Comparative Analysis Of Voltage Source Inverter Using Sinusoidal Pulse Width Modulation And Third Harmonic Injection Method For Different Levels And Loads

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Abstract
This paper presents a comparative analysis of Voltage Source Inverter using Sinusoidal Pulse Width Modulation Method and Third Harmonic Injection Pulse Width Modulation Method in Two and Three level inverter for different loads. In this paper we have designed the Simulink model of Inverter. All above technique is used to reduce the Total Harmonic Distortion (THD) on the AC side of the Inverter. Results are analyzed using Fast Fourier Transformation (FFT) analysis for observing the Total Harmonic Distortion. All simulation are performed in the MATLAB Simulink.

Keyword: Voltage Source Inverter (VSI), Sinusoidal Pulse Width Modulation (SPWM), Third Harmonic Injection Pulse Width Modulation (THIPWM).

Introduction
A circuit which converts DC power into an AC power at desired output Voltage and Frequency is known as Inverter. A phase controlled converter, when it is used in inverter mode, are known as line-commutated Inverter, only line-commutated inverter requires at the output terminals an existing AC supply which is used for their commutation. A Force commutated Inverter gives an independent AC output voltage of adjustable Voltage and Frequency, therefore its application is vast. In Inverter we require Forced commutation for thyristor, therefore we can use other self-commutating device like GTO, MOSFET, and other Transistors to avoid the commutation circuit. But for high power application we must use thyristor along with the forced commutation circuit. There are total four techniques to reduce the Total Harmonic Distortion in Inverter

1.   Sinusoidal Pulse Width Modulation
2.   Third Harmonic Injection Method
3.   Delta Method (60° Pulse modulation)
4.   Space Vector Pulse Width Modulatio
.
In this paper we focus on the Sinusoidal pulse width technique and Third harmonic injection technique

SINUSOIDAL PULSE WIDTH MODULATION
This technique is very useful for reducing the Total Harmonic Distortion. This technique is characterized by the constant amplitude pulse. And the width of these pulse is modulated to get Inverter output Voltage control and to reduce its harmonic content. Force commutation is essential for the pulse width modulation. The Switching sequences and topology of the Inverter is same. In this technique the Gate pulse of MOSFET is modulated and control the Switching of MOSFET to get the desired output voltage for input voltage of Induction motor. Fourier analysis of the voltage waveform and get the output voltage of Inverter.

$$V(t)= A_0 + 2*[\sum_{k=1}^{\infty} Ak * coskwt + Bk * sinkwt] \qquad (a)$$

The output voltage wave is odd symmetry. So, A_0 andAk is zero. So,

$$Bk= (2/\pi)*[\ \int_{\frac{\pi}{2}-d}^{\frac{\pi}{2}+d} Vs * \sin(nwt)d(wt)]$$
$$= ((4*Vs) / (n\pi))* [\sin (n\pi/2) *$$

$$\sin(nd)] \qquad (1)$$

$$V_0=(\sum_{n=1,3,5}^{\infty} [\left(\frac{4Vs}{n\pi}\right) * \sin\left(\frac{n\pi}{2}\right) * \sin(nd) * \sin(nwt)]) \quad (2)$$

nd is made equal to π. So, d= (π/n)

So, the pulse width is made 2d and that is equal to (2d/n).
Where n^{th} is the harmonic is eliminated from the inverter output voltage.
In the Simulink model sine wave frequency is 50 Hz and the amplitude of the sine wave is 5; and carrier frequency is sawtooth with frequency is 1000 Hz.

THIRD HARMONIC INJECTION PULSE WIDTH MODULATION METHOD
This method is also a very useful method for eliminating the harmonic in the system which comes due to the MOSFET or power electronic switches. In this method we inject the third harmonic in the system and control the pulse of the MOSFET. To get the harmonic free inverter output voltage. To find the

amplitude of the third harmonic of unknown amplitude of the third harmonic component.

So let us take simple sine wave whose fundamental frequency is 50 Hz with the third harmonic of unknown amplitude x.

$$Y(\alpha) = \sin(\alpha) + x*\sin(3\alpha) \qquad .(3)$$

For finding the maximum value of the function $d/d\alpha\,(Y(\alpha)) = 0$
Which gives,

$$\alpha = \cos^{-1}\sqrt{((9x-1)/(12x))} \qquad .(4)$$

From equation (3) and (4)

$$F(x) = Y(\alpha) = [(3x+1)(\sqrt{(3x+1)/(12x)} -$$

$$4x^{1.5}\sqrt{((3x+1)/(12x))}] . \qquad .(5)$$

For finding the maximum value of equation (5) using formula $d/dx\,(F(x))$
So we get x = -0.334, 0.1667
At x = -0.334
$d^2/dx^2\,(F(x)) = 0$
At x = 0.1667
$d^2/dx^2\,(F(x)) = 10.3923$

Which shows the given function is minimum. At x = 0.1667 the value of α is 60°
Now putting the value of α at x = 0.1667
$d^2/dx^2\,(Y(\alpha)) = -2$

This shows the function $Y(\alpha)$ is maximum.
So this is clear that the third harmonic should be 0.1667 of the amplitude of the $_d$
Putting the value of x = 0.1667 and α = 60° in equation (4)
Which gives $Y(\alpha)$ = 0.866025, which is the peak of resultant waveform with third harmonic. And the modulation factor of 1/0.866025 is 1.15470053 giving 15.47% more DC bus utilization.

$$\begin{aligned} Va &\quad Vsin(\alpha) \\ Vb &= Vsin(\alpha - 120°) \\ Vc &\quad Vsin(\alpha + 120°) \end{aligned} \qquad .(6)$$

Where,
V is Instantaneous Magnitude of fundamental
And
α is instantaneous phase of fundamental
For direct axis voltage and quadrature axis voltage using the equation

$$Va = 0.667*V_q*\cos\beta + 0.667*V_d*\sin\beta \qquad (7)$$
$$Vb = 0.33*V_q*\sin\beta - 0.5773*V_d*\cos\beta \qquad (8)$$
$$Vc = -Va - Vb \qquad (9)$$

Where,
Va is phase a voltage
Vb is phase b voltage
Vc is phase c voltage
V_d is direct axis voltage
V_q is quadrature axis voltage
From equation (6), (7), (8), and (9)

Instantaneous magnitude of fundamental waveform is

$$V = \sqrt{(Vq2 + Vd2)/1.5} . \qquad (10)$$

Now we find the value of $\sin(\alpha)$ from equation (6)
We get $\sin(\alpha) = Va/V$ $\qquad .(11)$
From equation (10) and (11) instantaneous third harmonic value is calculated

$$V_{ref} = (v/6)*\sin(3\alpha) \qquad .(12)$$

So phase voltage of third harmonic injection written as
$$Va_{THI} = (Va + V_{ref})*1.1547 \qquad .(13)$$
$$Vb_{THI} = (Vb + V_{ref})*1.1547 \qquad .(14)$$
$$Vc_{THI} = (Vc + V_{ref})*1.1547 . \qquad (15)$$

The above equation give the information about the amplitude of the output phase voltage is 1.15 times of the normal output phase voltage. In the Simulink model sine wave frequency is 50 Hz and the amplitude of the sine wave is 5; and carrier frequency is sawtooth with frequency is 1000 Hz. And additional sine wave is added to add the third harmonic in the Inverter whose sine wave amplitude is 5/3 and its frequency is 3 times of rated frequency.

TWO LEVEL INVERTER

In this mode each MOSFET conducts for 180° of a periodic cycle. Each phase has a pair S1, S4; S3, S6;S5, S2 and each trigger for 180° of time interval. And
S1, S3, and S5 conduct at an interval of 120°. Refer to Fig 1.
0° 60° 120° 180° 240° 300° 360°

S1		S3		S5	
S6	S2		S4		S6

Fig 1:-Switching period of MOSFET.

Specification for pulse generator of 180° mode VSI. Refer to Table 1.

Table 1:-For 50 Hz frequency Pulse Generator where amplitude = 5 and pulse width 50%.

S1	Phase Delay = 0msec
S4	Phase Delay = 10msec
S3	Phase Delay = 6.667msec
S6	Phase Delay = 16.667msec
S5	Phase Delay = 13.33msec
S2	Phase Delay = 23.33msec

THREE LEVEL INVERTER

This method is most useful method to eliminate the Harmonic in the system. In this level inverter one leg of the inverter consist Four MOSFET, and there is total three leg so total number of MOSFET is twelve. The basic formula of one leg consist of MOSFET is 2*(n-1), where n is the number of level.
In this three phase Three level inverter total twelve MOSFET. So, number of sectors are divided into Twelve sectors and one sector is of 30°.

No. of sectors = (360°/12) = 30°.
Pulse width of S1 MOSFET is 41.667%.
And for S4 the pulse width is 58.33%

Similarly second and third leg MOSFET is 120° and 240° apart of corresponding MOSFET of first leg respectively.The repeating sequence that is triangular output value is 0 to 4.1667 and other is 4.1667 to 10.
For sector table of first limb. Refer to Table 2.

Table 2:-Switching sectors of one leg MOSFET

Sector Degree / MOSFET	S1	S4	S1'	S4'
0°-30°	1	1	0	0
30°-60°	1	1	0	0
60°-90°	1	1	0	0
90°-120°	1	1	0	0
120°-150°	1	1	0	0
150°-180°	0	1	1	0
180°-210°	0	0	1	1
210°-240°	0	0	1	1
240°-270°	0	0	1	1
270°-300°	0	0	1	1
300°-330°	0	0	1	1
330°-360°	0	1	1	0

In this Simulink model we added the bias in the sine wave whose value is 5.

SIMULATION MODEL PARAMETER
Specification of model. Refer Table 3.

Table 3:-Model parameter and Specification

Inverter Power Supply	500 V DC	
Snubber circuit Parameter	R_s	8 ohm
	C_s	$3*10^{-7}$ farad
Induction Motor parameter	Stator Resistance	0.74ohm
	Stator Inductance	0.003045 Henry
	Rotor Resistance	0.74 ohm
	Rotor Inductance	0.003045 Henry
	Mutual Inductance	0.1241 Henry
	Supply Voltage	330 Volt
	Nominal Power	6048.48 W
	Speed	1440 rpm
	Slip	4%
	Pole	4
	Moment of Inertia	0.0343 Kg*m^2

	Friction Factor	0.000503 N.m.s
	Load Torque	35.53 N.m
	Efficiency	88.54%
Electrical parameter	R load	10 ohm
	R L load	10 ohm,0.038216 Henry
	R L C load	10 ohm, 0.038216Henry, 2.274*10^-4 Farad

SIMULINK MODEL AND WAVEFORM:
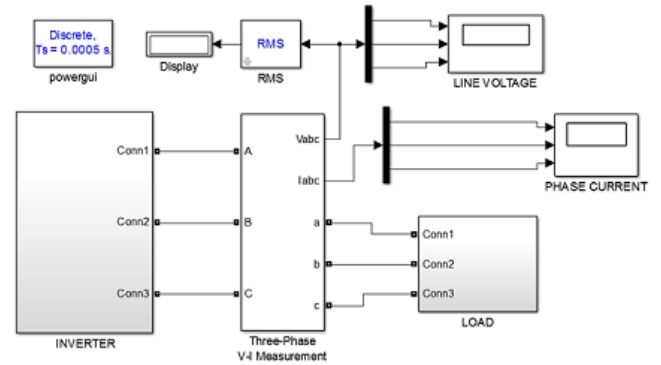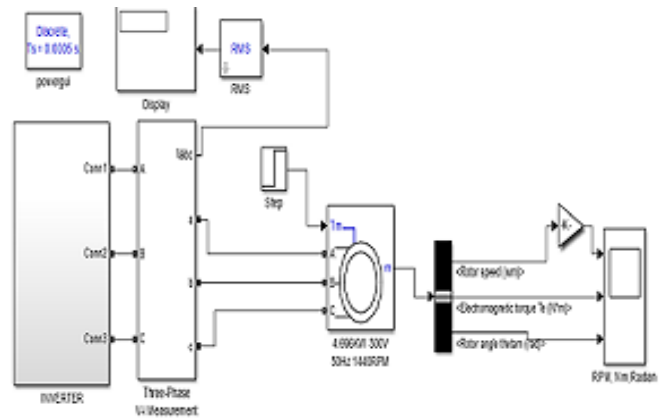

Fig 2:-Inverter with Load
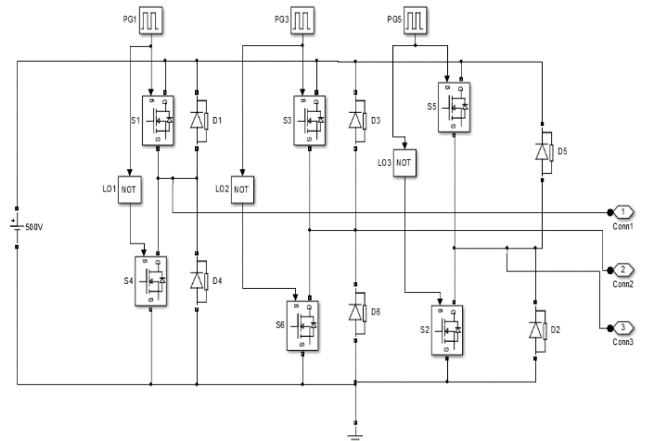

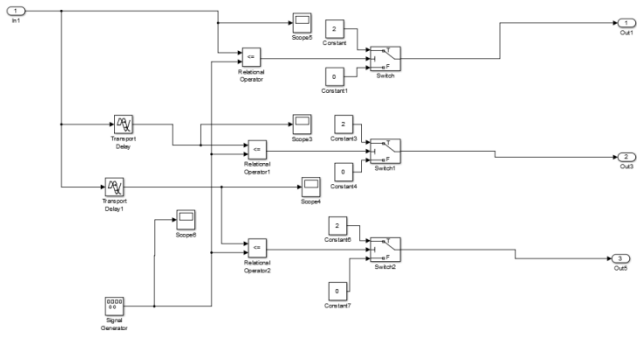**Fig 3:-Inverter with squirrel Cage Induction Motor**

Fig 4:-Two level Inverter

Fig 5:-Two level SPWM Inverter

Fig 6:-Two level THIPWM Inverter

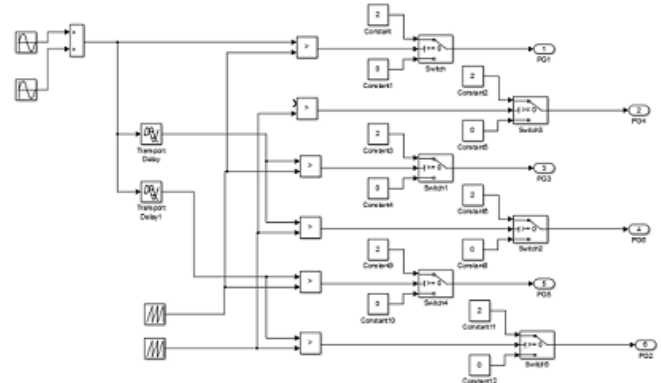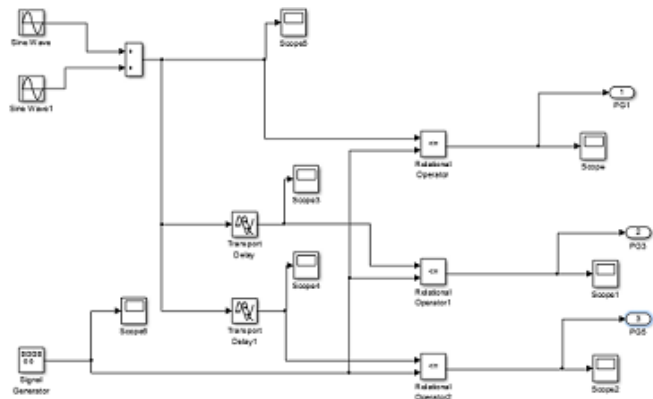**Fig 7:-Three level Inverter**

Fig 8:-Three level SPWM Inverter

Fig 9:-Three level THIPWM Inverter
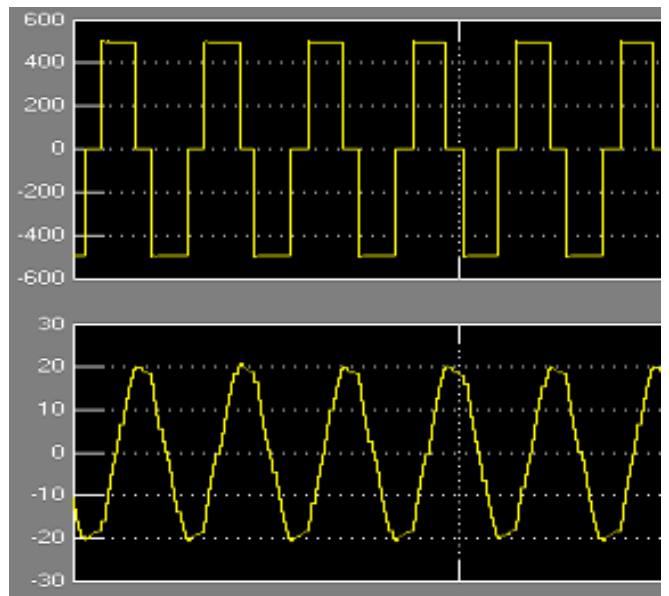
Fig 10:-Two level SPWM INVERTER RL load Line Voltage and Current

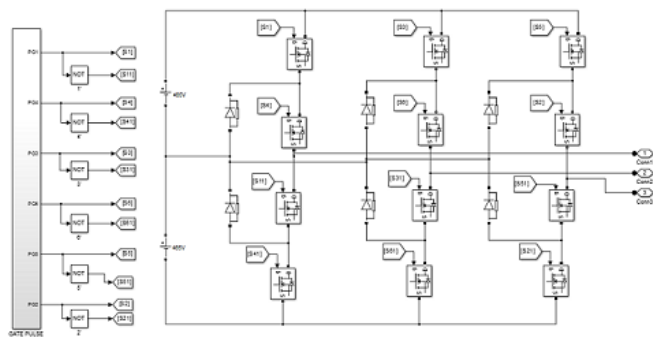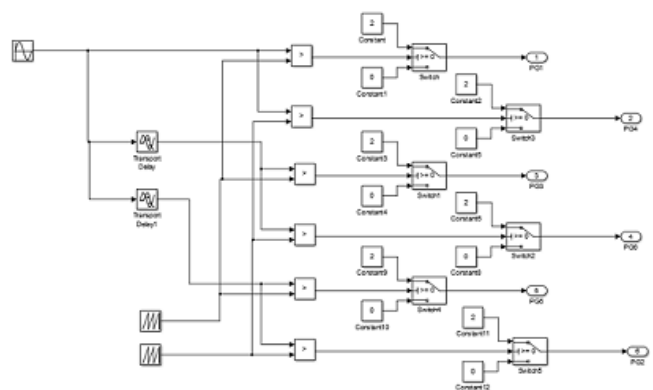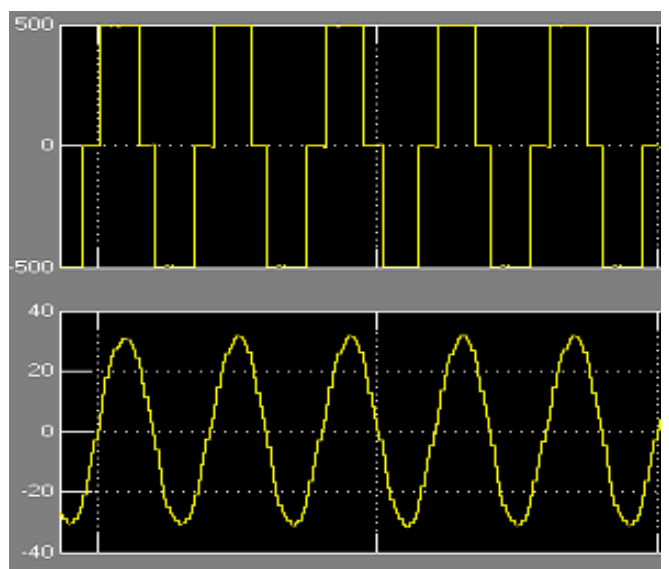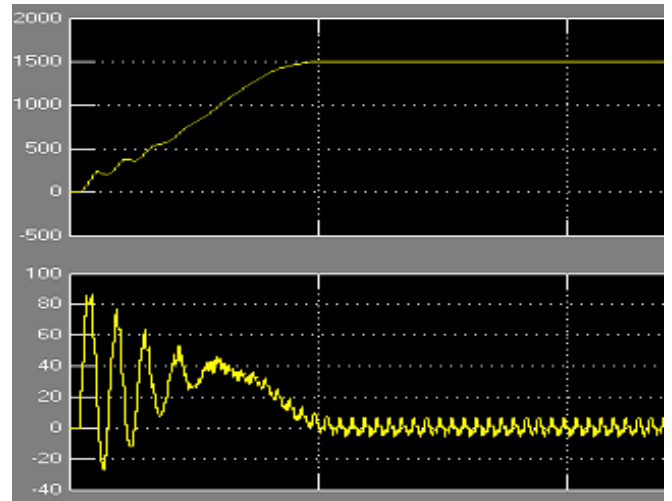
Fig 11:-Two level SPW M INVERTER RLC load Line Voltage and Current
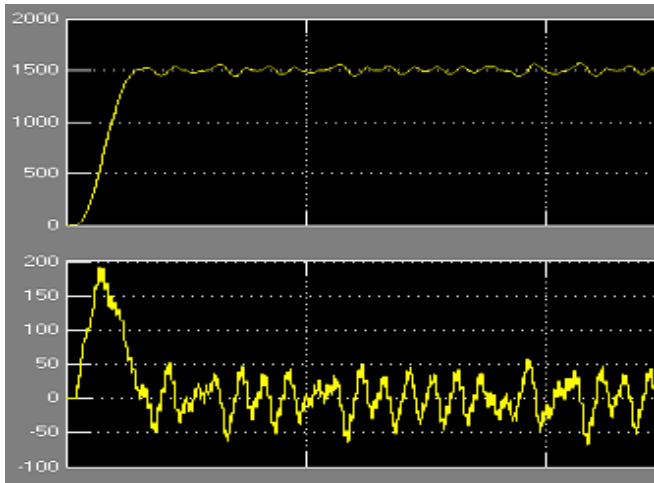
Fig 12:-Two level SPWM INVERTER Speed and Torque
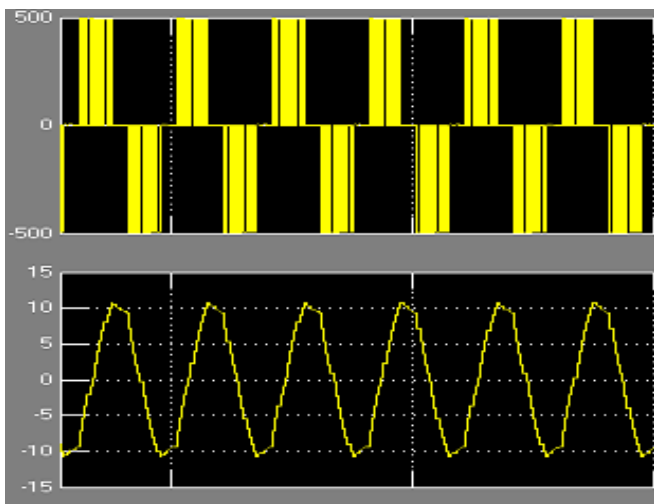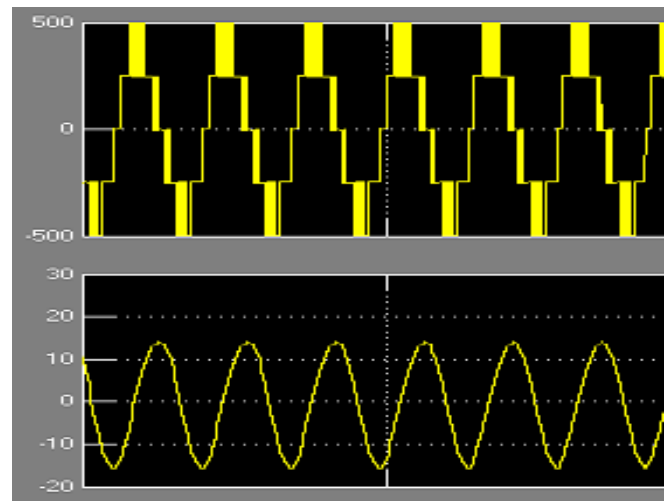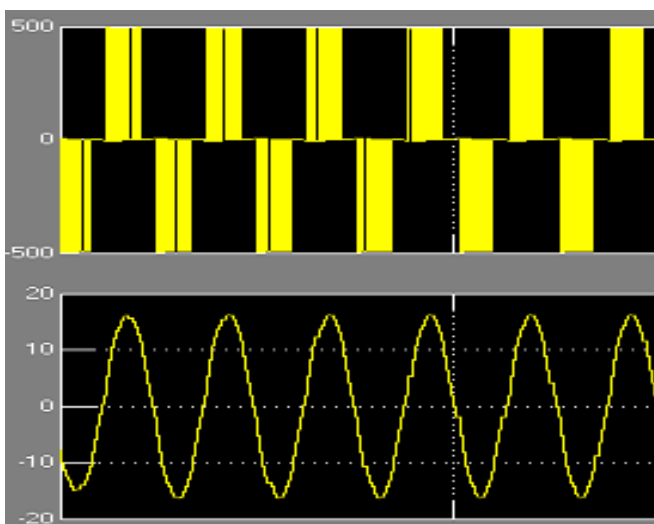

Fig 13:-Two level THIM INVERTER RL load Line Voltage and Current

Fig 14:-Two level THIM INVERTER RLC load Line Voltage and Current

Fig 15:-Two level THIM INVERTER Speed and Torque

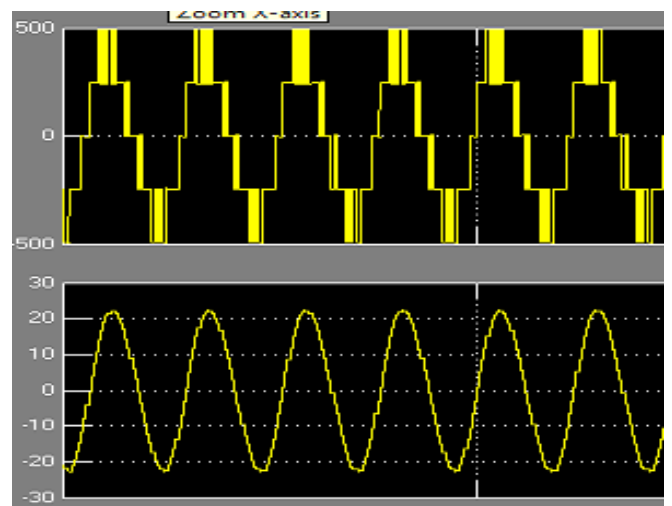**Fig 16:-Three level SPWM INVERTER RL load Line Voltage and Current**

Fig 17:-Three level SPWM INVERTER RLC load Line Voltage and Current

Fig 18:-Three level SPWM INVERTER Speed and Torque

Fig 19:-Three level THIM INVERTER RL load Line Voltage and Current

Fig 20:-Three level THIM INVERTER RLC load Line Voltage and Current

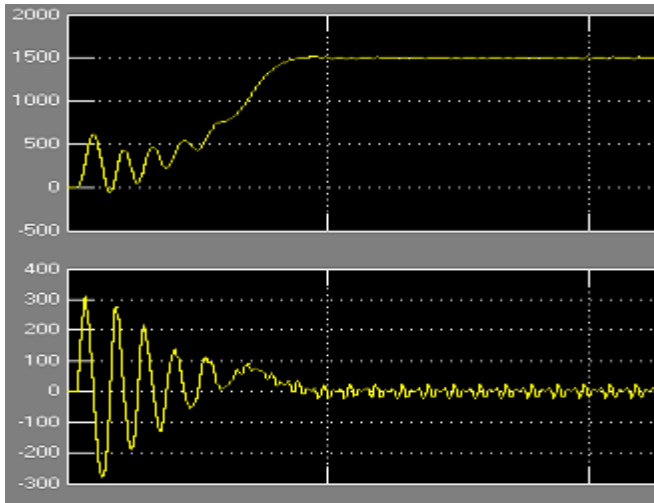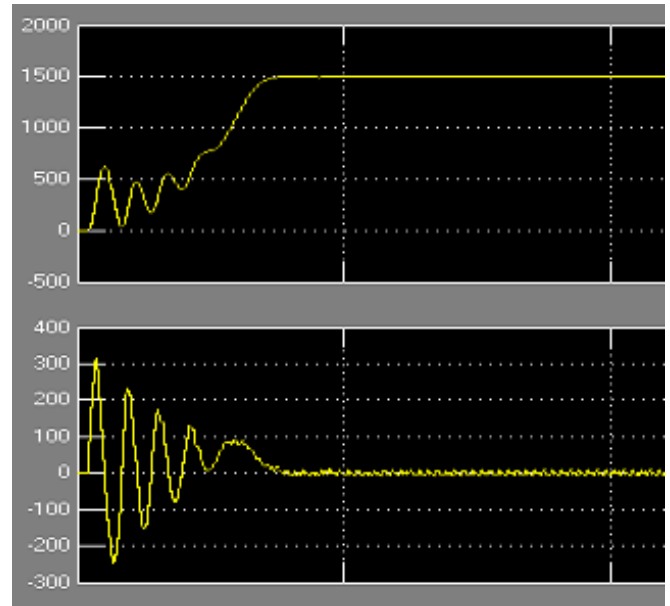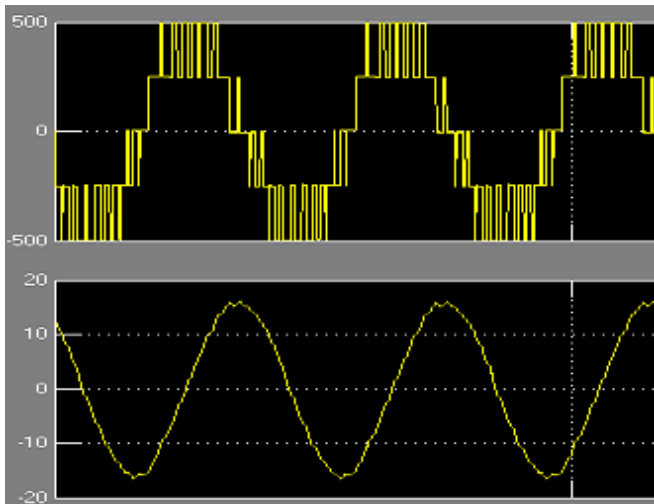**Fig 21:-Three level THIM INVERTER Speed and Torque**
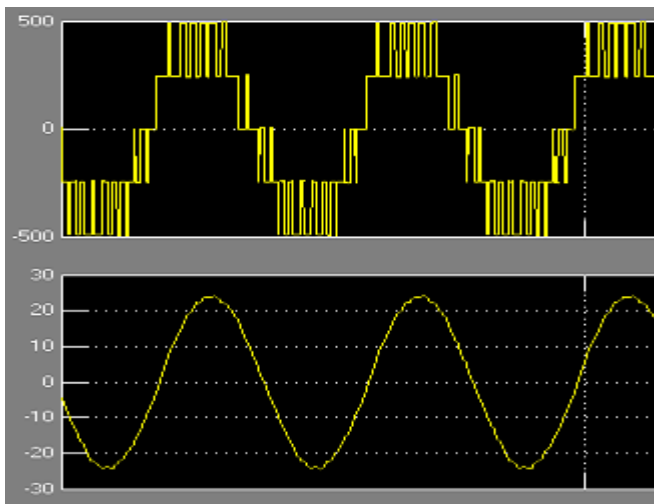
RESULTS

LEVEL	TECHNIQUE	LOAD	THD%
TWO	SPWM	RL	7.76
		RLC	6.45
		IM	44.66
	THIM	RL	7.76
		RLC	6.45
		IM	44.66
THREE	SPWM	RL	7.93
		RLC	7.15
		IM	10.58
	THIM	RL	6.33
		RLC	5.59
		IM	7.41

CONCLUSION

The SPWM technique and THIPWM technique is same for the RL, RLC and Induction Motor load for THD analysis. But the phase voltage of THIPWM technique is 1.15 times to the SPWM technique in Two level inverter. And in Three level Inverter the THIPWM technique is good as compare to SPWM technique. the THD of THIPWM technique is quite low is compare to SPWM technique. And one more advantage of the THIPWM technique is phase voltage of THIPWM technique over SPWM is 1.15 times of it. And the Speed And Torque Characteristics is always better in THIPWM technique as compare to SPWM while using to drive the Induction Motor, when it is used in Two level or in Three level voltage source Inverter.

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