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Simulation &Comparison of Three level SPWM and SVPWM for NPC Multilevel Inverter Fed Induction Motor Drive

Achu Praveen[1], Sandhya.P[2]

PG Student [PCD], Dept. of EEE, Mar Baselios College of Engineering and Technology, Trivandrum, Kerala, India[1]

Assistant Professor, Dept. of EEE, Mar Baselios College of Engineering and Technology, Trivandrum, Kerala, India[2]

ABSTRACT: AC drives are more predominant than other DC drives. In this paper presents the simulation, analysis and comparison of Neutral point clamped multilevel Inverter (NPC) and three level Space Vector Modulation fed Induction motor Drive. The basic aim of PWM technique is to control the overall output voltage and also harmonic reduction. In this paper by using PWM techniques like Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Pulse Width Modulation (SVPWM) to the inverter and study its performance. SPWM generate the gating signals by comparing a sinusoidal reference signal with a Triangular Carrier Wave. The simulations are performed using MATLAB/SIMULINK software and the results are presented. In these two topologies mentioned, simulations are carried out using three phase Induction Motor. By comparing the Total Harmonic Distortions (THD), the advantages of the SVM over SPWM are confirmed. The study reveals that SVM technique utilizes DC bus voltage more efficiently and also generates less harmonic distortion when compared with SPWM technique. In this paper, a model for SPWM & SVPWM is constructed and simulated using MATLAB/SIMULINK software and performance of SVPWM is compared with SPWM.

KEYWORDS: NPC, THD, SPWM, Space Vector PWM, PWM

I.INTRODUCTION

The Induction Machines are used in a wide variety of applications by means of converting the electric power into mechanical power and 3 phase Induction motors are simple and easy to maintain. Inverter is a device which converts DC to AC power at desired frequency and voltage level. Inverters are broadly classified into single level inverters and multilevel inverters. Multilevel inverters are considered as industrial solutions for high Dynamic performance and for power quality demanding applications. The number of levels of an inverter can be defined as the number of steps / constant voltage values which is generated between output terminal and with an arbitrary reference node, called neutral. By comparing the two level inverters of same power rating, multilevel inverters have some advantages of lower switching frequency and hence reduction in the switching losses and reduced EMI issues with reduction in the harmonic components of the line to line voltages. The major multilevel converter topologies are [1]-[2] Diode clamped or neutral point clamped MLI, Flying capacitor or capacitor clamped MLI, Cascaded multilevel inverters with isolated dc sources. Among three different topologies which mentioned above the Neutral point clamped (NPC) has been commonly used in applications. The main advantages of multilevel converters are staircase waveform quality having lower or reduced common mode voltages, which can operate at both fundamental and high switching frequency PWM, reduced switching stresses on devices etc [4]-[6]

The most widely used PWM technique for voltage source inverters is sinusoidal Pulse width modulation. The main aim of this paper is the analysis of Induction motor with SVPWM fed inverter and SPWM fed inverter and the harmonic analysis and comparison of both line and phase voltages. There is always an increasing trend of utilizing space vector PWM (SVPWM) because of its reduced harmonic content in voltage and increased fundamental output voltage by 15%. Space vector PWM technique is also developed based on vector space decomposition. In space vector PWM method for a three-level inverter fed induction motor drive, a number of Pulse Width Modulation (PWM) schemes are

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used for obtaining variable levels of voltage and also for the frequency supply from an inverter. There is an increasing trend of using SVPWM because of the easier digital realization and better dc bus utilization.

A. NEUTRAL POINT CLAMPED MULTILEVEL INEVERTER

In this topology there are mainly two pairs of switches and also two diodes are used in a three-level diode clamped multi level inverter. The DC bus voltage is divided into three different voltage levels with the help of two series connections of DC capacitors i.eC1 and C2 as shown in the figure 1. The voltage across each capacitor is Vdc/2 i.e voltage across capacitor C1 and C2 is equals to Vdc/2 [2].There are mainly twelve active combinations were taken and using these switching states twelve active voltage vectors are produced. There are nonzero voltage vectors and are from V1 to V12. Fig.1. shows the Three Level Diode Clamped Multilevel Inverter (MLI). Table I shows the switching states for one leg of the three-Level Diode Clamped Multilevel Inverter.

Table I
Switching States In One Leg of the Three-Level Diode Clamped Inverter

Switching State	State	Pole Voltage
T1=ON,T 2=ON T3=OFF,T 4=OFF	S=+ve	Vao=Vdc/2
T1=OFF,T 2=ON T3=ON,T 4=ON	S=0	Vao=0
T1=OFF,T2=OFF T3=ON,T 4=ON	S=-ve	Vao=-Vdc/2

Multilevel inverters have become an effective and practical solution for an increasing power level and by reducing harmonics of AC load. The a phase output voltage Van has three states: Vdc/2, 0, -Vdc/2. The gating signals for the chosen three level Neutral Point clamped MLI are developed using MATLAB-SIMULINK. The order of the numbering of switches for a phase is T1, T2, T3 and T4 and likewise for other two phases. The DC bus consists of two capacitors C1 and C2, acting as voltage divider for providing neutral point 0.

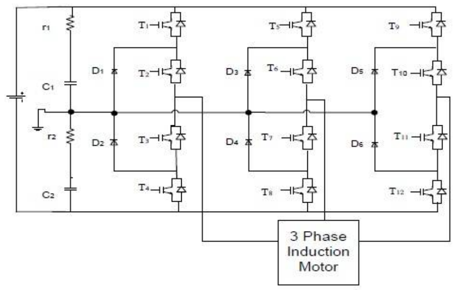

Fig.1.Diode clamped multilevel inverter circuit topology for 3-phase 3-level inverter fed induction motor drive

II. CONCEPT OF SINE PWM & SPACE VECTOR MODULATION

A. SINUSOIDAL PULSE WIDTH MODULATION

Because of the advances in solid state power devices (SSDs) and microprocessors, switching power converters are commonly used in industrial application in order to convert and also to deliver their required energy to motor or load. The different PWM techniques are Single Pulse Modulation, Multiple Pulse Modulation and Sinusoidal Pulse Width Modulation (or Carrier based Pulse Width Modulation Technique). The sinusoidal pulse width modulation (SPWM) technique produce a sinusoidal waveform by filtering the output waveform with a varying width. The desired output voltage can be achieved by varying the frequency and amplitude of reference or the modulating voltage. The variations in amplitude and the frequency of reference voltage wave changes the pulse width patterns of output voltage. The main operating principle of this method is based on the comparison of a sinusoidal signal i.e reference signal with a triangular carrier signal [3].The Result is a train of rectangular pulses with a variable width. Widths of pulses are

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proportional to the average value of sinusoidal signal. The Output pulses of this operation are directly delivered to the switching devices of the Inverter. As described inFig.2.the frequency of Vtri and Vcontrol are *fs* and *f1* respectively. where, *fs* = PWM frequency, and *f1* = Fundamental frequency.

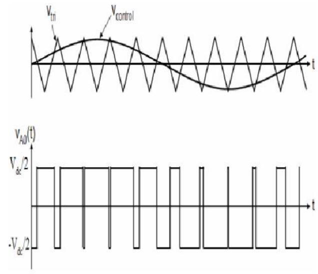

Fig.2.Pulse Width Modulation

The inverter output voltages can be determined as follows:
When Vcontrol>Vtri, VAO = Vdc/2
When Vcontrol<Vtri, VAO = −Vdc/2

B. SPACE VECTOR MODULATION

Space vector pulse width modulation (SVM) is quite different from other PWM techniques. With PWMs, the inverter can be thought of as three separate push-pull driver stages which create each phase waveform independently. Space Vector Modulation treats the inverter as a single unit. The inverter can driven to eight unique states. Modulation can be accomplished by the switching state of inverter. SVM is a digital modulation technique where the main objective is to generate PWM line voltages. This can be done in each sampling period by properly selecting the switching states of the inverter and proper calculation of appropriate time period for each state and the voltage vector is generated by using three adjacent vectors. The duration of each switch are obtained by vector calculations. The inverter have 27 possible combinations of switching states by taking all the three phases into account [7]. All those switching state combinations are transformed mainly into eighteen distinct voltage space vectors with fixed directions. Based on the magnitude i.e length, voltage vectors are divided into four different groups:

I. Zero vector (*Vo*), representing three switching states [PPP], [OOO], & [NNN]. The magnitude of all the three switching state is zero.
II. Small vectors (*V1 to V6*), all are having a magnitude of $\frac{Vd}{3}$ .In which each small vector has two switching states, one having [P] and the other containing [N], and so we can further classified it into a P- or N-type small vector.
III. Medium vectors (*V7to V12*), whose magnitude is$\frac{\sqrt{3}Vd}{3}$.
IV. Large vectors (*V13to V18*), all having a magnitude of $\frac{2Vd}{3}$.

The space vector diagram consists of six sectors and each sector is divided into four triangles. The tip of the voltage vector can be located anywhere inside the triangle as shown in Figure 3.

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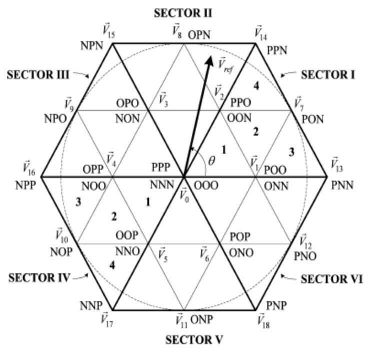

Fig.3.Division of sectors and regions

III. INDUCTION MOTOR MODEL

The mathematical model of Induction Motor can be modelled by different methods, such as, space vector phase theory or the two-axis theory of electrical machines. Stationary frame equations are given as:

$$Vs = R_s I_s + \frac{d}{dt}\,\psi_s$$

$$0 = R_r I_r + \frac{d}{dt}\psi_r - j_{\omega r}\psi_r$$

$$\psi_s = L_s\, I_s + L_m\, I_m$$

$$\psi_r = L_m\, I_s + L_r\, I_r$$

Where *is*, *us*, *ψs*, *ir*, and *ψr* are stator current vector, stator voltage vector, stator flux linkage , rotor current vector, vector, and rotor flux linkage vector, respectively; *Rr*, *Rs*, *Lr*, *Ls*, and *Lm* are the rotor resistance, stator resistance, rotor inductance stator inductance, and mutual inductance respectively and *ωr* is rotor speed and *p = d/dt* and is the differential operator. From the stator voltage equation, it can be seen that, by eliminating the stator resistance voltage drop, the stator flux can controlled directly from the stator voltage. This is the crude analysis and it may cause error at low speed. The electromagnetic torque can obtained from

$$T_e = \frac{3}{2} N_p \frac{Lm}{\sigma LsLr} \psi_r \mathrm{x} \psi_s$$

$$T_e = \frac{3}{2} N_p \frac{Lm}{\sigma LsLr} \psi_r . \psi_s \mathrm{Sin}\delta_{sr}$$

Where, *δsr* is spatial angle between the stator and rotor fluxes, Np is motor pole-pair number, and Te is electromagnetic torque.

IV. SIMULATION AND RESULTS

The comparison and analysis of diode clamped / neutral point clamped multilevel inverter fed IM using Sine PWM and using three level Space vector modulation fed IM are conducted using MATLAB/SIMULINK. Here the sinusoidal pulse width modulation (SPWM) and Space vector modulation (SVM) is used as the modulation technique. The output phase voltage, line voltage and Total harmonic distortion is obtained for different topologies using three phase Induction motor drive

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A .THREE LEVEL (NPC) INVERTER FED IM

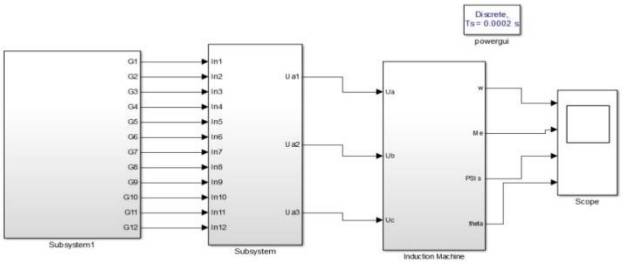

Fig.4.Neutral Point Clamped Multilevel Inverter Simulink Model

In fig 4, it shows simulink model of Neutral Point Clamped MLI having two subsystems with subsystem 1 consists of gating signal generation for inverter and second consists inverter model.

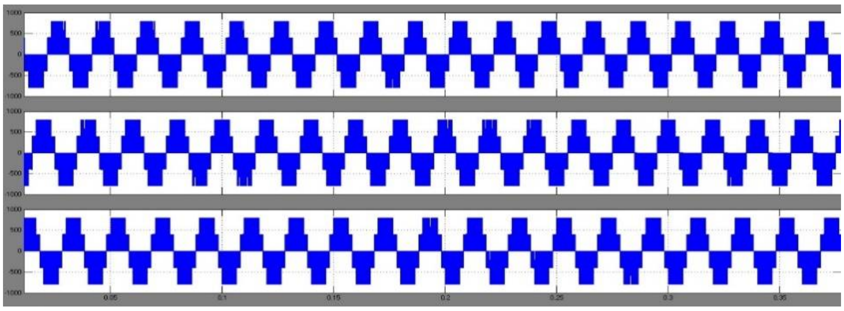

Fig.5.Inverter output line voltage

In fig 5, it shows the output line voltage of inverter. Line voltage is the voltage between two different phases.

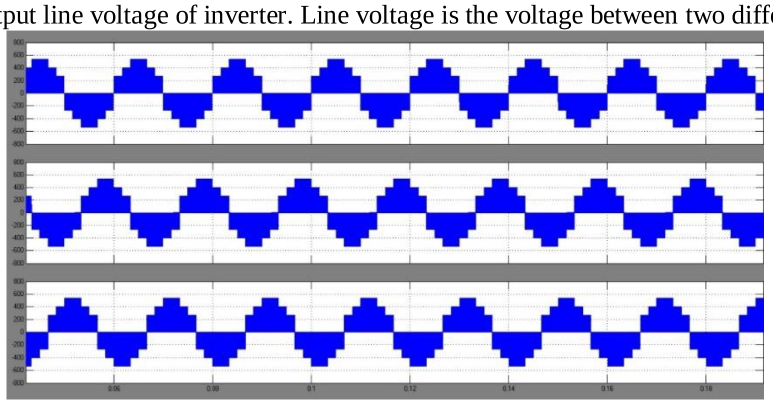

Fig.6.Inverter output phase voltage

In Fig.6, it shows the Inverter output phase voltage. Phase voltage is the voltage between phase and neutral.

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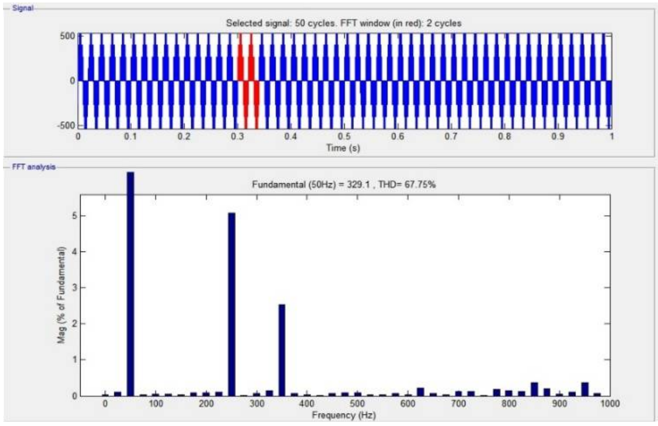

Fig.7.Inverter Line voltage THD

In Fig.7, it shows the Inverter Line voltage THD. THD is total harmonic distortion which is the measurement of harmonic distortion present.

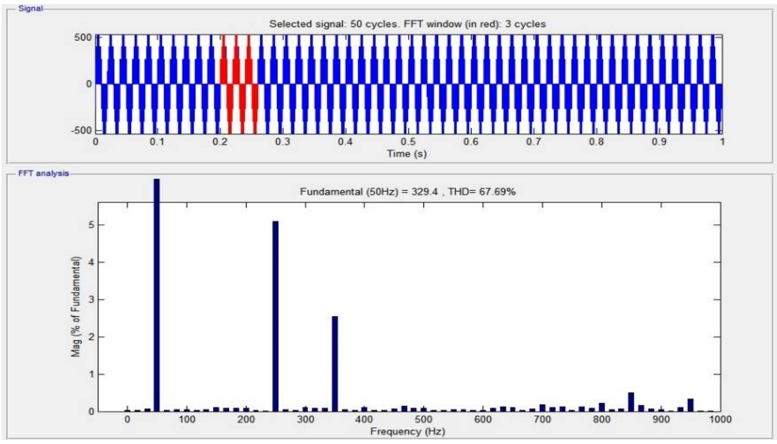

Fig.8.Inverter Phase voltage THD

In Fig.8, it shows the total harmonic content present in the inverter Phase voltage.

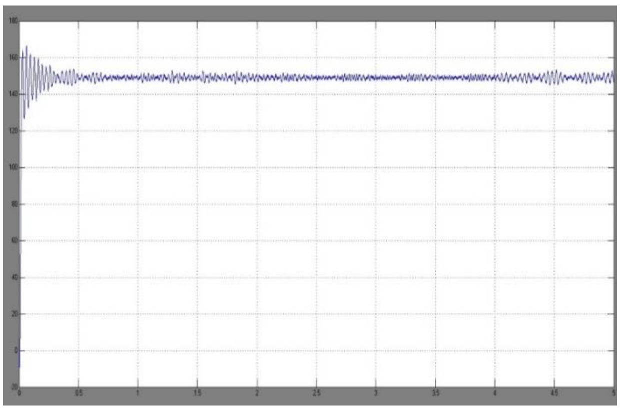

Fig.9.Speed Response using sine PWM

In fig.9, it shows the speed response of induction motor using sinusoidal pulse width modulation technique.

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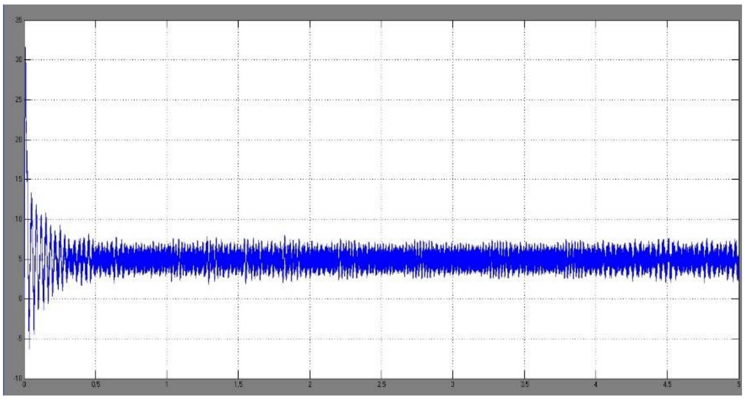

Fig.10.Torque response using Sine PWM

In fig.10, it shows the torque produced in the induction motor using sinusoidal pulse width modulation technique

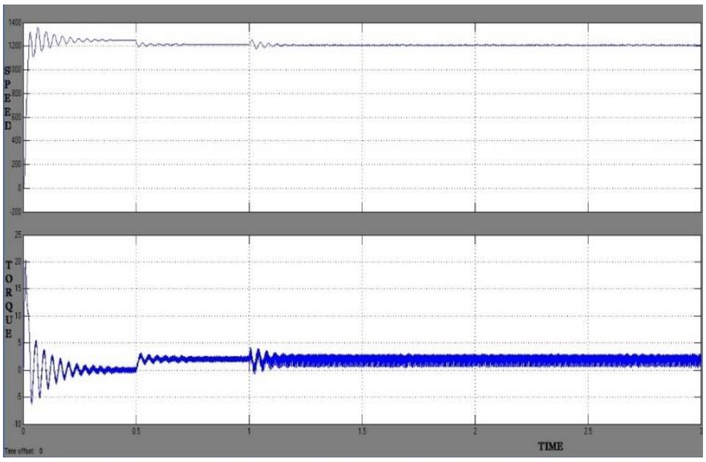

Fig.11.Speed and Torque response applying load torque

In fig. 11, it shows the speed and torque respectively by applying a load torque after 0.5 sec. the result shows that there is a decrease in speed and increase in torque after 0.5 sec.

B.THREE LEVEL SPACE VECTOR MODULATION FED IM

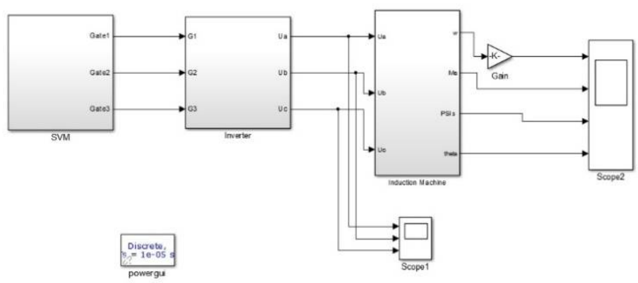

Fig.12.Three Level Space Vector Modulation Fed IM

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In fig.12, shows the model of Three Level Space Vector Modulation Fed IM in which space vector modulation is used for generating the gating signals for the inverter.

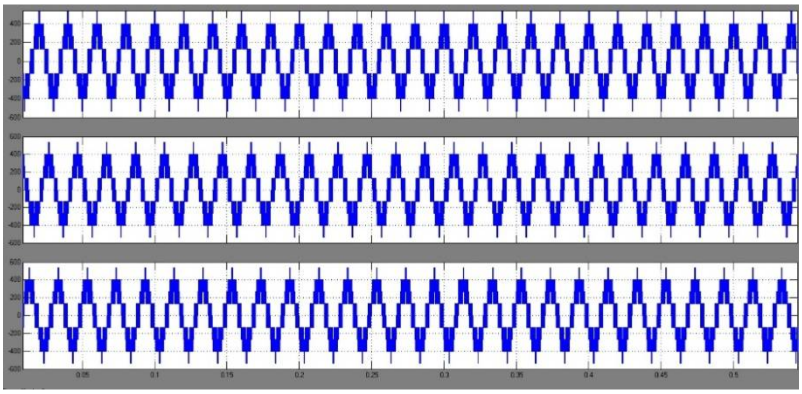

Fig.13.Inverter Output Line voltage

In fig.13, it shows the output line voltage of inverter using three level space vector modulation

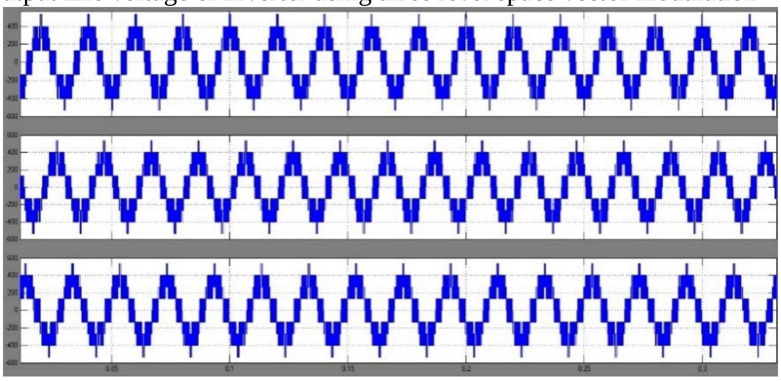

Fig.14.Inverter Output Phase voltage

In fig.14, it shows the output phase voltage of inverter using three level space vector modulation

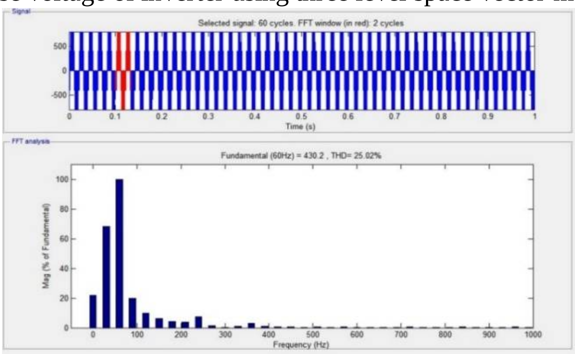

Fig.15.Inverter Line voltage THD.

In fig 15, shows the harmonic content present in the inverter line voltage and THD is ratio of sum of powers of all the harmonic components to the power of fundamental frequency.

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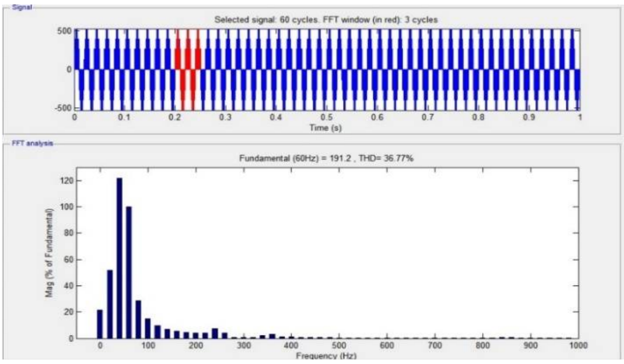

Fig.16.Inverter Phase voltage THD

In fig. 16 it shows the total harmonic components in the phase voltage which shows that the THD is greater than the line voltage using SVM technique.

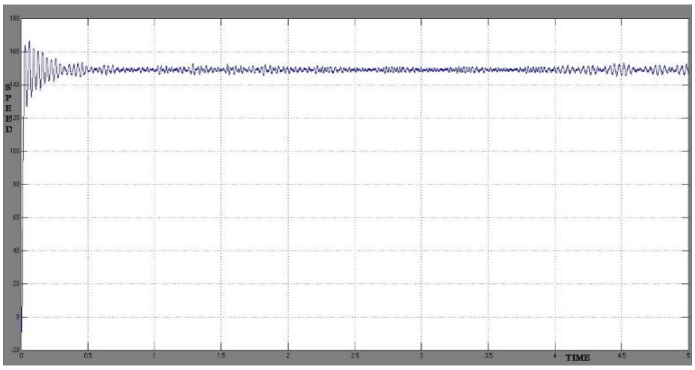

Fig.17.Speed response using SVM

In fig.17, shows the speed of induction motor drive with respect to time using space vector modulation

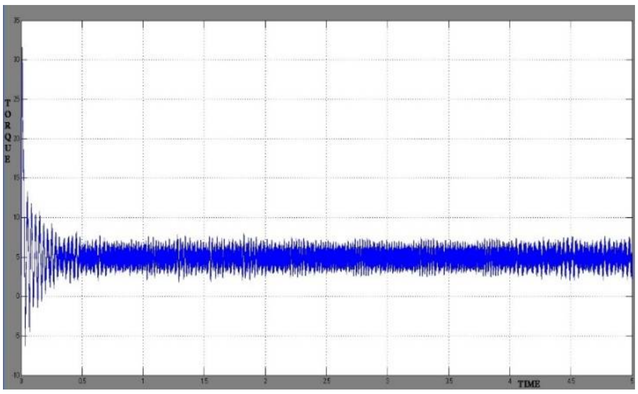

Fig.18.Torque response using SVM

In fig.18, it shows the torque response of induction motor drive with respect to time using three level space vector modulation

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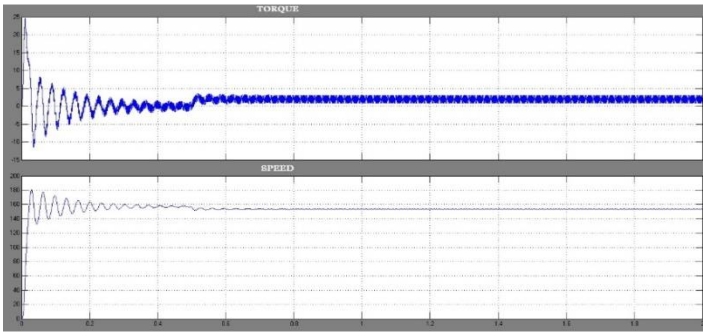

Fig.19.Speed & Torque with load torque

In fig.19, it shows the speed & torque response with applied load torque after 0.5 sec. from the figure it shows that torque is increased and speed is decreased after 0.5 sec

Table II shows the comparison of output line voltage and phase voltage THDs of NPC inverter fed IM using sine PWM and three level Space vector modulation. From the table it is clear that the total harmonic distortion decreasedin space vector modulation as compared to the Sinusoidal pulse width modulationwhich means the THD value for Three level neutral point clamped inverter using Sine PWM fed IM is greater than Three level neutral point clamped inverter using Space Vector modulation fed IM.

Table II
Comparison of Line and phase voltage THDs of various Inverter topologies

SL no	Topology	Voltage Total Harmonic Distortion (in%)	
		Line Voltage	Phase Voltage
1	Three level neutral point clamped inverter using Sine PWM fed IM	67.75%	67.69%
2	Three level neutral point clamped inverter using Space Vector modulation fed IM	25.02%	36.77%

VI.CONCLUSION

The simulation of three level diode clamped/ Neutral point clamped inverter using Sine PWM and three level Space Vector Modulation was carried out and which shown that there is a decrease in THD in space vector modulation as compared to the neutral point clamped multi level inverter. This paper briefly explains about the theory of sinusoidal pulse width modulation and three level space vector modulation. The speed and torque response corresponds to NPC fed induction motor using sine PWM and Space vector modulation is also shown here. The performance of two topologies were analysed using MATLAB/SIMULINK software.

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