Design and simulation analysis of Different PWM schemes for open loopZ –Source converter

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***Abstract*— Inverter is one of the most important parts of renewable energy system. To overcome disadvantage of voltage source and current source inverter, Impedance source inverter (ZSI) ,which is buck boost inverter without the need of a dc -dc converter has been presented in recent year. To be an economic alternative to conventional inverters, Z source inverter should have higher efficiency and lower cost and sustain a high quality output voltage. For meeting these requirements we used various control method. An alternative power conversion concept recently proposed by Z-source converter because it has both voltage buck and voltage boost capabilities .In ZSI hasan unique X –shaped impedance network which couples converter main circuit to the power source. In this paper we deal with comparative analysis of different modified PWM control methods of Z source inverter (ZSI), which is also known as impedance source inverter . For obtain boosted outturn voltage, a shoot through state should be created followed by an active state. Therefore, small changes have been made by us in the classical three phase sinusoidal Pulse Width Modulation (PWM) technique to provide different control techniques for the ZSI. Simple boost control with triangular carrier wave, simple boost control with sinusoidal carrier waveform, maximum boost control, maximum boost control with third harmonic injection, constant boost control and constant boost control. In this paper, simulations of various shoot through Control techniques are performed for the same modulation index and outline parameters of the ZSI. The output voltage and output current of the inverter for the same input and load conditions are analyzed using MATLAB/SIMULINK.**

***Index Terms*— Sinusoidal and PWM, maximum boost control, simple boost control, constant boost control, impedance source inverter (ZSI),MATLAB/SIMULINK-R2013a.**

I. INTRODUCTION

In switching waveform distribution the shoot through of the traditional pulse width modulation is the key factor to control the z-source inverter. Diagonal capacitor voltage, control range of AC output voltage, voltage stress across switching devices and harmonic profile of the output profile are purely based on the method control algorithm adapted to insert the shoot through .There are many number of control method which have been presented so for to control the Z –source inverter .This paper deal with three type of PWM control algorithm: Simple boost control (SBC), Maximum boost control (MBC), Constant boost control (CBC). The buck boost operation of z source converter is based on the boost factor, which is based on the placement of the shoot-through time period in between the active state. Shoot through period is carefully inserted before or after the active states by keeping the time period of the active states constant. With the help of z-source inverter dc input voltage can be boosted with no requirement of dc-dc boost converter or step up transformer, by this we overcome output voltage limitation as well as lower its limitation as well as lower its cost. If we take comparison among conventional PWM inverter, dc to dc boosted PWM inverter, and Z- source inverter.ZSI shows that Z source inverter employs the lowest semiconductors and control circuit cost which are the main costs of a powerelectronics system . It is a new approach to compare all of them with the same circuit parameters to get a certain comparison. These advantages result in increasing attention on Z-source inverter, especially for the application where the input DC source has a wide voltage variation range, such as the photovoltaic (PV) grid tied generation and fuel cell motor drive system Moreover, for Z source inverter, EMI influence is free from concern since shoot through is welcome and even exploited, which in turn enhances the inverter reliability.

II. Z-SOURCE INVERTER

Circuit configuration of 3 phase Z source inverter demonstrates in Fig2.1. It consists 2 identical inductors and 2identical capacitors which are connected to form a unique impedance network to avoid short circuit when the devices are in shoot through mode, a diode is used for blocking reverse current, and a three phase bridge as in traditional inverter. In 3 phase Zsource inverter, we introduce an additional control parameter is, known as the Boost Factor (*B*), which modifies the AC outputvoltage equation of traditional 3 phase PWM inverters following.

$$\hat{v}_{out} = BM\frac{V_o}{2}$$

where
Vout = inverter out put voltage

B= Boost factor
M= Modulation index
Vo= DC input voltage

BM is replaced with G; output equation may be rewritten as

$$\hat{v}_{out} = G\frac{V_o}{2}$$

G is inverter gain which is expressed by
G=BM
Traditional voltage source inverter also looked like as

$$\hat{v}_{out} = M\frac{V_o}{2}$$

Boost Factor is obtained by introducing shoot throughof minimal one pair of the inverter arm for a short
Period of time which called shoot through time

$$B = \frac{1}{1-2\frac{T_o}{T}} = \frac{1}{1-2D_o}$$

T0 =shoot through time
T =Switching period
D0 =Shoot through duty ratio

In the 3 phase Z source inverter 9 permissible switching states are acquired, unlike the traditional 3 phase V source inverter that has eight.They comprise 6 active states, 2 zero states, and 1 additional zero state called shoot through zero states that is forbidden in traditional voltage source inverter.

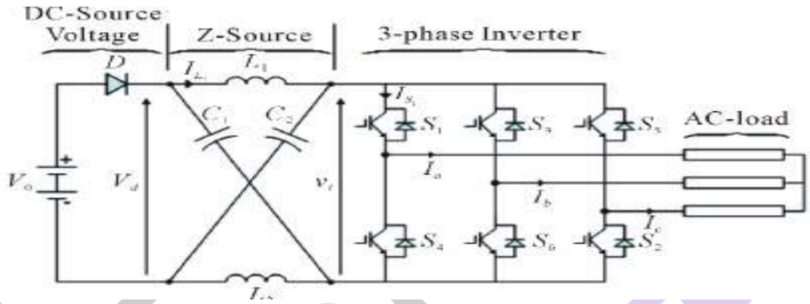


Fig2.1. ZSI voltage type configuration

*(A)**Operation and Analysis of Z-Source Inverter-***

In z source inverter a unique impedance network impedance network we use which connect the converters main circuit to the power source, load and other converter. In impedance network two inverter and two capacitor are cross connected, to form the second order fitter network. We use the same value of inductor and capacitor. We use three operating state in z source inverter.

1. Active State
2. Zero state
3. Shoot though Zero state

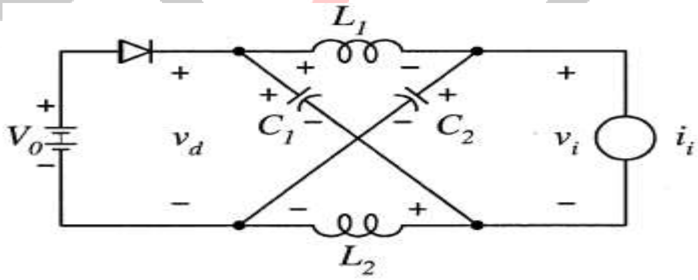


Fig2.2. Equivalent circuit of ZSI

*(i)**Active state***

In this mode, the inverter bridge is operating in one of the four traditional active vectors. Both the inductor have identical current value due to circuit symmetry. Due to this unique feature widen the line current conducting intervals, thus reducing the harmonic.

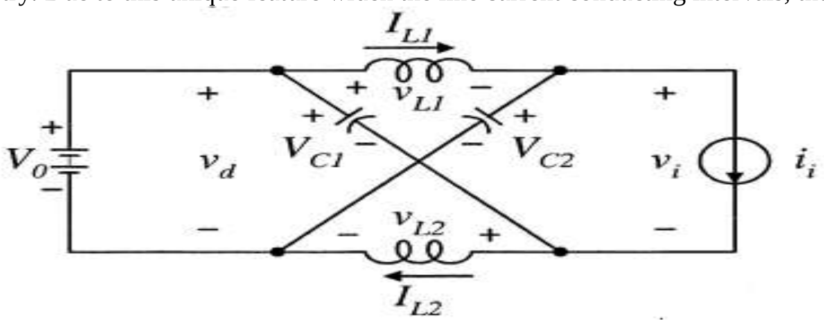


Fig2.3. Active state of ZSI.

*(ii)**Zero State***

Inverter Bridge is operating in one of two traditional Zero vector and shorting through upper or lower three device , thus acting as open circuit viewed from the Z source circuit. Again in this mode current carrying by inductor which contributes to the line current harmonic reduction.

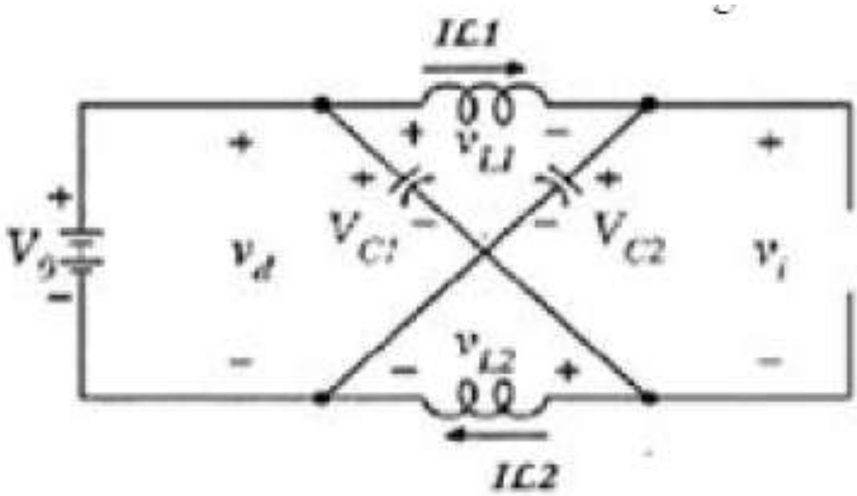


Fig2.4. Zero state operation of ZSI.

(iii) Shoot through state

The inverter bridge is operating in one of the seven shoot-through states. DC link is serrated by AC link in this mod. This shoot through mode to be used in every switching cycle during the traditional zero vector period generated by the PWM control.Depending on how much a voltage boost is needed, the shoot-through interval (T0) or its duty cycle (T0/T) is determined. It can be seen that the shoot-through interval is only a fraction of the switching cycle.

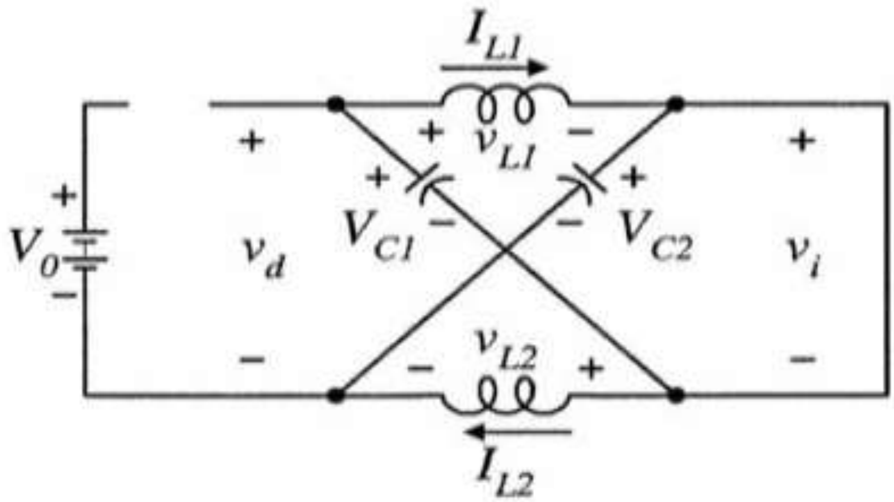


Fig2.5. Shoot through operation of ZSI.

SWITCHING STATES	S1	S2	S3	S4	OUTPUT VOLTAGE
Active states	1	0	0	1	Finite voltage
	0	1	1	0	
Zero states	1	0	1	0	Zero
	0	1	0	1	
Shoot through state	1	1	S3	S4	Zero
	S1	S2	1	1	
	1	1	1	1	

Fig2.6. Switching states of ZSI.

III. PWM TECHNIQUES

Pulse-width modulation (PWM) is the base for control in power electronics. Theoretically zero rise and fall time of an ideal PWM waveform recommend a most popular way of driving modern semiconductor power devices. The exception of some resonant converters the vast majority of power electronic circuits. It turned ON or OFF as quick as practically possible to decrease the switching transition time. The associated switching losses generate by different issue like parasitic ringing and electromagnetic interference (EMI) emission may impose. The upper limit on the turn-ON or OFF speed in practical situations the resulting finite rise and fall time can be ignored in the analysis of PWM signals.

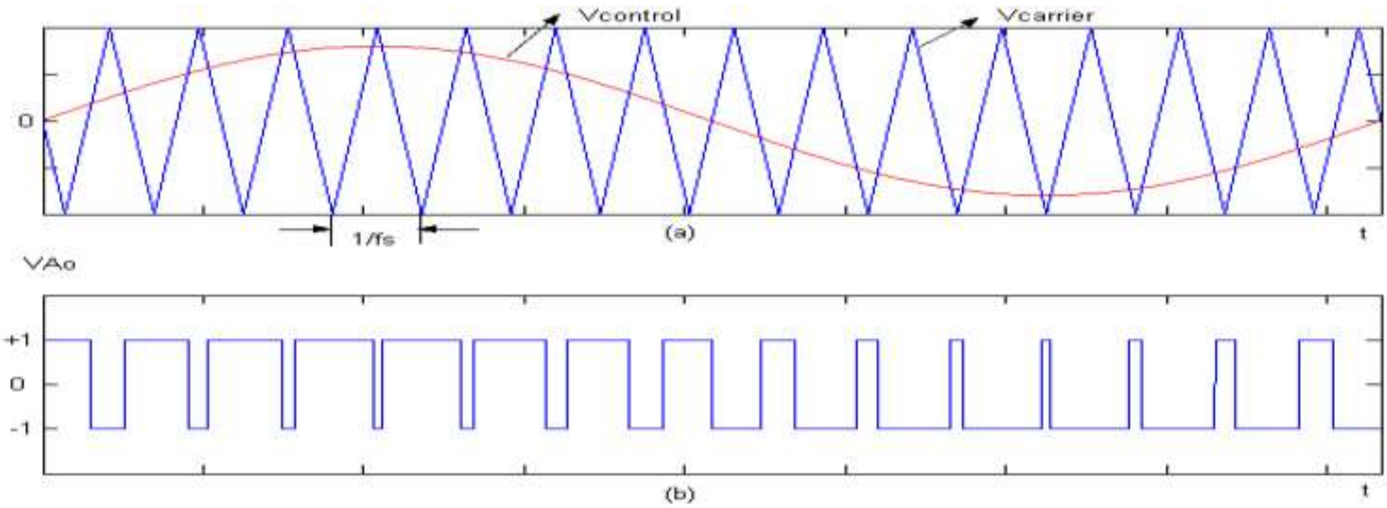


Fig 3.1. Description of PWM modulation

In order to produce a sinusoidal voltage at desired frequency known as f_1 and sinusoidal control signal $V_{control}$ at the desired frequency f_1 is compared with a carrier voltage signal $V_{carrier}$ as shown in Figure3.1 (a), at several compare match point a transition in PWM waveform is generated as shown in Figure 3.1 (b). When $V_{control}$ is greater than $V_{carrier,}$ the PWM output waveformis positive and When $V_{control}$ is smaller than $V_{carrier}$ the PWM waveform is negative and the frequency of carrier waveform $V_{carrier}$ establishes the inverter's switching frequency. We define the modulation index m_i as:

$$m_i = \frac{V_{control}}{V_{carrier}}$$

Where Vcontrol is the peak amplitude of the control signal while Vcarrier is the peak amplitude of the carrier signal. Also the frequency modulation is known as:

$$m_f = \frac{f_s}{f_1}$$

m_f is the ratio between the carrier and control frequency. The fundamental component (Vout) of the H bridge output voltage V_{out} has the property as depicted in equation below in a linear modulation region:

$$(V_{out})_{1=} m_i \,.\, V_d m_i \leq 1.0$$

This equation shows an interesting result. The amplitude of the fundamental component of the output voltage varies linearly with the modulation index value from 0 to 1 is defined as the linear control range of sinusoidal carrier PWM.

(A)BASIC PWM TECHNIQUE

There are three PWM techniques;

i. Single pulse width modulation
ii. Multiple pulse width modulation
iii. Sinusoidal pulse width modulation

(i)Single pulse width modulation

In this modulation technique one pulse per cycle and width of pulse is varied to control output voltage of an inverter.

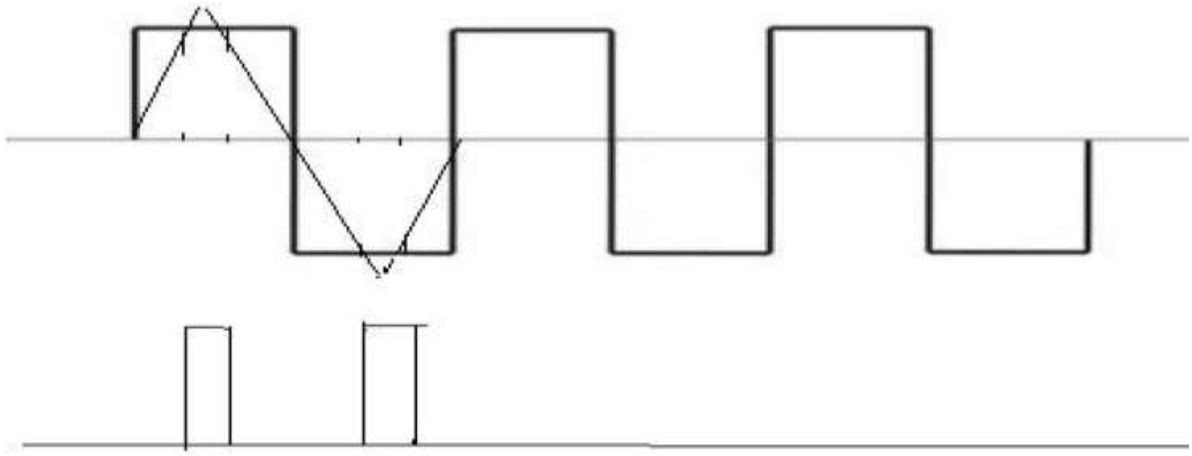


Fig3.2.Single pulse width modulation

*(ii)**Multiple pulse width modulation***

The harmonic in waveform is reducing to increase in switching frequency which is done by increasing the number of pulse per cycle. In this modulation technique bipolar signal are use/ the waveform where the frequency of carrier signal decide the number of pulse per half cycle so by varying frequency of carrier signal hence modulation index is varies and we can control the inverters output.

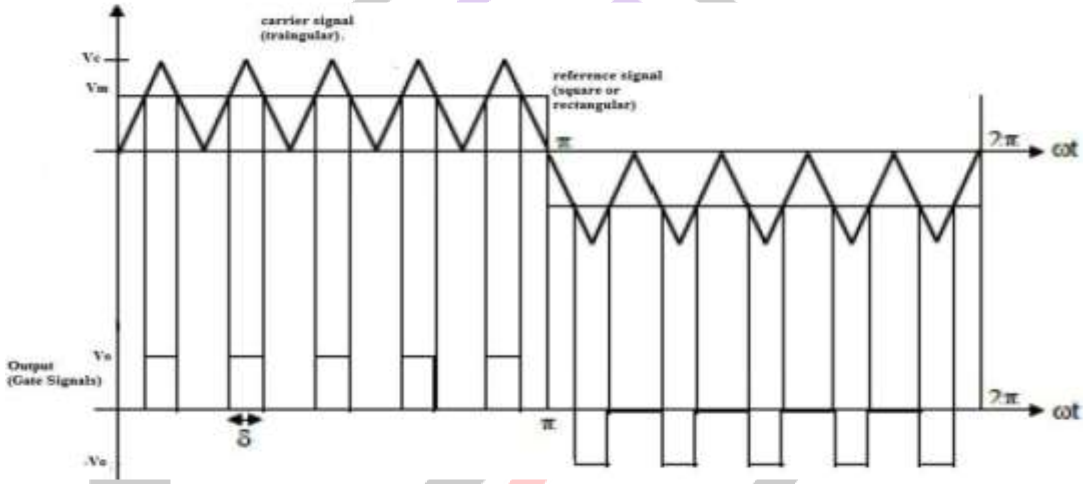


Fig3.3.Multiple pulse width modulation

(iii) Sinusoidal pulse width modulation

In this modulation technique instead of maintaining the width of all pulse as in multiple PWM technique, pulse width varied according with the amplitude of sine wave, the advantage of this technique is that the lower order harmonics and distortion reduce. The gating signal can be generated by comparing the reference signal and carrier signal as shown in figure3.3 and the reference signal frequency is Fr and carrier signal is Fc frequency.The output frequency depends on the reference signal frequency and the amplitude of output voltage is depends on amplitude of sin wave. The reference signal and the number of pulse per half cycle is change with change in carrier frequency.

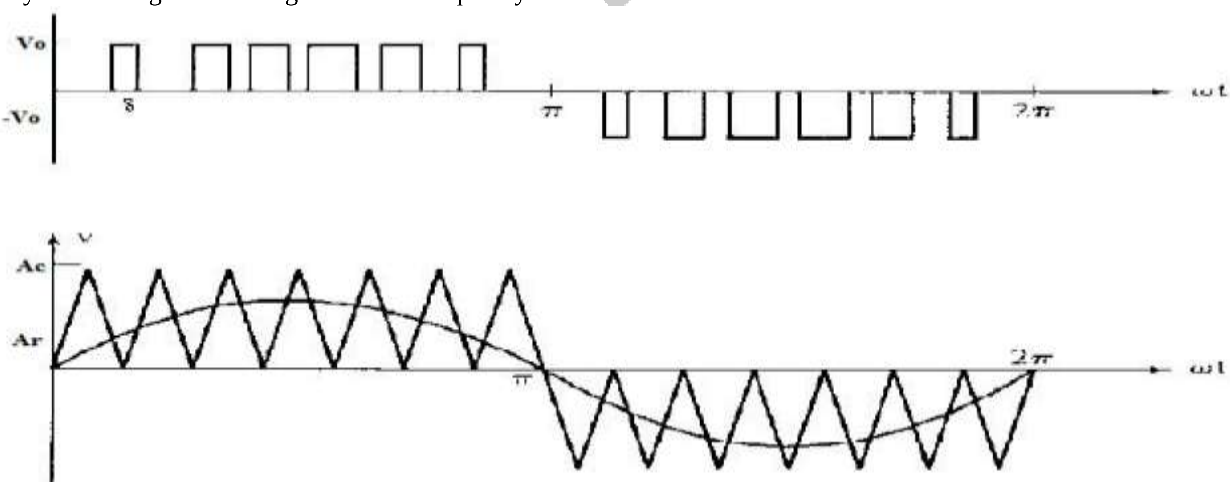


Fig3.4.Sinusoidal pulse width modulation

(B)PWM CONTROL METHODS OF ZSI

Various Sinusoidal Pulse Width Modulation (SPWM)schemes can be applied to the ZSI and their input-outputrelationship is still hold. Minor modifications in SPWMtechniques can provide shoot through pulses for ZSI.
Different PWM methods used to control ZSI are asfollows:
(i) Simple Boost Control (SBC)
(ii) Maximum boost control (MBC)
(iii) Constant boost control (CBC)

(I) Simple boost control methods

Actually, this control strategy inserts shoot through in all the PWM traditional zero states during one switching period. This maintains the six active states unchanged as in the traditional carrier based PWM. The simple boost control method shown in below. Two straight lines are employed to realize the shoot through duty ratio (Do). The first one is equal to the peak value of the three-phase sinusoidal reference voltages while the other one is the negative of the first one. Whenever the triangular carrier signal is higher than the positive straight line or lower than the negative straight line, the inverter will operate in shoot-through. Otherwise it works as a traditional PWM inverter. The driver signals for the six switches and the ST signals of simple boost control method. Since the value of the positive straight line equals to the maximum of the sinusoidal reference signals and the value of the negative straight line equals to the minimum of the sinusoidal reference signal, then the modulation index (M) and the shoot-through duty ratio (Do) are interdependence each other. We can see from the equation that shoot-through duty ratio (Do) decreases with increasing modulation index (M).

$$D_0 = 1 - M$$

We know that

$$G = BM = \frac{M}{1 - 2D_0}$$

Since $D_0 = 1 - M$, thus

$$G = \frac{M}{1 - 2D_0} = \frac{M}{1 - 2(1 - M)} = \frac{M}{2M - 1}$$

This Equation infers that the inverter gain (G) can be controlled by adjusting modulation index (M).

As we know

$$\hat{v}_{out} = M\frac{BV_0}{2}$$

BV_o should be the dc input voltage of the traditional VSI which in the case of Z-source inverter is the dc voltage applied to Inverter Bridge

$$BV_0 = V_{inv}$$

Vinv is the voltage stress of the inverter's devices.

$$B = 2G - 1$$

The voltage stress across the devices is

$$V_{inv} = (2G - 1)V_0 = \frac{1}{2M - 1}V_0$$

(ii)Maximum Boost Method

Maximum boost control method converts all traditional zero states to shoot through while maintaining the six active states remain unchanged, which is obtained by comparing the maximum and the minimum curve of the sinusoidal reference with the triangular carrier. Whenever the maximum is lower than the triangular or the minimum is higher than the triangular, the inverter shoots through. Otherwise, it is operated in the traditional PWM mode. By using this switching strategy, the shoot through duty cycle varies each cycle. The inverter gains maximum shoot through time, which in turn gives the inverter a higher boost factor. Thus, with the same modulation index as in simple boost control method, a higher voltage gain is obtained. As the shoot through duty cycle varies in each cycle, What we are interested in is the average value of the duty cycle. In the interval (π/6, π/2), the average shoot Through duty ratio can be expressed as following.

.

$$\frac{\overline{T_o}}{T} = \int_{\pi/6}^{\pi/2} \frac{(2 - M\sin\theta - M\sin(\theta - 2\pi/3))}{2} d\theta$$
$$= \frac{2\pi - 3\sqrt{3}\pi}{2\pi}$$

$$B = \frac{1}{1 - 2\frac{\overline{T_o}}{T}} = \frac{\pi}{3\sqrt{3}M - \pi}$$

The voltage gain (G) is obtained as

$$G = BM = \frac{\pi}{3\sqrt{3}M - \pi} M = \frac{\pi M}{3\sqrt{3}M - \pi}$$

Similarly, as with the simple boost control method, the voltage gain can be controlled by adjustment of themodulation index.

The voltage stress across the inverter's devices is

$$V_{inv} = BV_o = \frac{\pi}{3\sqrt{3}M - \pi} V_o$$

(iii)Constant Boost Control

High voltage stresses caused by constant boost control and on the other hand variable short circuit operating rate caused by maximum boost control have brought both control techniques to be disadvantageous. Therefore, a novel control technique has been develop to sustain low voltage stress and constant shoot through duty ratio . Short-circuit operation rate is determined by upper and lower control curves (Vp, Vn) . The amplitude values in different time zones of the upper and lower control curve, the shoot through duty ratio, boosting factor, sinusoidal PWM modulation index and voltage stress expressions relating to the method.

$$V_{p1} = \sqrt{3}M + \sin(\theta - \frac{2\pi}{3})M \qquad 0 < \theta < \frac{\pi}{3}$$

$$V_{n1} = \sin(\theta - \frac{2\pi}{3})M \qquad 0 < \theta < \frac{\pi}{3}$$

$$V_{p2} = \sin(\theta)M \qquad \frac{\pi}{3} < \theta < \frac{2\pi}{3}$$

$$V_{n2} = \sin(\theta)M - \sqrt{3}M \qquad \frac{\pi}{3} < \theta < \frac{2\pi}{3}$$

$$D = 1 - \frac{\sqrt{3}M}{2}$$

$$B = \frac{1}{\sqrt{3}M - 1}$$

$$M = \frac{G}{3\sqrt{3}G - 1}$$

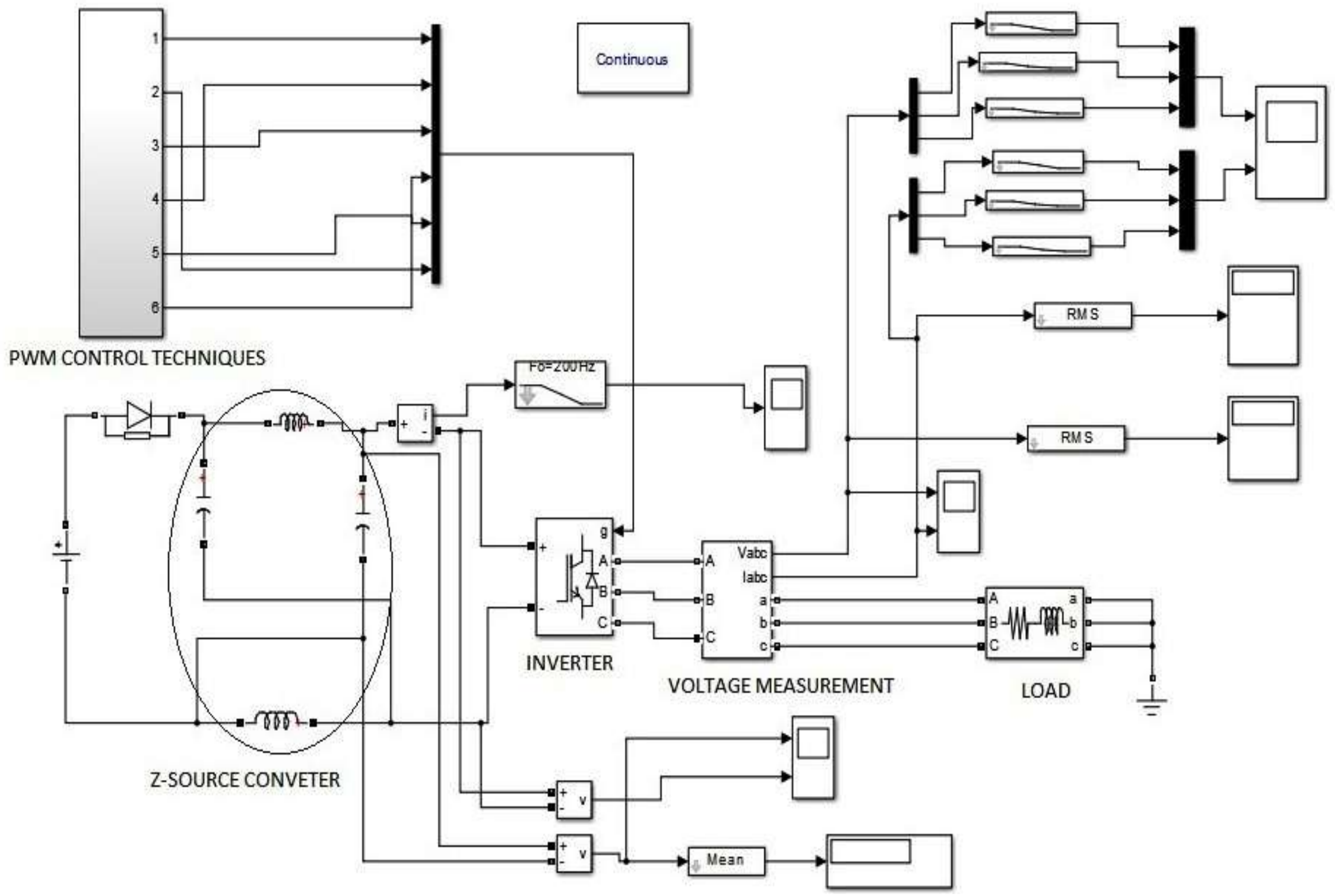
$$V_{in} = BV_g = \frac{V_g}{\sqrt{3}M - 1} = (\sqrt{3}G - 1)V_o$$

PWM control method	SBC (with triangular carrier)	SBC (with sine carrier)	MBC	MBC with third harmonic injection	CBC	CBC with third harmonic injection
Shoot through duty ratio (D_0)	1-M	$\frac{\pi - 2\sin^{-1} M}{2\pi}$	$\frac{2\pi - 3\sqrt{3}M}{2\pi}$	$\frac{2\pi - 3\sqrt{3}M}{2\pi}$	$\frac{2 - \sqrt{3}M}{2}$	$\frac{2 - \sqrt{3}M}{2}$
Gain (G)	$\frac{M}{2M-1}$	$\frac{\pi M}{\sin^{-1} M}$	$\frac{\pi M}{3\sqrt{3}M - \pi}$	$\frac{\pi M}{3\sqrt{3}M - \pi}$	$\frac{M}{\sqrt{3}M - 1}$	$\frac{M}{\sqrt{3}M - 1}$
Boost factor(B)	$\frac{1}{2M-1}$	$\frac{\pi}{\sin^{-1} M}$	$\frac{\pi}{3\sqrt{3}M - \pi}$	$\frac{\pi}{3\sqrt{3}M - \pi}$	$\frac{1}{\sqrt{3}M - 1}$	$\frac{1}{\sqrt{3}M - 1}$
Modulation index(M)	1	1	1	$2/\sqrt{3}$	1	$2/\sqrt{3}$
Voltage stress (Vs)	$(2G-1)Vin$	$\frac{\sin^{-1} G}{\pi} Vin$	$\frac{3\sqrt{3}G - \pi}{\pi} Vin$	$\frac{3\sqrt{3}G - \pi}{\pi} Vin$	$(\sqrt{3}G - 1)Vin$	$(\sqrt{3}G - 1)Vin$

Table- Comparison of various pwm control techniques

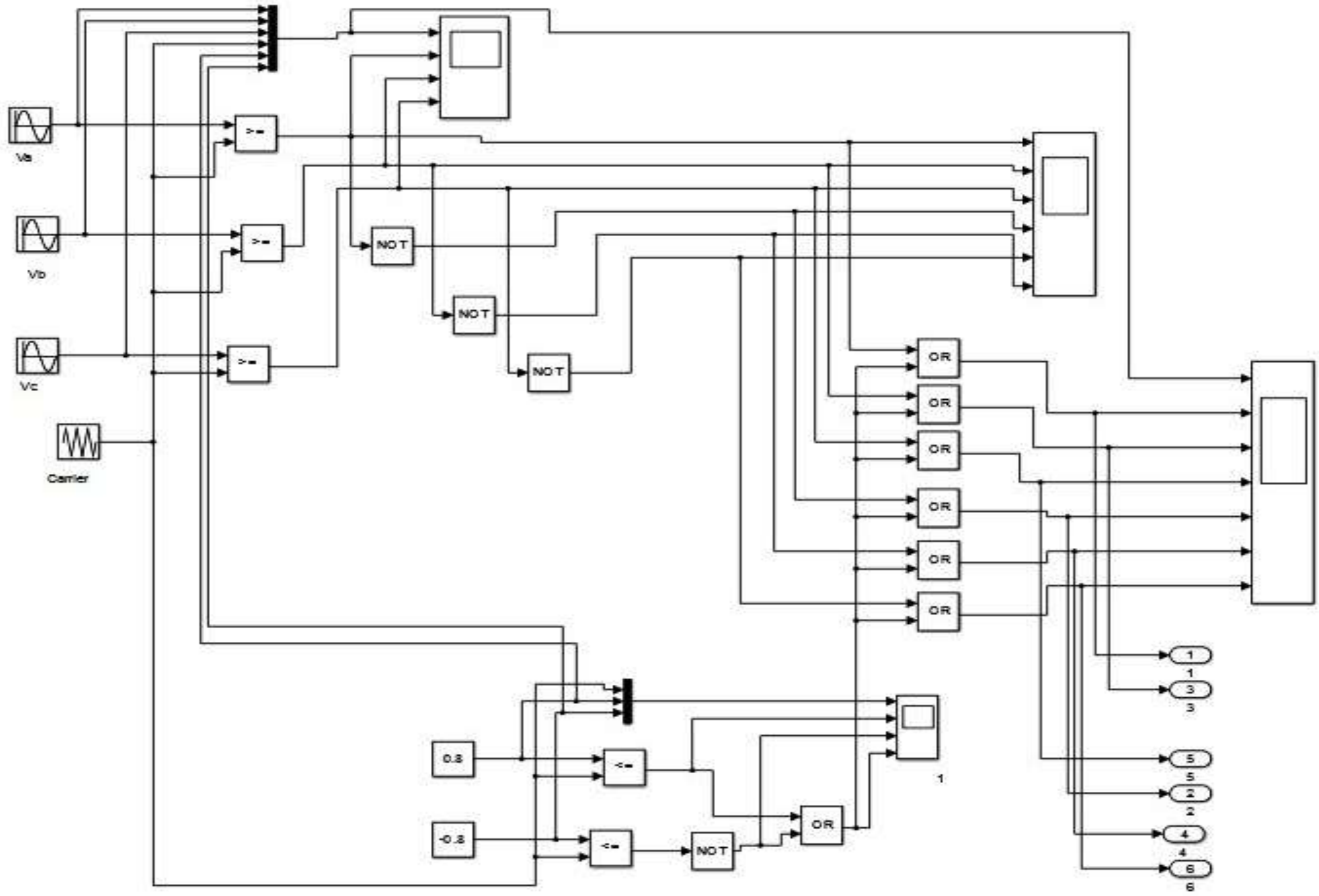
(IV)MATLAB SIMULATION MODEL

(A) Simulink model of ZSI with different pwm control techniques

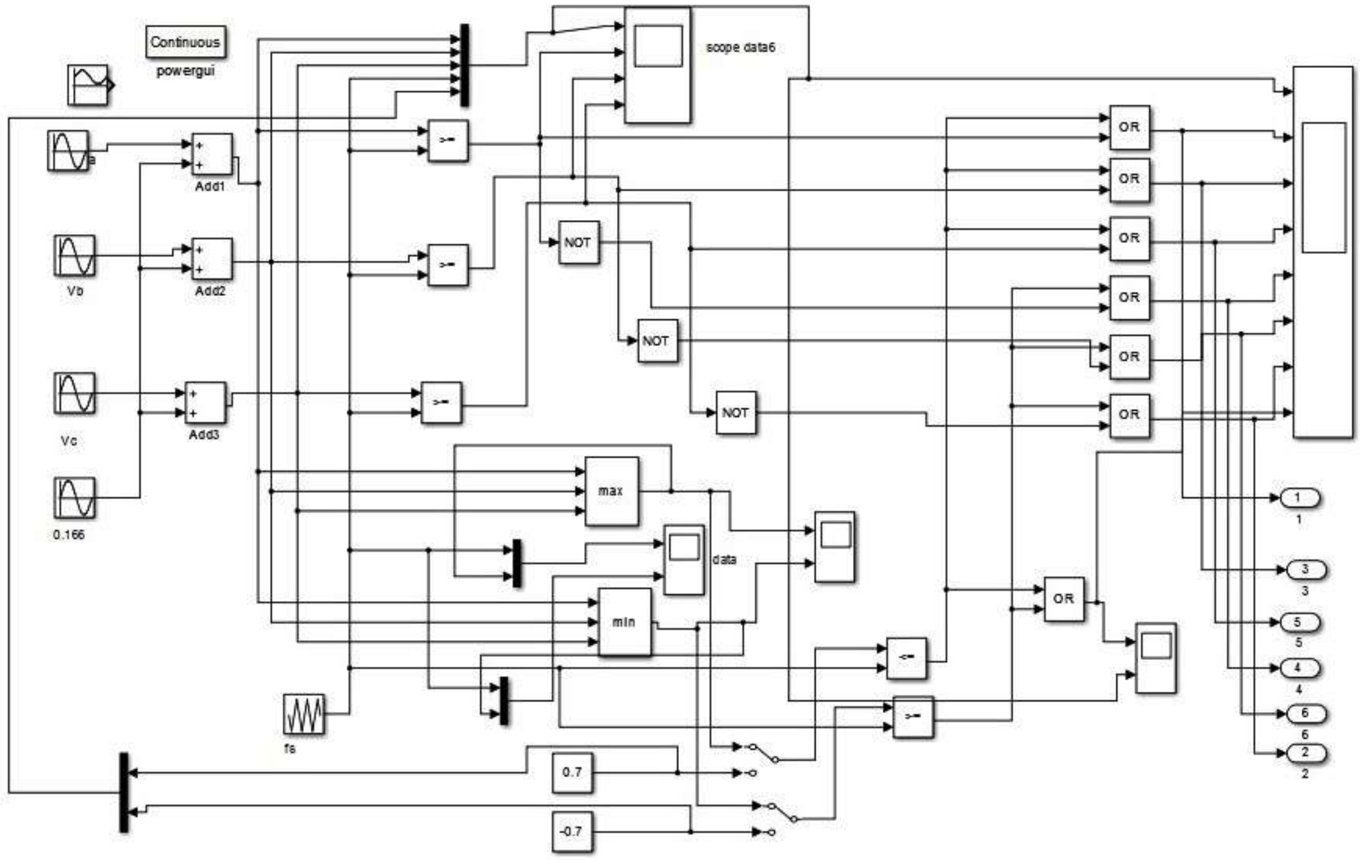


(B)Simulink model of different PWM control techniques

(i) Simple boost control



(ii)Maximum boost control



(iii)Constant boost control

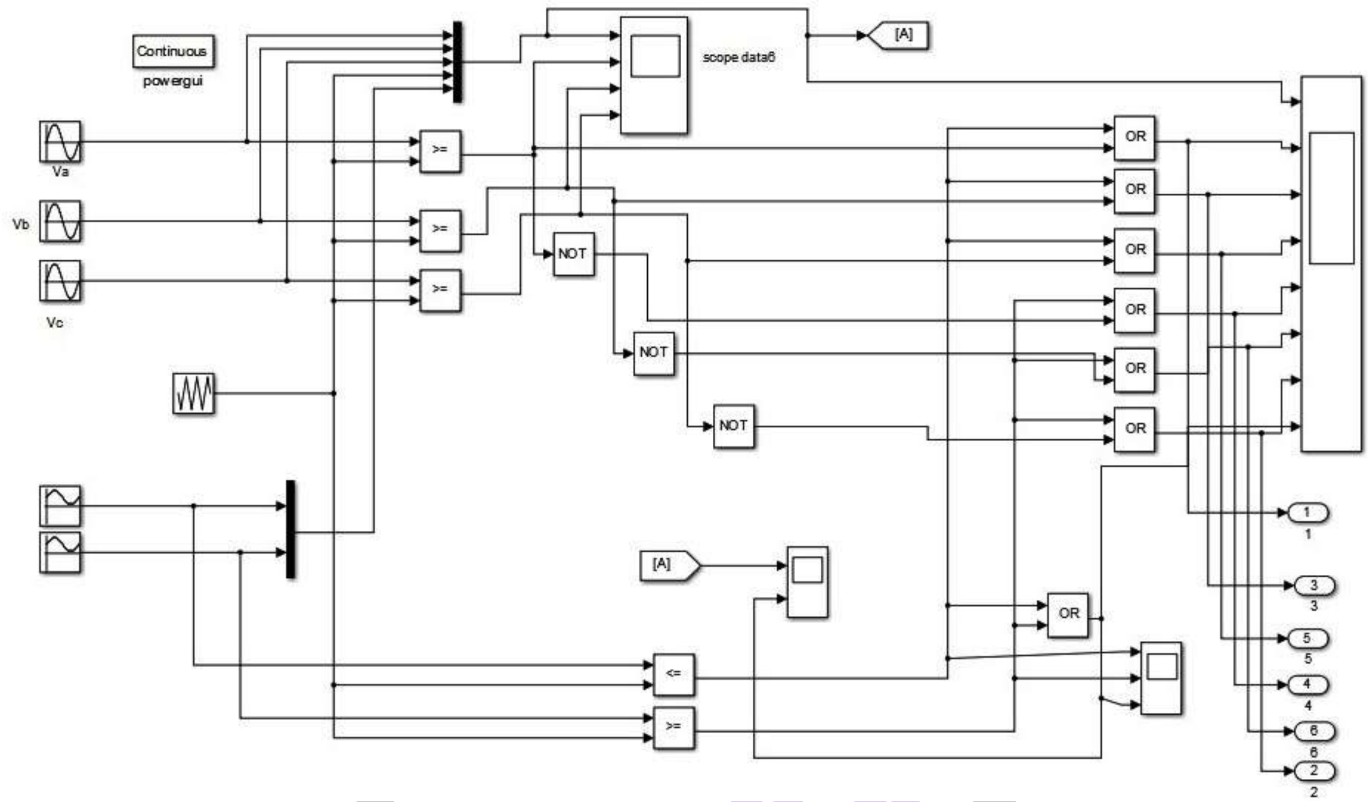
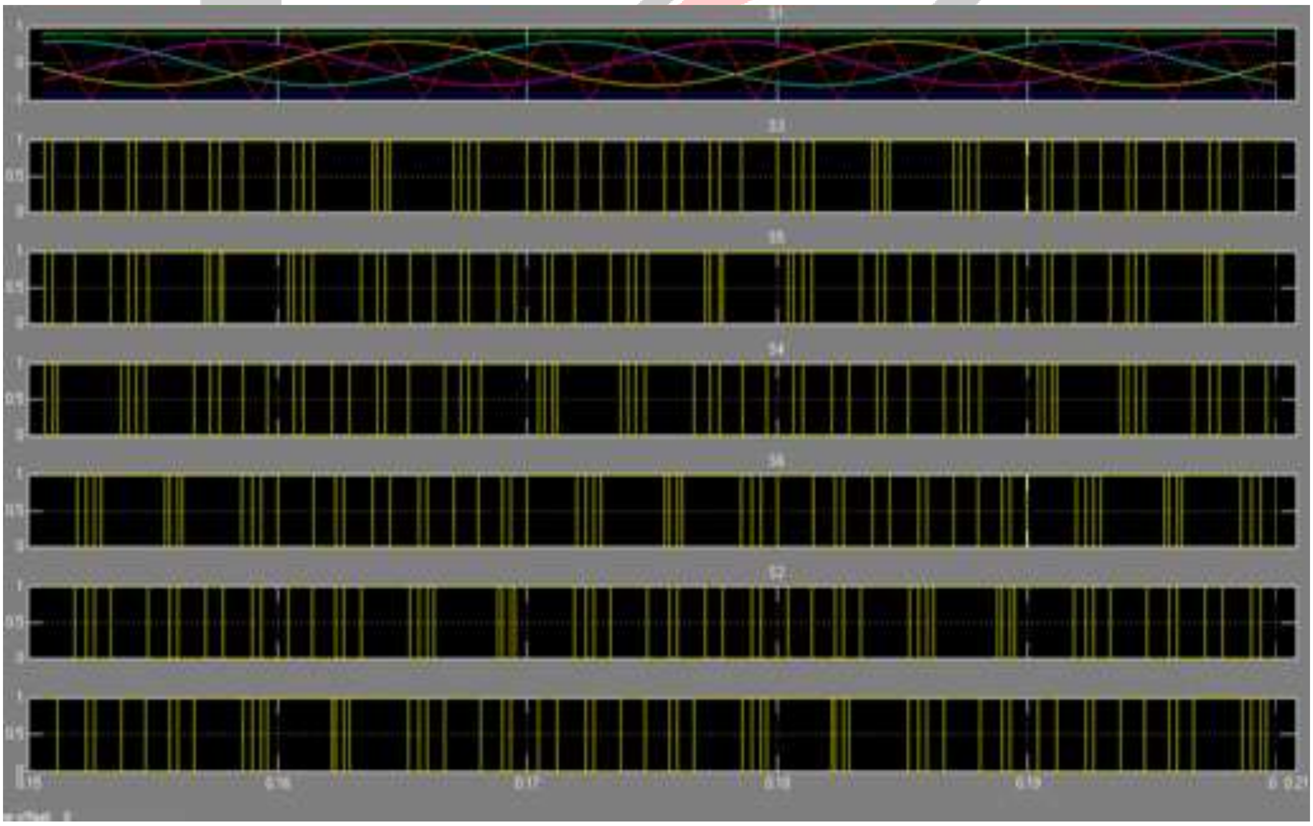


Fig 4.Simulation of different PWM control techniques

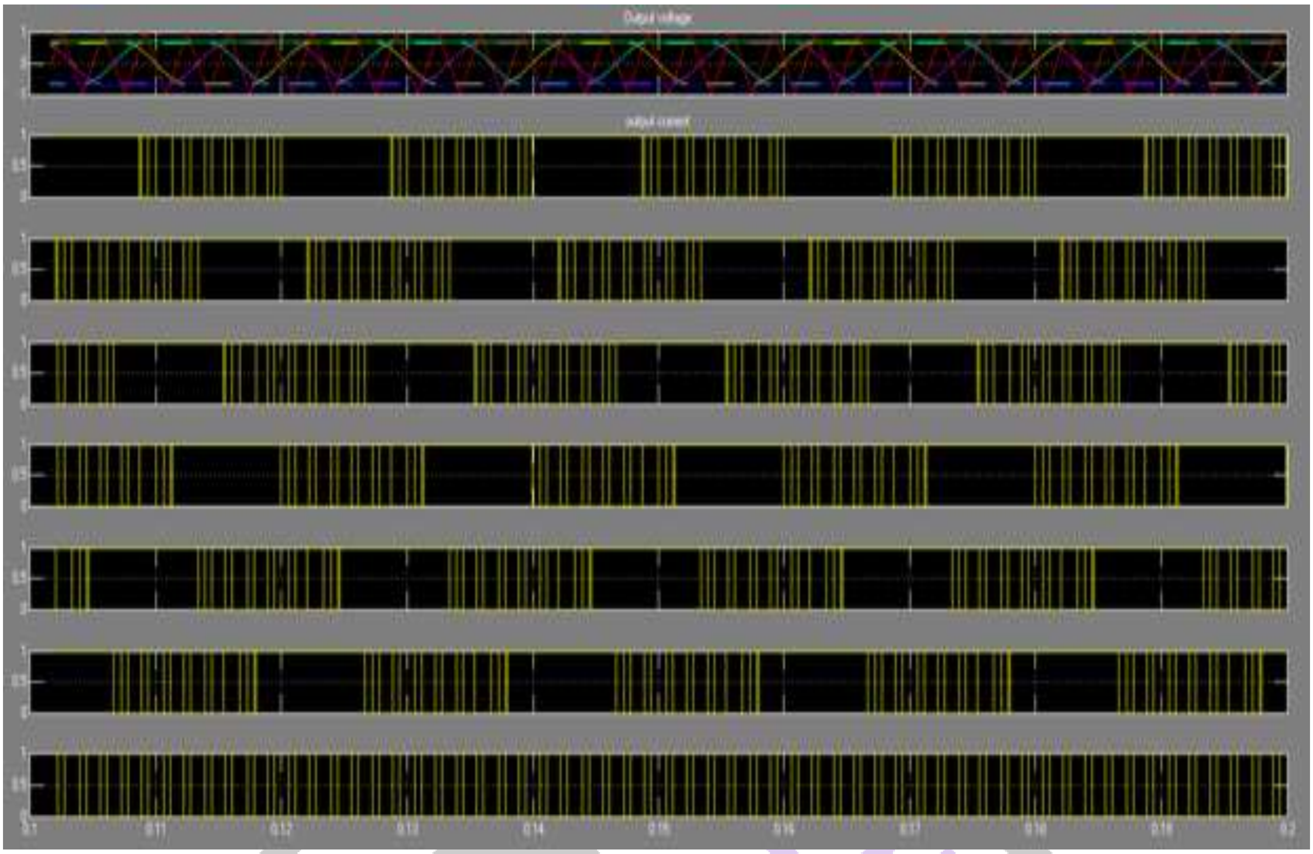
V.SIMULATION RESUTS:

(A)Output waveform of different pwm schemes

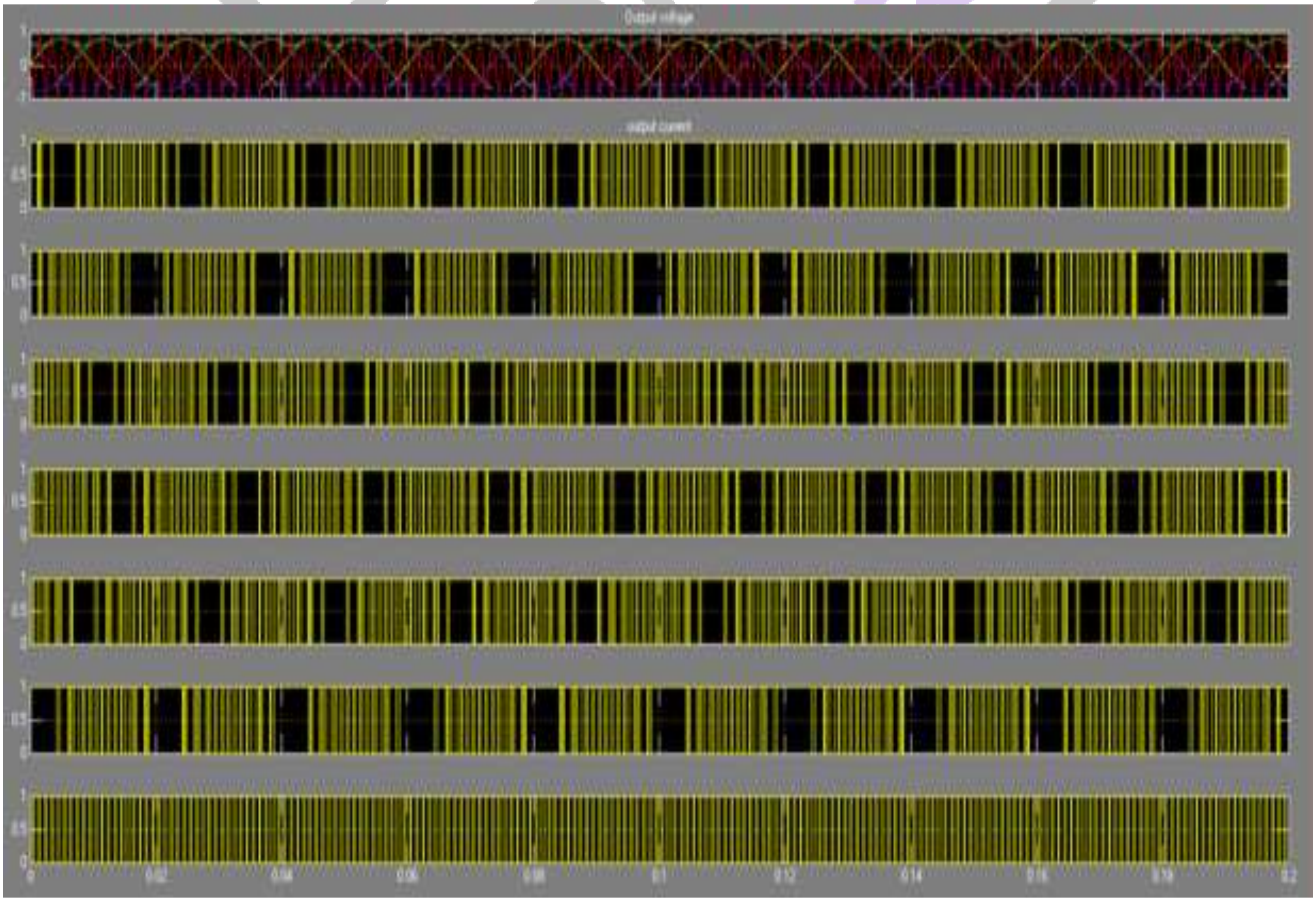
(i)Simple boost control



(ii)Maximum boost control



(iii)Constant boost control



(B) Comparison of harmonic profile

PWM CONTROL TECHNIQUE	THDv%	THDi%	MEAN VOLTAGE(V)	FUNDMENTAL FREQUENCY(V)	FUNDAMENTAL FREQUENCY(I)	MAX OUTPUT (V)	MAX OUTPUT(I)
SBC	6.73	10.35	182	103.1	10.1	107.9	10.38
MBC	5.66	5.65	126.7	50.02	2.79	48.07	2.66
CBC	2.53	1.93	435.2	103.7	10.25	269.5	26.52

Table- comparison of harmonic profile

(C) *Comparative Result and discussion:*

The comprehensive comparison of different control method of z source control method is shown below:

For comparison of THD we have taken different parameter in to the consideration and trying to reduce the harmonics in the output:

Z source inductor $L_1=L_2=L=160\mu H$

Z source capacitor $C_1=C_2=C=100\mu F$

Load resistance $R_L=5\Omega$

Load inductance $L_L=2$ mH

Source voltage, V=100

The graph of different method are shown below

1. Simulation result of Simple Boost Control:

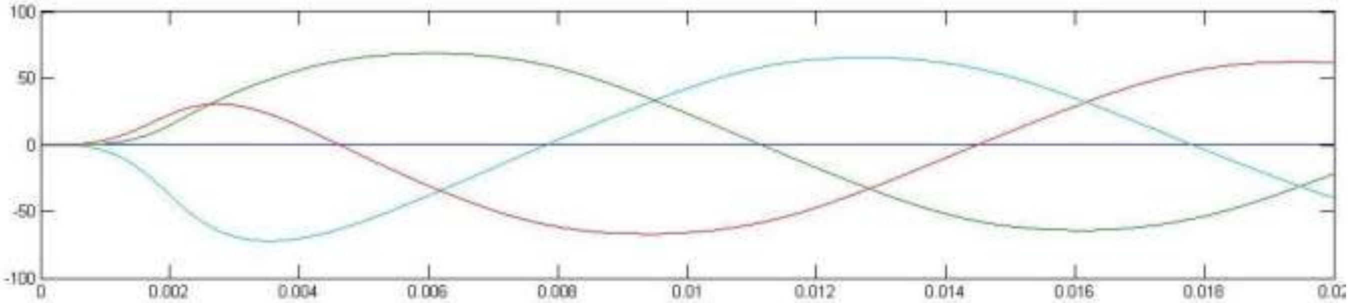


Fig. Output voltage of SBC.

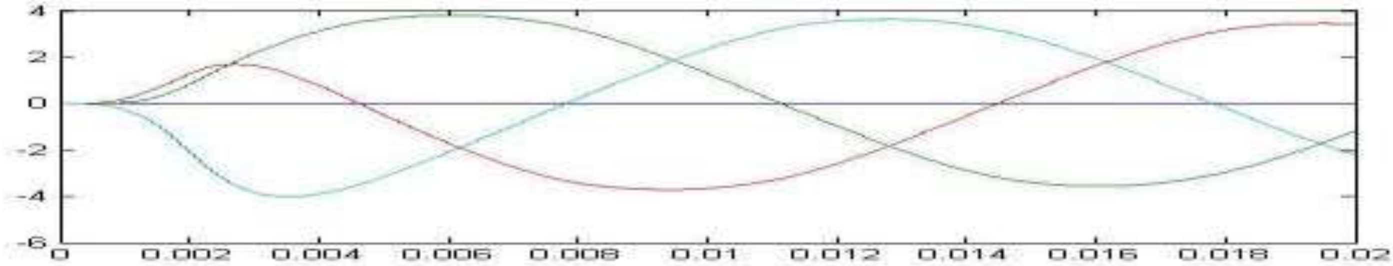


Fig. Output current of SBC

2 Simulation result of Maximum Boost Control:.

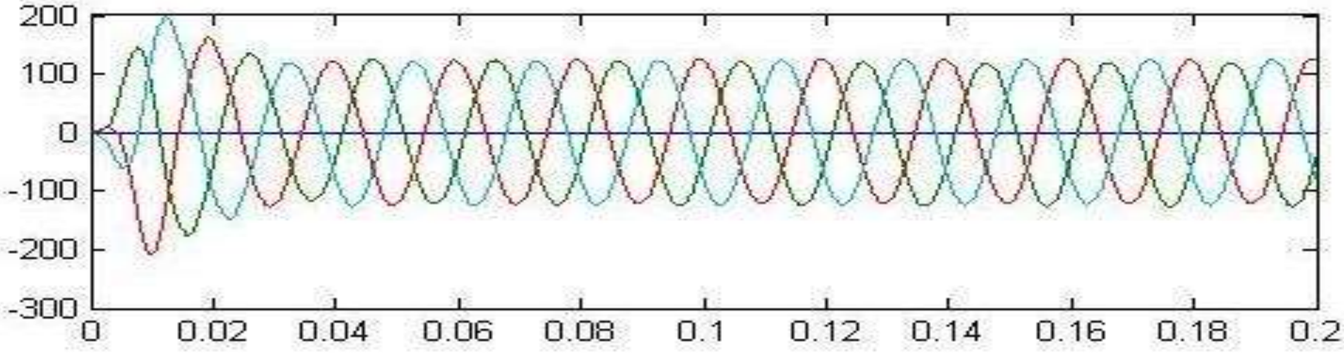


Fig. Output voltage of MBC.

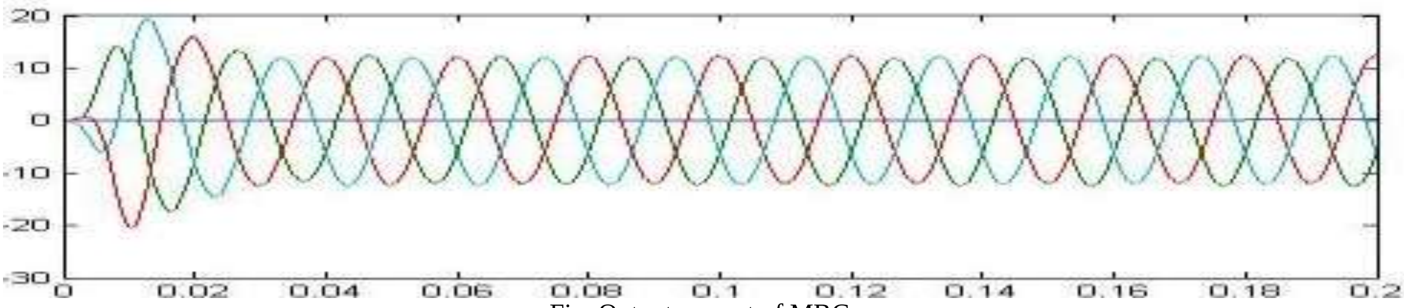


Fig. Output current of MBC

3. Simulation result of Constant Boost Control:

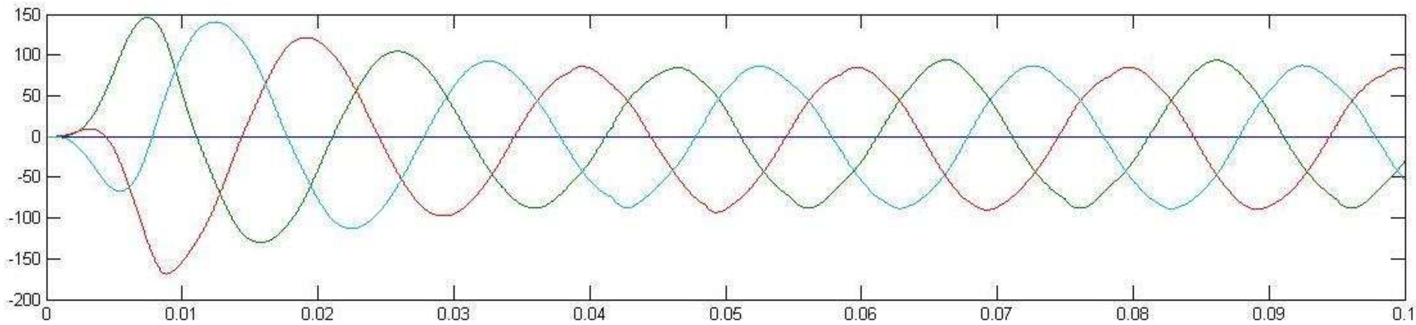


Fig. Output voltage of CBC

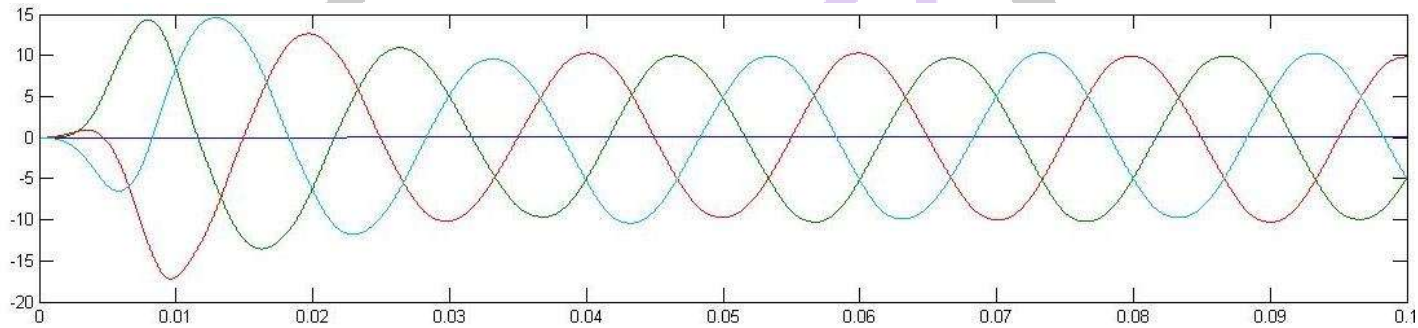


Fig. Output current of CBC

CONCLUSIONS

In this work we have Simulate all open loop modified sinusoidal PWM control methods of Z-source inverter is carried out with same input voltage and load conditions. The boost factor, voltage gain, duty ratio, and voltage stress across the switches for all the methods are analyzed. It shows that constant boost control can give more boosted output voltage. Also better performance can be obtained if modulation index (M) and shoot-through duty ratio (D_0) are fixed to a high value. Various control methods are useful in promoting the applications of ZSIs. In constant boost control we get less THD across voltage and current compare to various pwm control technique.

Nomenclature

Z	Impedance
*D*0	Shoot-through duty ratio
*T*0	Shoot-through period in one switching cycle
SBC	Simple boost control
MBC	Maximum boost control
CBC	Constant boost control
PWM	Pulse width modulation
THD	Total harmonic distortion
G	Voltage gain of the inverter
Ma	Modulation index

C1 & C2	Z-source diagonal capacitors (split capacitors)
L1 & L2	Z-source inductors (split inductors)
Fs	Switching frequency

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