

Comparison of Full Bridge Voltage source Inverter with Different PWM Techniques

Prachi S. Dharmadhikari

M Tech (III SEM-PEPS): Dept. of Electrical Engg
Ramdeobaba College of Engineering and Management
Nagpur, (India)

ABSTRACT

In this paper, a comparative analysis of the carrier based pulse width with third harmonic injection and Digital pulse Width used in the inverter control is presented. The placement of the modulating components within the carrier interval determines the harmonic performance of the modulation strategy. The third harmonic injected modulated inverter and the digital pulse width modulation technique gives higher value of line to line voltage as compared with the conventional sine pulse width modulated (SPWM) inverter. The optimized third-harmonic injection controls the blanking time and minimum pulse width of an operating inverter switch. Whereas Digital Pulse-Width Modulation technique eliminates limit cycle oscillations for the applications with high switching frequency. The simulation results are presented with different PWM techniques and study of total harmonic distortion in the line voltage and current is analyzed for the three phase voltage source inverter using IGBT as a switching device.

Keywords

Harmonics, Sine pulse width modulation, Third-harmonic pulse width modulation, voltage source inverter.

1. INTRODUCTION

Pulse Width Modulated (PWM) voltage source inverters (VSI's) are widely utilized in ac motor drive application. Many PWM-VSI drives employ carrier based PWM methods due to fixed-switching frequency, low ripple current & well-defined harmonic spectrum characteristics. While designing power electronics circuitry it is focused to reduce the number of active and passive element. But a pulse width modulated inverter employing pure sinusoidal modulation cannot supply sufficient voltage to enable a standard motor to operate at rated power and rated speed. Sufficient voltage can be obtained from the inverter by over modulating, but this produces distortion of the output waveform. In variable speed v/f controlled PWM-VSI induction motor drives, operation in this range results in poor performance, and frequent over current faults conditions [1]-[2]. In recent past, Third-Harmonic injection Pulse Width Modulation (THIPWM) switching technique is developed and widely used for three phase PWM inverter and the multilevel inverters [3]. It has been generally reported that third-harmonic injected modulation strategies offer superior performance compared to regular sampled pulse width modulation, in terms of reduced harmonic current ripple, optimized switching sequence and increased voltage transfer ratios. The voltage can be generally increased by harmonic suppression for the rectifiers as well as inverters. This can be mainly done by injecting the third harmonic component with fundamental in balanced three phase loads. At present, induction motors are the dominant

drives in various industries. It is quite cumbersome to control an induction motor (IM) because of its poor dynamic response in comparison to the DC motor drives. In recent years, demand for power converters that operate in high switching speed, low voltage with high power efficiency has become very high. By applying the digital power converter, complicated control algorithms that are difficult to realize in the conventional analog power converter, change of parameter function, malfunction diagnosis and life estimation, communication with peripheral equipment can be easily realized. As results, ripple-reduction and faster response that increase the circuit efficiency, unnecessary circuit change and part addition that increase the custom correspondence performance, low cost and small area circuit realization can be expected. Digital Pulse-Width Modulation technique eliminates limit cycle oscillations for the applications with high switching frequency. [4]- [7].

This paper contributes for the analysis and comparison of the different PWM techniques using MATLAB/SIMULINK.

2. GENERAL THEORY OF VOLTAGE SOURCE INVERTER

Voltage source inverters as the name indicate, it receives dc voltage at one side and convert it to ac voltage on other side. The ac voltage and the frequency may be variable or constant depending on the application. A voltage fed inverter should have a stiff voltage source at the input i.e. its Thevenin impedance should be ideally zero. A large capacitor can be connected at the input if the source is not stiff.

Three phase bridge inverter are widely used for ac motor drives and general purpose ac supplies. The circuit consist of three half bridge, which are mutually phase shifted by $2\pi/3$ angle to generate the three phase voltage waves.

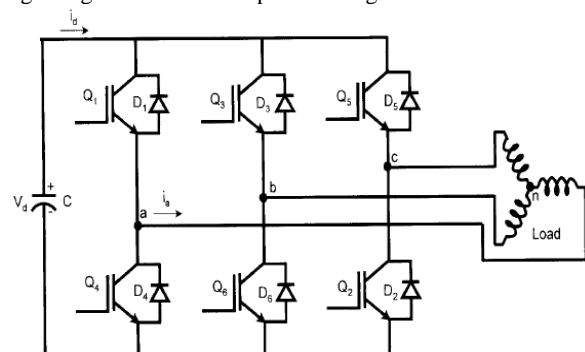


Fig 1. Circuit configuration of VSI.

The three phase bridge inverter is basically a six step bridge inverter. A step means firing of next SCR in the sequence. Thus in a cycle (360°), firing of six DCRs in a particular sequence forms six steps. Therefore, each firing is delayed by 60° from earlier firing. It means that the SCRs are fired at

regular interval of 60° in a particular sequence to synthesize three phase voltage at the output terminals. The diodes used in the circuit are feedback diodes. The capacitor at input terminals helps to maintain constant dc supply voltage to inverter. This capacitor also helps to suppress harmonics resulting from inverter operation and prevent them from reaching to DC source. The three phase load connected at output terminals a, b, c is assumed to be a star or delta connected purely resistive load.

2. DIFFERENT PULSE WIDTH MODULATION TECHNIQUES

Up to date, due to the improvement of fast-switching power semiconductor devices and machine control algorithm, more precise PWM (Pulse Width Modulation) method finds particularly growing interest. The used PWM techniques are:

- 1 Sinusoidal pulse width modulation (SPWM)
2. Third Harmonic Injection pulse width modulation (THIPWM)
3. Digital pulse width modulation (DPWM)

2.1 Sinusoidal Pulse Width Modulation

Sinusoidal Pulse Width Modulation (SPWM) technique is used to generate the gate pulses. SPWM technique is widely used in industries. This technique is also used to reduce harmonic contents and to improve voltage level. In this technique, pulse magnitude will be constant and only pulse time (width) can be changed. In this pure sine wave is compared with carrier (triangular) wave producing gate pulses. Sine wave has fundamental frequency and carrier wave can be taken more than fundamental frequency.

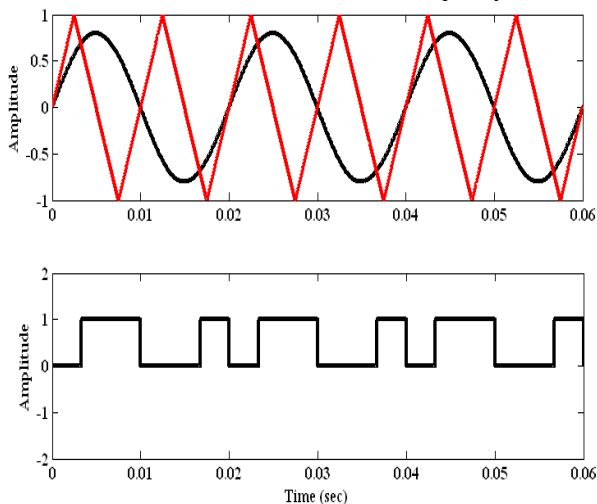


Fig 2. Carrier & Reference Waveform along with the pulses of Sinusoidal Pulse Width Modulation

But a pulse width modulated inverter employing pure sinusoidal modulation cannot supply sufficient voltage to enable a standard motor to operate at rated power and rated speed. Sufficient voltage can be obtained from the inverter by over modulating, but this produces distortion of the output waveform. The linear output range of SPWM is restricted to 0.785 compared with six step inverter. The non-linear region operation (over-modulation) is leading to large amounts of sub carrier frequency harmonic currents, reduction in fundamental voltage gain and switching device gate pulse dropping. The gating signals can be generated using unidirectional triangular carrier wave as shown in the figure 2.

This makes the SPWM technique most suitable for the inverter used to feed induction as for the production of non pulsating torque production in induction motor the harmonic content in stator voltage must be as less as possible.

3.2 Third-Harmonic Injection Pulse Width Modulation

The third – harmonic PWM is similar to the selected harmonic injection method & it is implemented in the same manner as sinusoidal PWM. The difference is that the reference ac waveform is not sinusoidal but consists of both a fundamental component and a third-harmonic component. As a result, the peak-to-peak amplitude of the resulting reference function does not exceed the DC supply voltage V_s , but the fundamental component is higher than the available supply V_s . The reference voltage V_{ref} is added with signal having frequency three times of fundamental frequency and the magnitude is $1/6$ th of the fundamental amplitude. The resultant is then passed through comparator which compares the modified signal with the carrier signal of frequency 2 KHz.

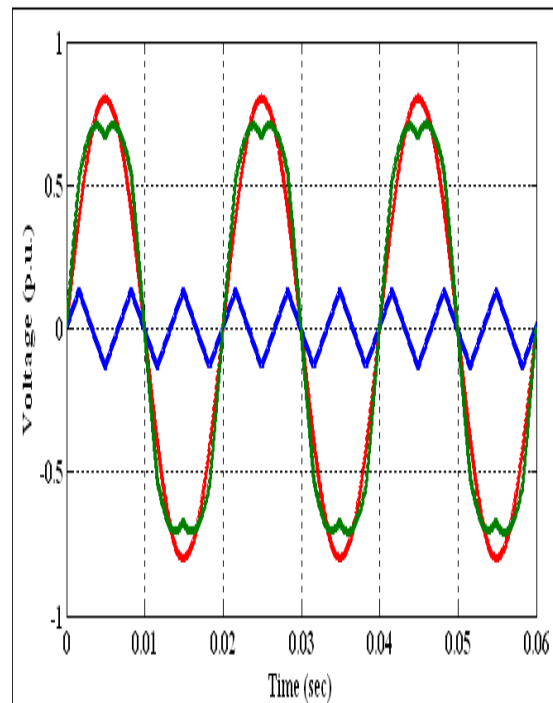


Fig 3. Waveform of fundamental signal (V_1), Third harmonic signal (V_3) and resultant signal (V_r)

The presence of exactly the same third-harmonic component in each phase results in an effective cancellation of the third harmonic component in the neutral terminal, and the line-to-neutral phase voltages are all sinusoidal with the peak amplitude. By injecting the third harmonic into the reference voltage signal, the fundamental of the phase voltage can be increased. The voltage can be increased by harmonic suppression for the rectifiers as well as inverters. This can be mainly done by injecting the third harmonic.

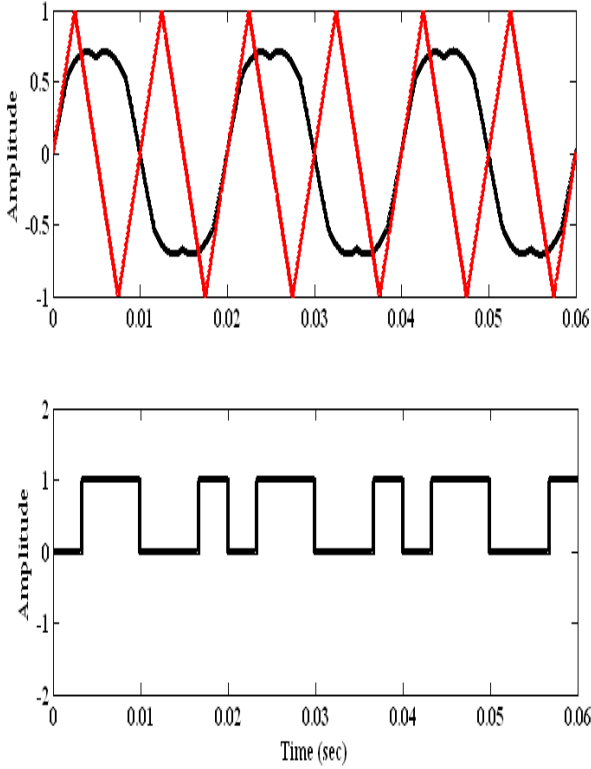


Fig 4. Carrier & Reference Waveform along with the pulses of Third Harmonic Injection Pulse Width Modulation

3.2.1 Calculation of optimum distortion

The generation of the phase voltage waveform having no third harmonics can be generated by addition of the third harmonics in the sinusoidal reference waveform. These additions of the various amounts of third, ninth, fifteenth etc. harmonics is used to produce flat-topped phase waveforms which improves the efficiency of the class B inverters. The optimal amount of third harmonic should extend the ratings of all PWM inverters. The best modification that can be made to the inverter phase output waveform is assumed a priori to be the addition of a measure of third harmonics. The desired waveform of the type

$$y = \sin \omega t + A \sin 3\omega t \quad (1)$$

Where A is to be determined for the optimal of Y.

The optimal injection is obtained by differentiating (1)

$$\frac{dy}{dt} = \cos \omega t + 3A \cos 3\omega t = 0$$

The maxima and minima of the waveform therefore occur at

$$\cos \omega t = 0 \quad \text{and} \quad \cos 3\omega t = \left(\frac{9A-1}{12A}\right)^{\frac{1}{2}}$$

$$\sin \omega t = 1 \quad \text{and} \quad \sin 3\omega t = \left(\frac{1+3A}{12A}\right)^{\frac{1}{2}}$$

Manipulating the (1) using identity, we get

$$y = (1+3A) \sin \theta - 4A \sin^3 \theta$$

Substituting the values of $\sin \theta$ obtained, we get

$$\hat{y} = 1-A \quad \text{and} \quad \hat{y} = 8A \left(\frac{1+3A}{12A}\right)^{\frac{3}{2}} \quad (2)$$

The optimum value of A is that value which minimizes \hat{y} and can be found by differentiating the expression for \hat{y} and equating it to zero. Thus the values of A are

$$A = \frac{-1}{3} \quad \text{and} \quad A = \frac{1}{6}$$

The value of \hat{y} cannot be greater than unity for this reason the value $A = -1/3$ is discarded. The required value of A is therefore 1/6, and the required waveform is

$$y = \sin \theta + \frac{1}{6} \sin 3\theta \quad (3)$$

3.3 Digital Pulse Width Modulation

In recent years, the interest on digital control for switching power converters has grown considerably. In order to reduce limit cycle oscillations, high resolution digital pulse width modular (DPWM) is mandatory for the system implementation. The reference voltage V_{ref} is added with signal having frequency three times of fundamental frequency and the magnitude is 1/6th of the fundamental amplitude. The resultant is then passed through comparator which compares the modified signal with the carrier signal of frequency 2 KHz.

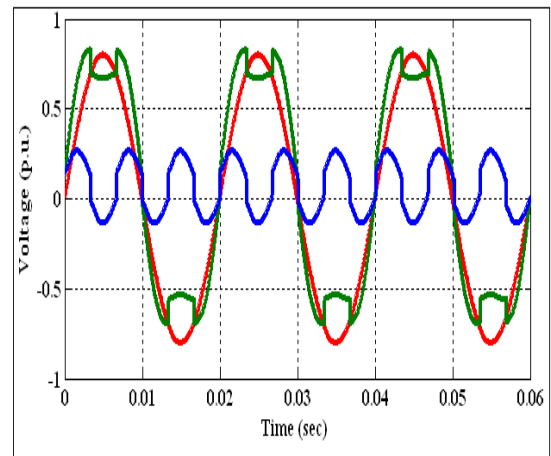


Fig 5. Waveform of fundamental signal (V_1), Modified signal (V_3) and resultant signal (V_r)

Although the delay-line based DPWM can achieve much higher resolution than the counter-based DPWM, it requires large silicon area than the counter-based one. Moreover, the accuracy of the delay time of the delay cell is limited due to variations of the operating temperature, manufacturing process, and the supply voltage. For the method of dithering DPWM, it increases the resolution by averaging several adjacent switching periods' duty cycle values; hence, a large magnitude output ripple is resulted although the limit-cycle oscillation could be reduced.

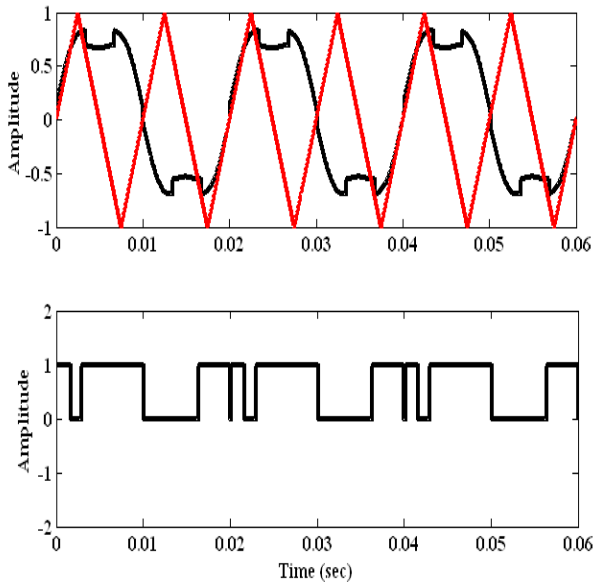


Fig 6. Carrier & Reference Waveform of Digital Pulse-Width Modulation

4. SIMULATION PERFORMANCE

The six switch inverter is simulated and its control signals are derived in MATLAB/SIMULINK.

Table 1. Inverter parameters

DC Bus Voltage	750 V
Carrier frequency	2 kHz

Table 2. Induction motor parameters

Power	3.7 KVA	Stator resistance (R_s)	1.115 ohms
Voltage	460 Volts	Stator inductance (L_{ls})	0.005974 H
Frequency	50Hz	Rotor Resistance (R_r)	1.083 ohms
Rotor Inductance (L_{lr})	0.005974	Magnetizing Inductance	0.2037 H

Simulation results for SPWM

In the fig.7 (a) the current and the voltage waveforms obtained from the inverter when fed with the SPWM pulses are shown.

The current waveform contains some harmonic distortion in the form of spikes i.e. overshooting of the magnitude. The frequency of both current and voltage is 50Hz that can be observed from the waveform.

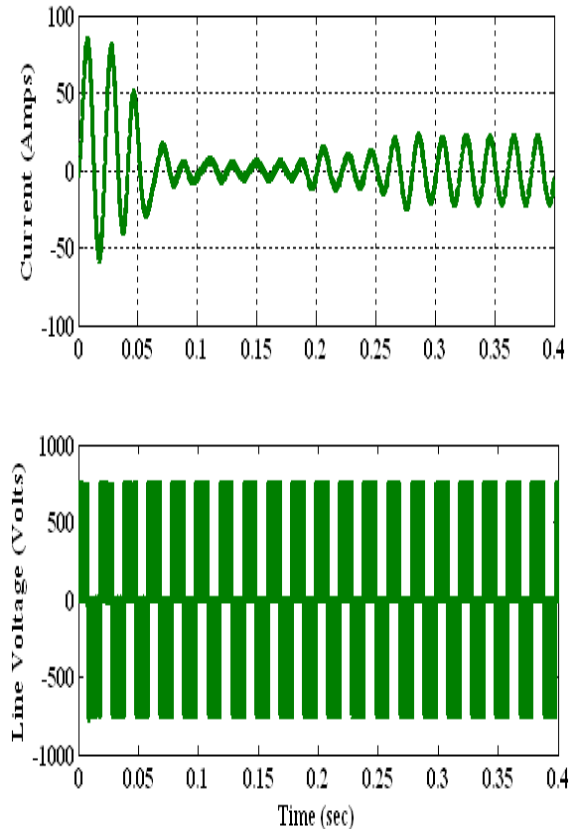


Fig.7 (a) Machine Line voltage and current with $V_{DC}=750V$ and load torque is [25 50] Nm at $t=[0.18\ 0.25]$ sec for SPWM

In this case, the load on the motor is changed through variation in the torque for different time instants but due to proposed control, there is no change in speed. It seems that the drive can operate at constant speed at different values of load torque. The corresponding torque generated by motor (electromagnetic torque) and speed of induction motor are shown in Fig. 7 (b)

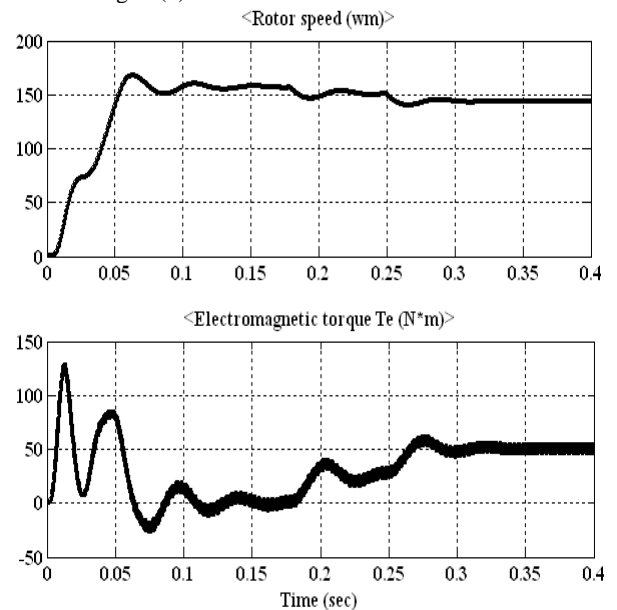


Fig. 7 (b) shows speed & Electromagnetic Torque of SPWM

Simulation results for THIPWM

In the fig 7 (c) the current and the voltage waveform of the inverter fed induction motor drive is shown:-

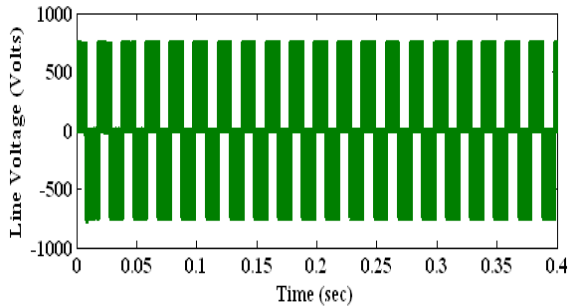
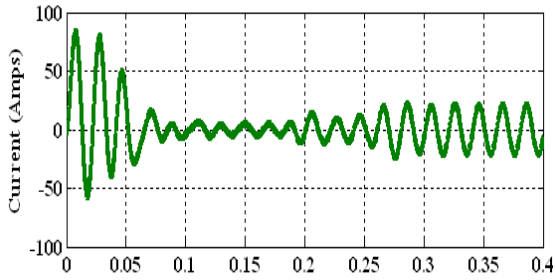


Fig.7 (c) Current and Voltage waveform of THIPWM

The corresponding torque generated by motor (electromagnetic torque) and speed of induction motor are shown in Fig. 7(d)

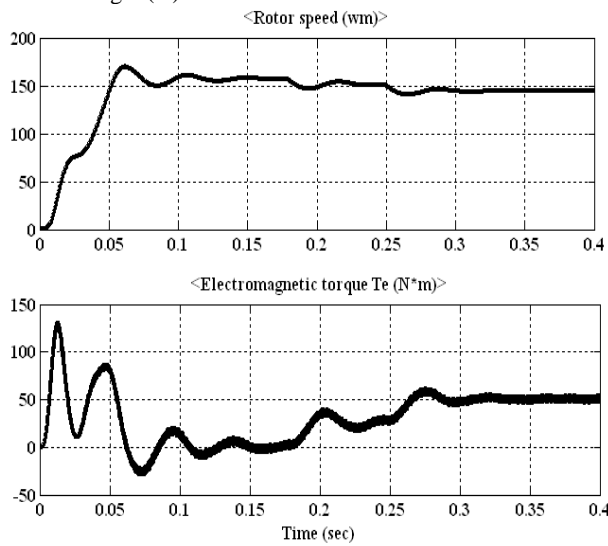


Fig. 7 (d) shows speed & Electromagnetic Torque of THIPWM

Simulation results for DPWM

In the fig 7 (e) the current and the voltage waveform of the inverter fed induction motor drive is shown:-

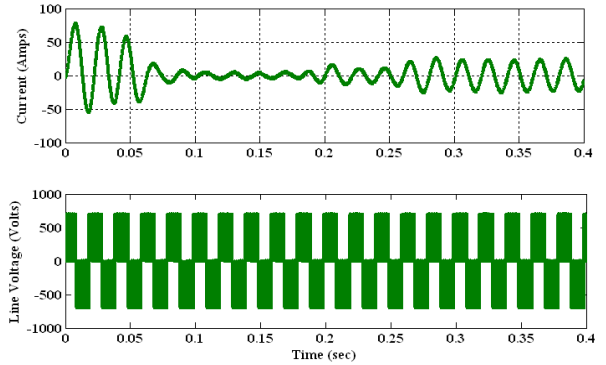


Fig.7 (e) Current and Voltage waveform of DPWM

The corresponding torque generated by motor (electromagnetic torque) and speed of induction motor are shown in Fig. 7 (f)

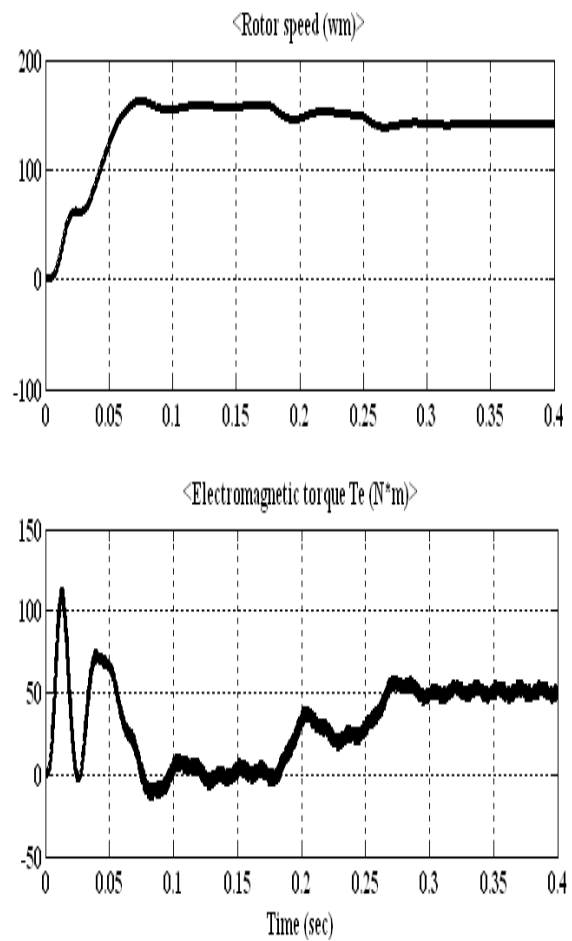


Fig. 7 (f) shows speed & Electromagnetic Torque of DPWM

Table 3 shows the values of the THD for output voltage and current for SPWM, THIPWM & DPWM techniques. It is been observed that the THD for THIPWM technique is better than the SPWM & DPWM

Table 3
Values Total Harmonic Distortion for Voltage & Current at different Modulation index for SPWM, THIPWM & DPWM techniques
 (Carrier frequency= 2 kHz)

Modulation Index	Voltage (THD value)			Current (THD value)		
	SPWM	THIPWM	DPWM	SPWM	THIPWM	DPWM
M = 1	68.3	54.2	59.6	12.4	10.9	11.2
M = 0.8	91.5	78.5	80.3	9.4	7.5	8.2
M = 0.6	120.4	109.6	110.8	6.0	4.8	5.6

5. CONCLUSIONS

The six switch inverter operation with SPWM, THIPWM & DPWM is simulated and their performance has been presented. The independent control is feasible with each of the three phase load. The effectiveness of THIPWM technique in this operation improves the inverter output rms voltage for a given DC bus voltages as compare to SPWM & DPWM. Thus it gives effective utilization of the inverter and enhancement of rms content of the output voltage.

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