

Simulation & Analysis of Z Source Inverter Using Different Modulation Control Techniques

Sandeep Kumar, Er. Vinay Kumar Tripathi²PG Student [PE], Dept. of EE, SHIATS, Allahabad, UP, India¹Assistant Professor, Dept. of EE, SHIATS, Allahabad, UP, India²

ABSTRACT: The Z-source converter (ZSC) is an alternative power conversion topology that can both buck and boost the input voltage using passive components. It uses a unique LC impedance network for coupling the converter main circuit to the power source, which provides a way of boosting the input voltage, a condition that cannot be obtained in the traditional inverters. It also allows the use of the shoot-through switching state, which eliminates the need for dead times that are used in the traditional inverters to avoid the risk of damaging the inverter circuit. The selection of high modulation index and shoot-through duty ratio can reduce the inverter's dc link voltage overshoot and increasing power delivery capacity of the inverter. Also by controlling the shoot-through duty cycle of IGBTs in inverter system, the line harmonics reduces, improves power factor, and extends output voltage range. This paper presents the analysis Maximum Boost and the Maximum Constant Boost control techniques in Z-source inverters. The voltage gain versus modulation index from simulation result is compared. Further detailed analysis of total harmonic distortion of output voltage at different modulation indexes for different boosting techniques of a Z-source inverter are performed by MATLAB based simulation.

KEYWORDS: Z-source converter, Maximum Constant Boost control techniques, Total Harmonic Distortion.

I. INTRODUCTION

To overcome the limitations and problems of the traditional or conventional source converters, an impedance-source (or impedance-fed) power converter (that can be abbreviated as ZSC) is introduced. Figure-1 depicts the general structure of ZSC. It employs a special impedance network (or circuit) that connect the voltage source converter and current converter main circuit to the power source, load, or another converter, for providing special features that cannot be seen in the conventional voltage source and current source converters where a capacitor and inductor are used, respectively [7]. ZSC structure using the series combination of switching devices like IGBT and diode is depicted in Figure-1, The Z source concept is applicable on all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. The configuration of a ZSI consists of the following components:

1. Two Inductors
2. Two Capacitors
3. DC source
4. Inverter or Converter
5. Load or Converter

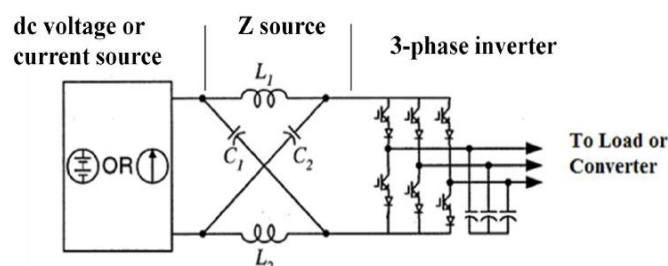


Figure-1.1: Structure of ZSI



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

Figure-1.1 depicts the general structure of the ZSI. A ZSI structure uses the series combination of IGBT and diode. It overcomes all the theoretical barriers and limitations of the traditional VSI and CSI and gives rise to a new power conversion concept. Figure-1 depicts a two-port network that consists of two split-inductors L1, L2 and capacitors C1,C2 connected in X shape to provide an impedance source (Z-source) coupling the converter (or inverter) to the dc source, load, or another converter [7]. The dc source/or load may be either a voltage or a current source/or load. Hence, the dc source can be a battery, diode rectifier, thyristor converter, fuel cell, an inductor, a capacitor, or any combination of these. Series combination of IGBTs and diode are used as switches in the converter circuit. The inductance L1 and L2 can be provided by a split inductor or two separate inductors.

II. Z SOURCE INVERTER

ZSI can be used for dc-to-ac, ac-to-dc, dc-to-dc or ac-to-ac power conversion. It employs a special impedance network to combine the converter main circuit to the dc power supply. ZSI structure is already shown in Figure-1. The two port network consists of split-inductors L1 and L2 and capacitors C1 and C2 connected in X-shape [10]. Unlike traditional inverters [2] it provides special buck-boost feature to inverter by utilizing the shoot-through zero states by gating on both upper and lower switches of a phase leg. Therefore the ZSI can boost voltage and produce a required output voltage that is greater than the available dc bus voltage. In addition to this, the reliability of the inverter is greatly improved because the shoot through due to miss gating can now no longer destroy the circuit. Thus it gives a low-cost, reliable, and high efficiency single stage structure for buck and boost power conversion.

III. OPERATING PRINCIPLE OF ZSI

The special feature of the ZSI is that its output ac voltage can be any value between zero and infinity. That is, the ZSI is a buck-boost inverter that has a wide obtainable voltage area. The traditional VSIs and CSIs do not provide such characteristics. Unlike the traditional or conventional three-phase VSI that has eight switching states the ZSI bridge has nine permissible switching states (vectors).

- The six active vectors when the dc voltage is connected across the load.
- Two zero vectors when the load terminals are shorted through either the upper or lower three devices, respectively.
- One more zero state (or vector) when the load terminals are shorted through both the upper and lower devices of any one of the phase leg (i.e., both devices are gated on), any two phase legs, or all three phase legs.

This shoot-through zero state (or vector) is not present in the traditional VSI, otherwise shoot-through would occur. This extra zero state (vector) is called the shoot through zero state (or vector). This shoot-through zero state can be produced in seven different ways:

- Shoot-through via any one phase leg
- Combinations of any two phase legs
- All three phase legs

The Z-source network has accomplished the shoot-through zero state. This shoot-through zero state gives the special buck-boost feature to the inverter. Figure-3.1 depicts the equivalent circuit of the ZSI when seen from the dc link [9]. The inverter bridge is similar to a short circuit when the inverter bridge is in the shoot-through zero state, as depicted in Figure-3.2, whereas the inverter bridge becomes an equivalent current source as depicted in Figure-3.3 when it is in one of the six active states. The inverter bridge can also be illustrated by a current source with zero value (i.e., an open circuit) when it is in one of the two conventional zero states.

It is supposed that $L1 = L2$, and $C1 = C2$. The output ac voltage equation of PWM based ZSI is given by:

$$V_{ac} / V_{o/2} = M \quad (1)$$

Where V_{ac} is maximum sinusoidal inverter output voltage, B is boost factor, M is the modulation index and V_o is input dc voltage. The product $(B.M)$ is called inverter gain and is expressed by G . So, equation (1) can be written as

$$V_{ac} = G V_o / 2 \quad (2)$$

Boost factor is decided from the given relation

$$B = 1 / 1 - 2 T_0 / T \quad (3)$$

Where T_0 is the shoot-through time interval over a switching cycle T . Therefore, in the 3-phase ZSI there are nine permissible switching states – six active states or vectors, two zero states and one extra zero state (when the both devices of any one of the phase leg are gated on) called shoot through state.

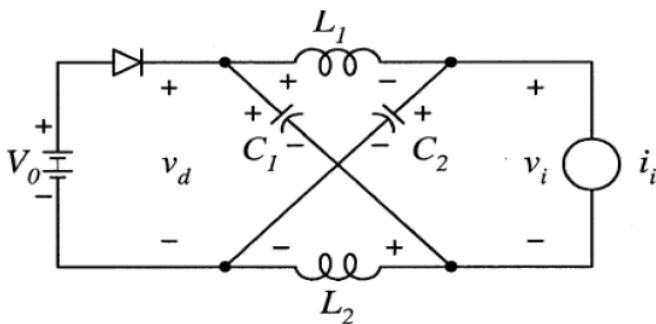


Figure- 3.1: Equivalent Circuit of ZSI when viewed from dc link

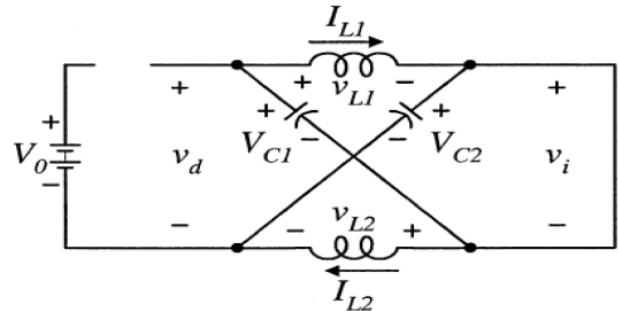


Figure-3.2: Equivalent Circuit of ZSI in Shoot-through state

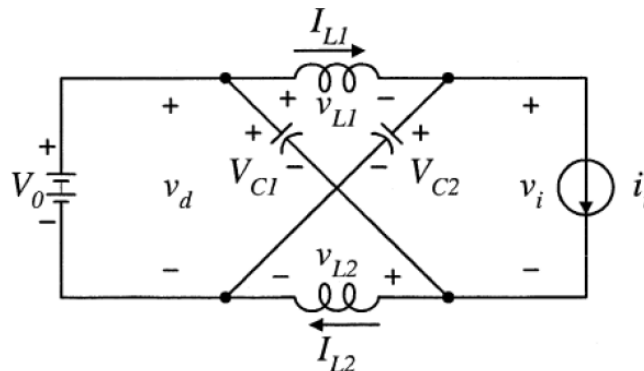


Figure- 3.3: Equivalent Circuit of ZSI in Active State

IV.CONTROL STRATEGIES OF MODULATION

There are several reformed PWM control methods for ZSI over traditional or conventional inverter:

- i) Simple boost control method
- ii) Maximum boost control method
- iii) Constant Maximum boost control method

4.1 MAXIMUM BOOST CONTROL METHOD

It is alike to the traditional or conventional carrier-based PWM control method. In this control method the six active states remain as it is and all zero states get switched into shoot through states [11]. Thus maximum T_0 and B are achieved for any given modulation index M without deforming the output waveforms. As can be viewed from Figure-4.1, the circuit is in shoot-through state when the triangular carrier wave is either more than the maximum curve of the citations (V_a, V_b, V_c) or smaller than the minimum of the citations. To determine the voltage gain it is desired to find out average shoot-through duty cycle [10]. The shoot through state iterate periodically every $\pi/3$. It is supposed that the switching frequency is much greater than the modulation frequency; the shoot-through duty ratio over one switching cycle in the interval $(\pi/6, \pi/2)$ can be illustrated as

$$\frac{T_0}{T} = \frac{2 - (M \sin\theta - \sin(\theta - \frac{2\pi}{3}))}{2} \quad (1)$$

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

The average shoot-through duty ratio can be determined by integrating Eq. (1)

$$\frac{T_o}{T} = \int_{\pi/6}^{\pi/2} 1 - \frac{2 - (M \sin\theta - \sin(\theta - \frac{2\pi}{3}))}{2} dV \quad (2)$$

$$= \frac{2 - M3\sqrt{3}}{2\pi} \quad (3)$$

From equation (13) the boost factor is given by:

$$B = \frac{T}{T_1 - T_o} = \frac{1}{1 - 2T_o} = \frac{2\pi}{2 - M3\sqrt{3}} \quad (4)$$

The voltage gain can be calculated by modulation index M

$$= \frac{M}{1 - 2D_o} = MB = \frac{\pi M}{3\sqrt{3}M - \pi} \quad (5)$$

This method has wider operating area as well as higher modulation index can be used as a result of which voltage stress or tension across the switches is reduced. The maximum value of modulation index that can be employed for a given voltage gain is given by:

$$M = \frac{\pi G}{3\sqrt{3}G - \pi} \quad (6)$$

Thus voltage stress or tension becomes

$$V_s = BV_o = \frac{\pi V_o}{3\sqrt{3}M - \pi} = \frac{3\sqrt{3}G - \pi}{\pi} V_o \quad (7)$$

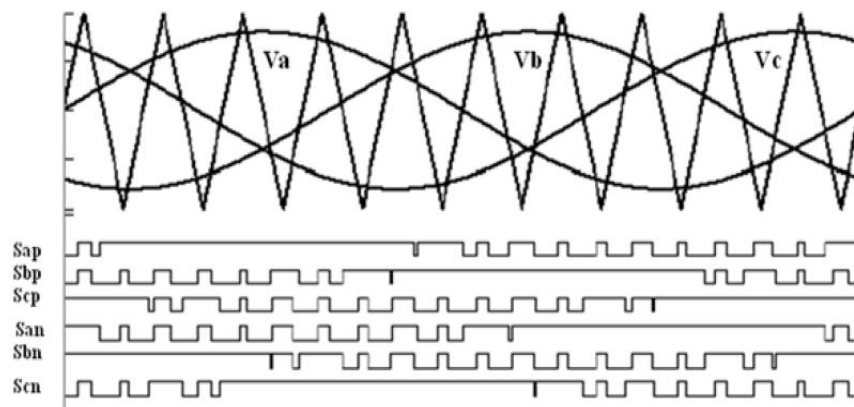


Figure-4.1: Maximum Boost Control

Maximum boost control is convenient for applications that have a fixed or correspondingly high output frequency. However for applications with variable and low output frequency, this method may need a large dc inductor. So, this method is convenient only for high frequency & large current rating.

4.2 CONSTANT MAXIMUM BOOST CONTROL

This control technique overcomes the hitches of maximum boost control. In this method low frequency current ripple are removed by using constant duty ratio. This method consists of five modulation curves -three reference signals Va, Vb, and Vc, and two shoot-through envelope signals Vp and Vn. For Vp some positive bias value is provided while for Vn negative bias value is provided. When the triangular carrier wave is more than the top most shoot-through envelope Vp or lower than the rear end shoot-through envelope Vn, the inverter is switched to a shoot through zero state as shown in Figure-4.2. The essential point is to get the maximum B while keeping it constant all the time. The top most and rear end envelope curves are periodical and are three times the output frequency. There are two half-periods for



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

both curves in a cycle. For the first half-period, $(0, \pi/3)$ in Fig. 4.2, the top most and rear end envelope curves can be illustrated as given below:

$$V_{P1} = \sqrt{3} M + \sin \left(\theta - \frac{2\pi}{3} \right) M \quad \text{for } 0 < \theta < \pi/3 \quad (8)$$

$$V_{n1} = \sin \left(\theta - \frac{2\pi}{3} \right) M \quad \text{for } 0 < \theta < \pi/3 \quad (9)$$

$$V_{P2} = \sin \theta M \quad \text{for } \pi/3 < \theta < 2\pi/3 \quad (10)$$

$$V_{n2} = \sin \theta M - \sqrt{3} M \quad \text{for } \pi/3 < \theta < 2\pi/3 \quad (11)$$

The distance between these two curves deciding the shoot-through duty ratio is always kept constant for a given modulation index M , that is, $\sqrt{3}M$. Therefore, the shoot through duty ratio is constant and can be written as

$$\frac{T_o}{T} = \frac{2 - M\sqrt{3}}{2} = \frac{1 - M\sqrt{3}}{2} \quad (12)$$

The boost factor B , and voltage gain G is expressed as:

$$G = \frac{V_o}{V_{dc}/2} = MB = \frac{M}{-1 + M\sqrt{3}} \quad (13)$$

For modulation index M , the maximum active-state duty ratio $D_{a \max}$ can be written as

$$D_{a \max} = \max \left(\frac{M \sin \omega t - M \sin \left(\omega t - \frac{2\pi}{3} \right)}{2} \right) = \sqrt{3}/2 \quad (14)$$

In order to maintain the active states unaffected while keeping the shoot-through duty ratio always constant, the maximum shoot-through duty ratio that can be obtained is

$$D_{o \max} = 1 - D_{a \max} = 1 - \sqrt{3}/2 \quad (15)$$

For a given modulation index M , the most lengthy shoot through period is

$$T_o = (1 - \sqrt{3}/2 M - (1 - M/2))T_s \quad (16)$$

Where T_s is the switching cycle

The maximal switching frequency current ripple I_r is represented by:

$$I_r = \frac{V_{cap} \cdot 1 + M(1 - \sqrt{3})}{L \cdot 2} T_s \quad (17)$$

Where V_{cap} is the voltage across capacitor of the Z-source network.

This control method generates the maximum constant boost while miniaturizing the voltage stress or tension while keeping the shoot through ratio constant so as to produce of no dc voltage & current ripples.

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

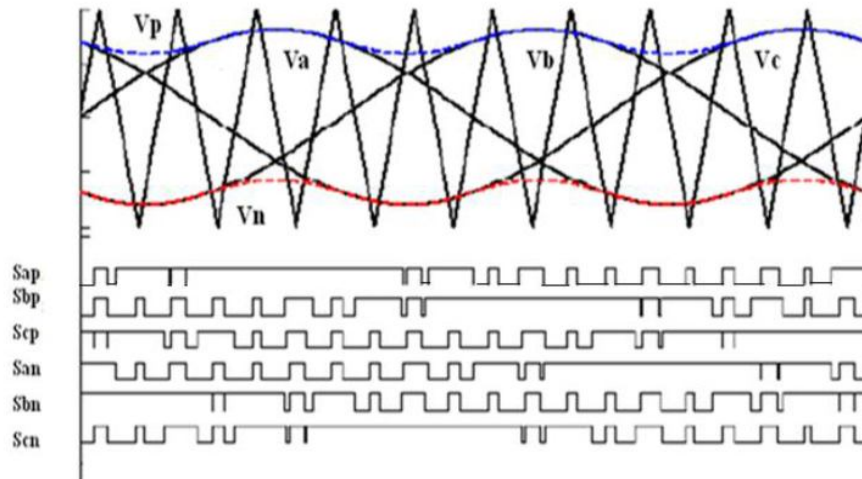


Figure-4.2: Constant Maximum Constant Boost Control

V. RESULT AND DISCUSSION

MATLAB simulations were performed to verify and compare different control methods. The SIMULINK model used is shown in Figure 5.1. The parameters used are: $L1=L2= 1 \text{ mH}$, $C1=C2=1000 \mu\text{F}$, $V=100 \text{ V}$ (DC), Load: $R/\text{phase} = 10 \text{ ohm}$, $L/\text{phase} = 5 \text{ mH}$. The purpose of the system is to compare the performance of the different control techniques under different modulation indexes ($M = 0.10$, $M = 0.15$, and $M = 0.20$ respectively) with constant DC voltage input (100 V). A comparative analysis of voltage gain at different M is performed based on the mathematical calculation and simulation result for various control techniques. Results are shown in Figures 5.2 & 5.3 respectively.

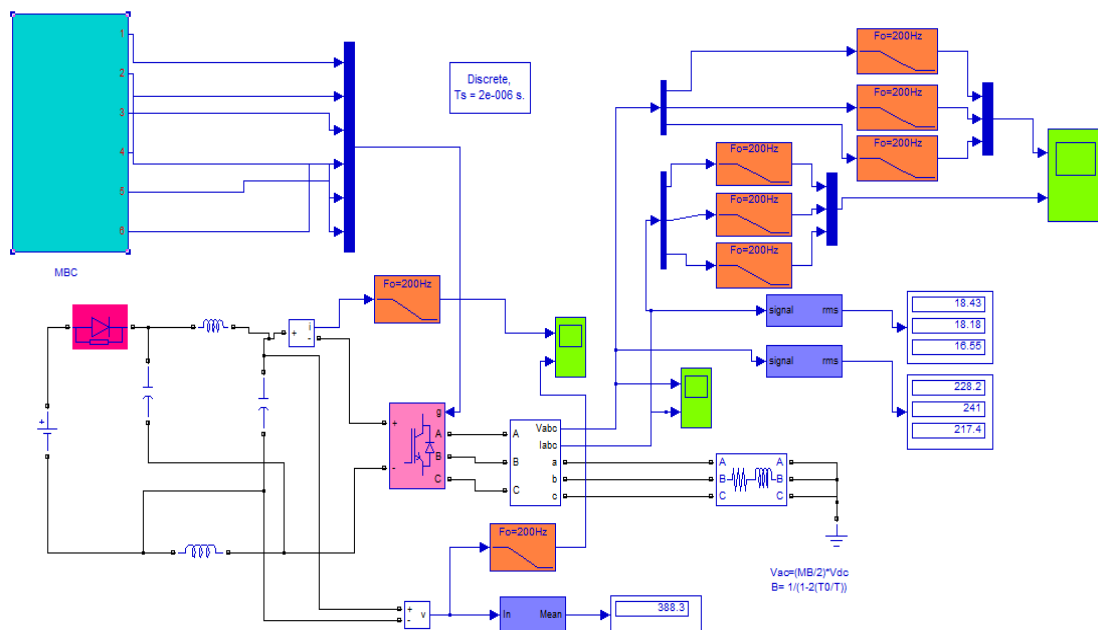


Figure 5.1: Modelling of Z Source Inverter

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

Operating Condition	Maximum Constant Boost Control Output	Maximum Boost Control Output
M = 0.10 V_{dc} = 100 V	V _a = 15.56 V, I _a = 193.0 A V _b = 15.27 V, I _b = 193.0 A V _c = 15.98 V, I _c = 193.0 A THD = 97.75 % THD = 43.20 %	V _a = 18.82 V, I _a = 233.3 A V _b = 18.40 V, I _b = 244.5 A V _c = 17.04 V, I _c = 223.8 A THD = 96.39 % THD = 43.62 %
M = 0.15 V_{dc} = 100 V	V _a = 15.29 V, I _a = 189.8 A V _b = 15.08 V, I _b = 201.4 A V _c = 13.89 V, I _c = 183.5 A THD = 97.75 % THD = 43.48 %	V _a = 18.48 V, I _a = 228.8 A V _b = 18.18 V, I _b = 241.3 A V _c = 16.63 V, I _c = 218.5 A THD = 96.69 % THD = 43.26 %
M = 0.20 V_{dc} = 100 V	V _a = 15.31 V, I _a = 190.0 A V _b = 15.07 V, I _b = 202.40 A V _c = 15.03 V, I _c = 185.2 A THD = 98.30 % THD = 43.70 %	V _a = 18.38 V, I _a = 221.3 A V _b = 18.23 V, I _b = 241.1 A V _c = 16.47 V, I _c = 216.2 A THD = 97.18 % THD = 43.53 %

Table I: Variations of fundamental output voltage, current and their THD level

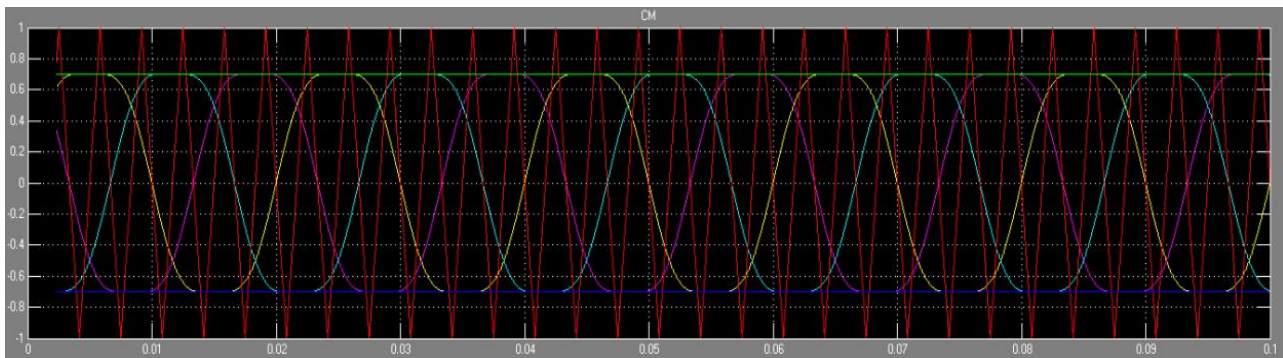


Figure 5.2: Maximum Constant Boost Control.

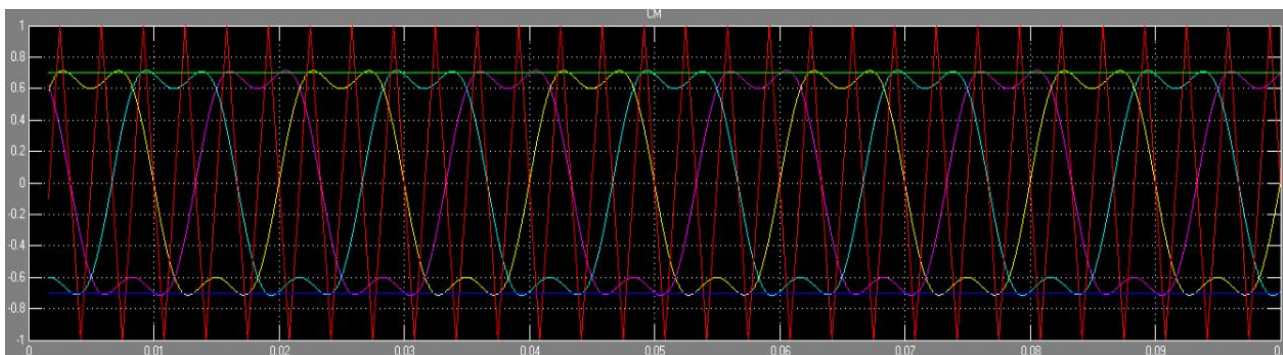


Figure 5.3: Maximum Boost Control



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

VI. CONCLUSION

The three phase Z-source inverter has been simulated with modulation strategies namely maximum boost and maximum constant boost control. A comparison has been drawn between these control strategies and the performance parameters of the inverter have been investigated. This paper compares the performance of the different control techniques under different modulation indexes with constant DC voltage input. The better performances of the control methods of ZSI to achieve the maximum output within the prescribed limit of harmonics and THD percentages are obtained. The method can be achieved by the minimum passive components requirement and maintain low voltage stress at the same time.

REFERENCES

- [1]. Amol R. Sutar, Satyawan R. Jagtap, Jakirhusen Tamboli, "Performance Analysis of Z-source Inverter Fed Induction Motor Drive in *International Journal of Scientific & Engineering Research*, Volume 3, Issue 5, May-2012 ISSN 2229-5518
- [2]. Andreas Liske, Gerhard Clos and Michael Braun; "Analysis and Modeling of the Quasi-Z-Source-Inverter"
- [3]. Cursino Brandao Jacobina, Antonio Marcus Nogueira Lima, "Current Control for Induction Motor Drives Using Random PWM" in *IEEE Transactions On Industrial Electronics*, VOL. 45, NO. 5, pp.704-712, 1998
- [4]. F. Z. Peng: "Z-source inverter", IEEE Transactions on Industry Applications, Vol. 39, No. 2, March/April 2003, pp.
- [5]. Fang Zheng Peng, Miaosen Shen, Zhaoming Qian, "Maximum Boost Control of the Z-Source Inverter" IEEE Transactions on Power Electronics, vol. 20, no. 4, July 2005.
- [6]. M. Baba, C. Lascu, I. Boldea; "Z converter control of a V/f induction motor drive" 13th International conference on Optimization of Electrical and Electronics Equipment 2012.
- [7]. Miaosen Shen , Jin Wang ,Joseph A , Peng F. Z. , Tolbert, L.M. , Adams, D.J. ; "Maximum Constant Boost Miaosen Shen, Jin Wang, Alan Joseph, Fang Zheng
- [8]. Miaosen Shen, Jin Wang, Alan Joseph, Fang Zheng Peng, Leon M. Tolbert, Donald J. Adams; "Constant Boost Control of the Z-Source Inverter to Minimize Current Ripple and Voltage Stress", IEEE transactions on Industry Applications, vol. 42, no. 3, May/June 2006.
- [9]. Omar Ellabban, Joeri Van Mierlo and Philippe Lataire, "Comparison between Different PWM Control Methods for Different ZSource Inverter Topologies" IEEE Transactions on industry application, May/June 2010
- [10]. Omar Ellabban, Joeri Van Mierlo, and Philippe Lataire; Experimental Study of the Shoot-Through Boost Control Methods for the Z-Source Inverter.
- [11]. Papavasiliou, S.A. Papathanassiou, "Current Control of a Voltage Source Inverter connected to the Grid via LCL Filter" in *IEEE Trans. On Industry Applications*, Vol. 37, No. 2, pp. 229-235, 2010
- [12]. Poh Chiang Loh, Mahinda Vilathgamuwa, "Pulse-Width Modulation of Z-Source Inverters" in *IEEE Transactions On Power Electronics*, VOL. 20, NO.6, pp.1346-1355, 2005
- [13]. S. Rajakaruna, Member, IEEE and Y. R. L. Jayawickrama, "Designing Impedance Network of Z-Source Inverters" IEEE Transactions on industry application.
- [14]. Sivaraman.P, A. Nirmalkumar, " Modelling and Simulation of Photovoltaic Array fed T-Source Inverter" in *International Conference on Sustainable Energy and Intelligent System*, 2011
- [15]. Yuan Li, Joel Anderson, Fang Z. Peng, and Dichen Liu; "Quasi-Z-Source Inverter for Photovoltaic Power Generation Systems" Twenty – Sixth Annual IEEE on Applied Power Electronics Conference and Exposition 2011.

BIOGRAPHY



Sandeep Kumar Belongs to Allahabad Uttar Pradesh Received his Bachelor of Technology degree from Allahabad Agriculture Deemed University, Allahabad in 2013. He is pursuing his M.Tech in Electrical Engg. (Power Electronics) from SHIATS, Allahabad, UP-India. His field of interest includes power electronics, power converters and power quality.



Er. Vinay kumar tripathi belongs to district Allahabad of uttar pradesh. He received his bachelor of technology degree from UCER, allahabad in 2003. He obtained his M. Tech. in electrical eng. (control & instrumentation) from MNNIT, allahabad, Uttar pradesh in 2006 and pusuing Phd. from sam higinbottom institute of agriculture technology and sciences university (SHIATS), allahabad, up, india. He is having 10 years' experience in teaching and presently working as asst. prof. in electrical engineering department, SSET, SHIATS, allahabad. His field of interest includes control and instrumentation, multiphase system, power quality and electric drive.