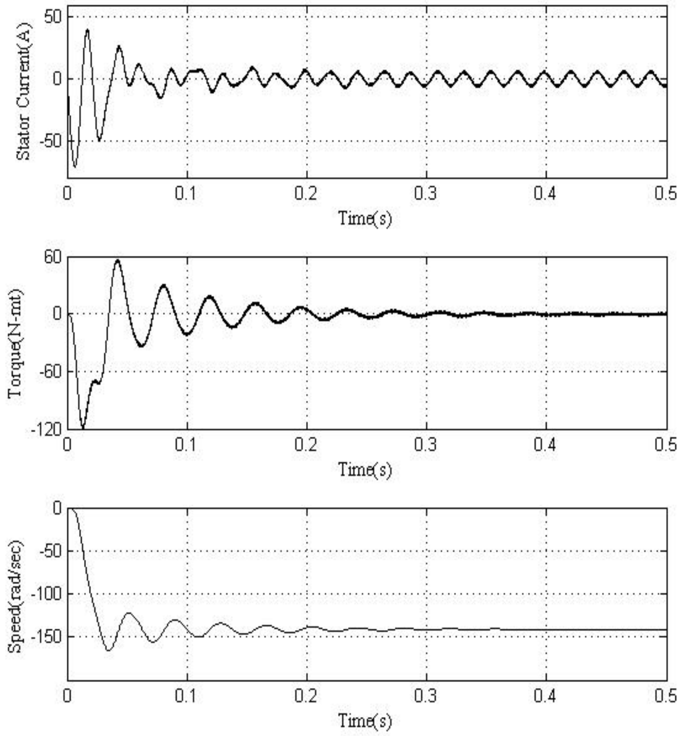
Space Vector PWM Technique for Two level Inverter, three level Inverter and Five level Inverter:

Two level Inverter

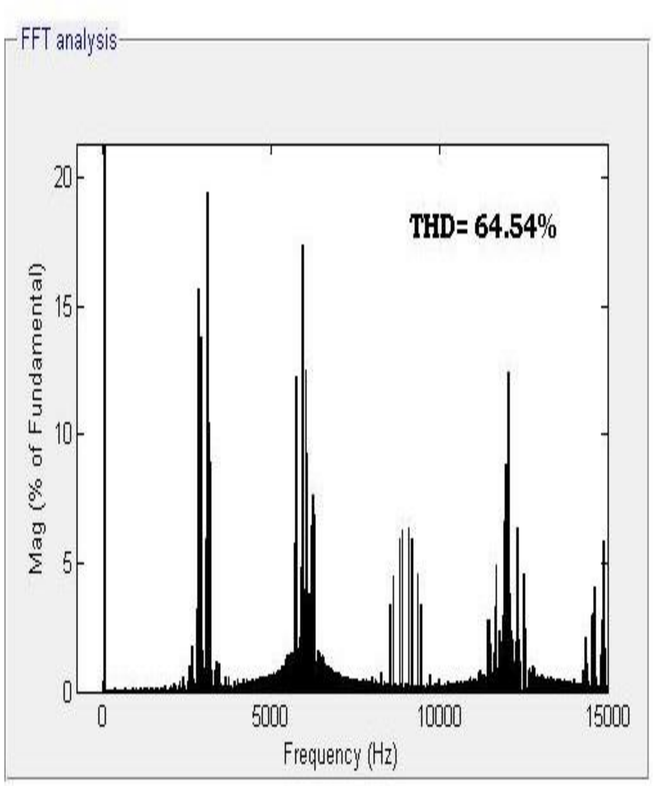
Phase Voltages

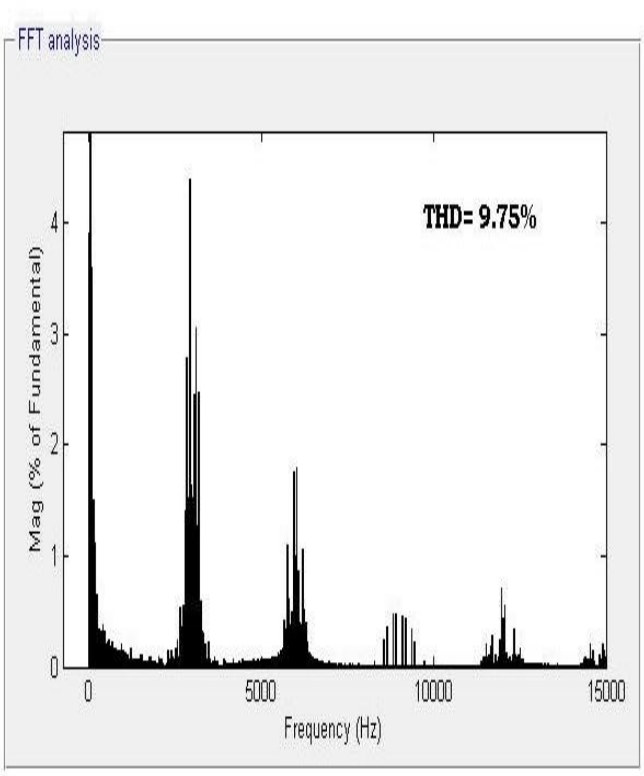


Stator Current, Torque and Speed



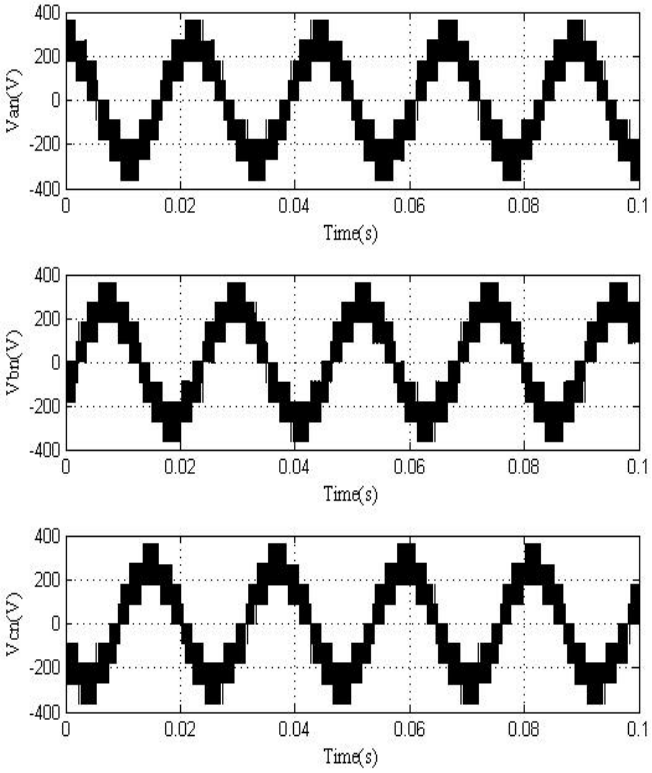
Total Harmonic Distortion (THD) of Phase voltage and Stator Current



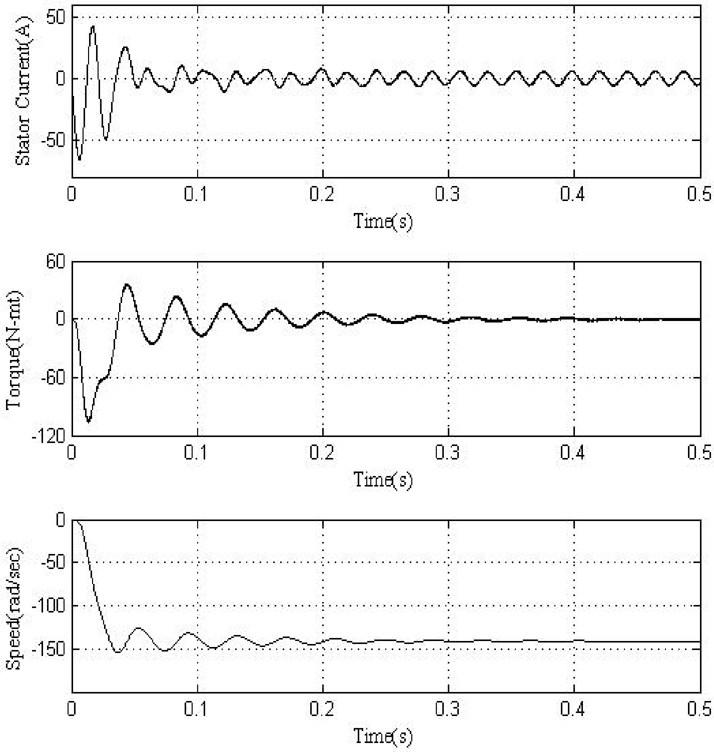


Three level Inverter

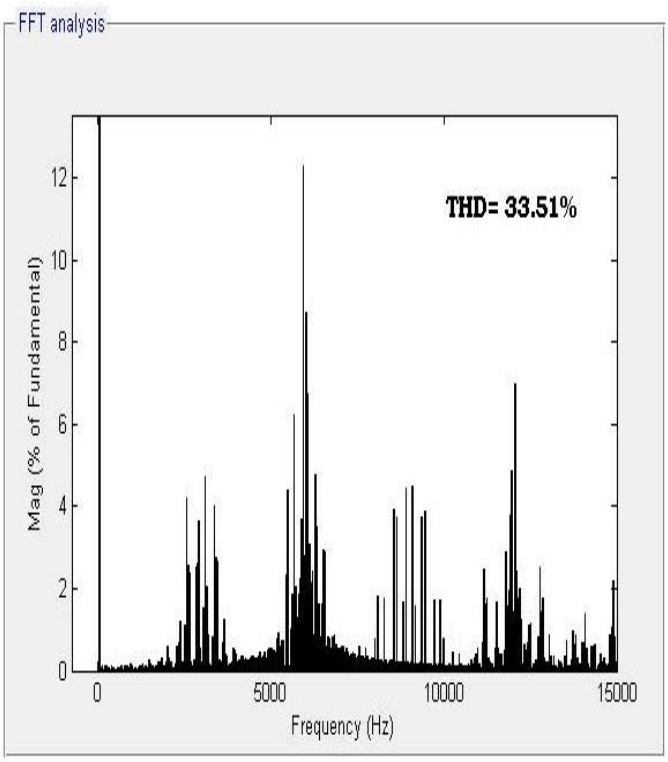
Phase Voltages

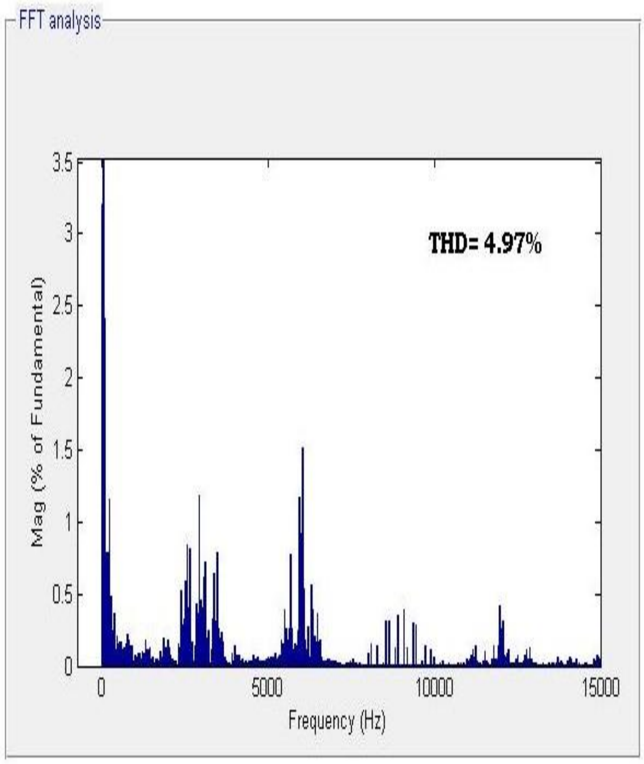


Stator Current, Torque and Speed



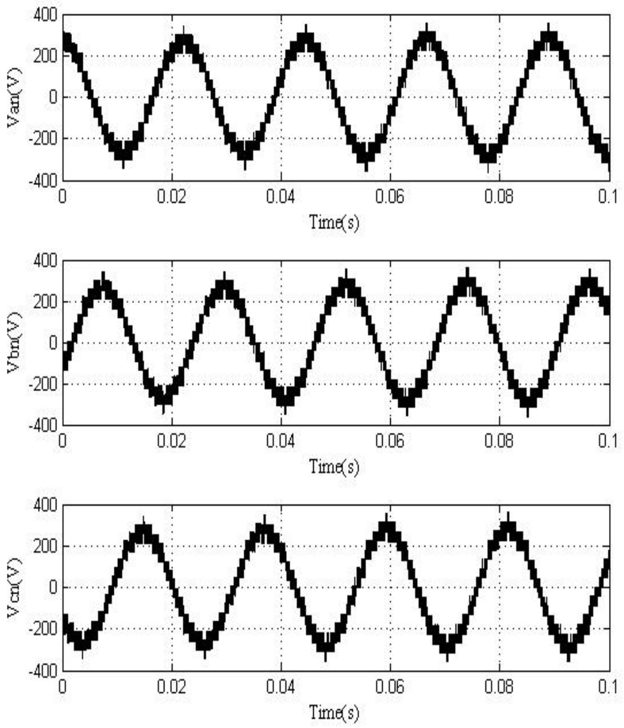
Total Harmonic Distortion (THD) of Phase voltage and Stator Current



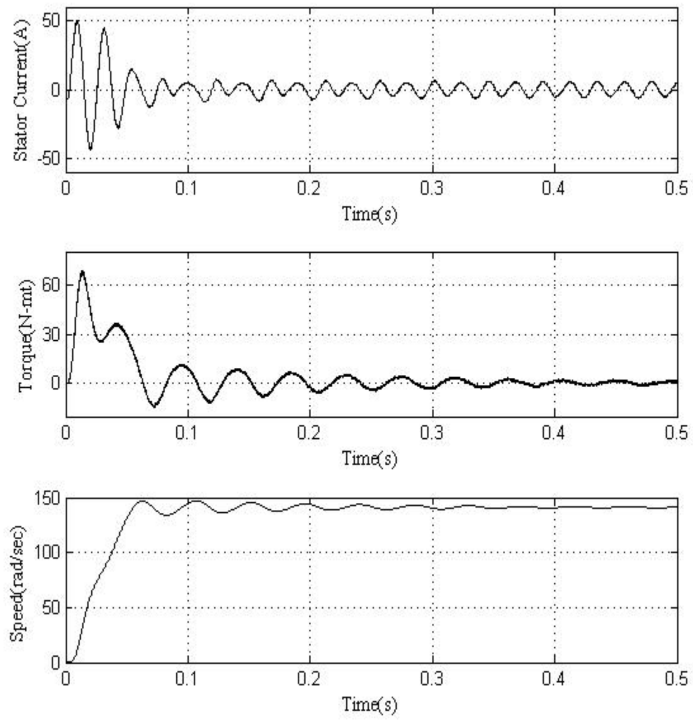


Five level Inverter

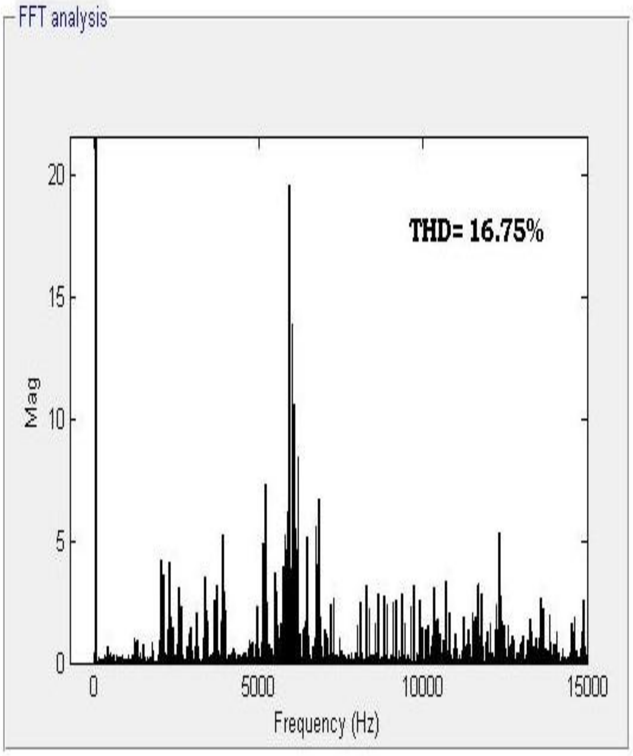
Phase Voltages

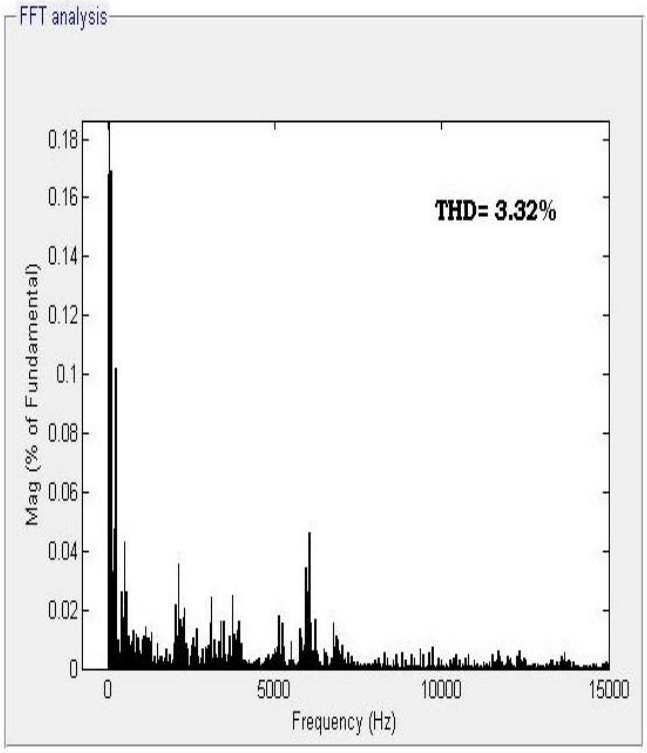


Stator Current, Torque and Speed



Total Harmonic Distortion (THD) of Phase voltage and Stator Current





THD Comparison

LEVEL	SPWM		SVPWM	
	Van	Ia	Van	Ia
Two	68.48%	12.42	64.54	9.75
Three	35.31	6.21	33.51	4.97
Five	17.01	3.87	16.75	3.32

VI. CONCLUSION

The conclusion of simplified PWM algorithms for three-phase multilevel inverters highlights their efficacy in achieving high-quality output waveforms with reduced computational complexity. The multilevel inverter output has reduced harmonics. This reduces the heat generated in the stator winding of the induction motor. The torque of the motor is improved due to the elimination of the fifth harmonic, which produces negative torque. Both Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Pulse Width Modulation (SVPWM) are effective techniques for controlling three-phase multilevel inverters. SPWM offers simplicity and ease of implementation but may suffer from higher harmonic distortion, especially at lower modulation indices. SVPWM excels in minimizing harmonic distortion and maximizing voltage level utilization, with higher computational complexity.

The choice between SPWM and SVPWM depends on the application requirements, with SPWM suitable for simpler applications and SVPWM preferred for demanding applications requiring high-quality output waveforms. Both techniques contribute to advancing power electronics, enabling efficient control of multilevel inverters across various applications, from motor drives to grid-connected systems. SVPWM is better than SPWM because of less harmonics and losses.

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