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Implementation and Performance Analysis of Z Source Inverter with Space Vector PWM Technique with Low THD Factor and High Gain

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Abstract: In this paper we implement the methodology of three phase Z- source inverter with space vector PWM technique. This inverter has a unique impedance network coupled between the power source and converter circuit to provide the buck boost voltage at the output. This Z network has the ability to boost the input voltage and convert it into alternating current. However, conventional inverters needs the special boost circuit with input to boost up the voltage. That's why Z source inverter is more efficient than normal inverters because of its single stage boosting and converting. The topology of Z-source inverter can easily be merge with the Renewable resources like Photovoltaic Cells, Fuel cell, wind and motor drives applications. The Advanced techniques like SPWM (Sinusoidal Pulse Width Modulation) and SVM (Space Vector Modulation) enhance its boost capacity and modulation index. To facilitate the understanding of Z source Inverter in this paper we implement this methodology on the system of the 100kW. We compare the output voltage with no load condition and also design the LC filter for the system. The MATLAB simulation and hardware implementation of ZSI with SVPWM on 100kW system gives the output with low THD factor and high voltage gain.

Keywords: Z Source Inverter, Space Vector Pulse Width Modulation, Total Harmonic Distortion, Current Source Inverter, Voltage Source Inverter

1. Introduction

There are two types of power inverter named as VSI and CSI we are using traditionally. They can either buck or boost the output voltage and also have many other limitations. The output voltage range of VSI and CSI can either be greater or smaller than input voltage. They are also vulnerable to electromagnetic noise EMI when it comes to reliability. So, we introduce a network of inductors and capacitors termed as Z-source also shown in Figure 1. It can buck or boost the voltage also it has additional shoot through states and zero states [1]. Its special and unique impedance network allows it to buck or boost the voltage. The traditional inverters do not have this network or shoot through states [2]. By using ZSI the switching losses reduced and cost of the system also minimized. In VSI both switches of any phase leg cannot be gated on or short at the same time but in ZSI we can on or short both switches of any phase leg by shoot through state. The special impedance network of Z-source inverter preferably uses the shoot through state to boost the dc bus voltage by gating on both upper and lower switches of a phase leg and produce a desirable output voltage that is greater than the available dc bus voltage. Power density of the system can be enhanced by reducing the size of impedance network of Z source inverter [3]. Capacitors size of the network reduced by using improved Z source inverter topology. There are number of applications in which Z source inverter can be used such as adjustable speed drives offshore wind energy and uninterruptable power supply [4].

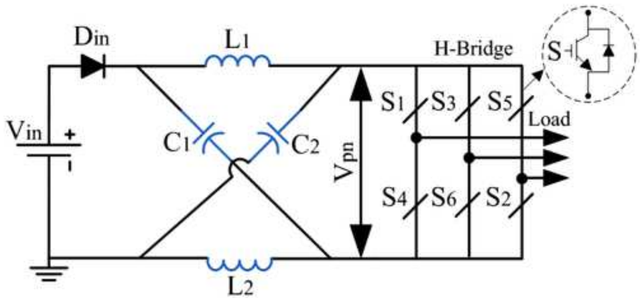

Figure 1. *Topology of Z-source inverter.*

2. PWM Control Methods for Inverter

To boost the output voltage a shoot through state has been added which has no effect on active states. By doing little changes in pulse width modulation of traditional three phase inverters it produces different PWM techniques control for Z-source inverter. So, the methods we are using before for PWM techniques are simple boost control method and maximum boost control method and maximum constant boost control method. In simple boost control, pulses are produced by relating the three sinusoidal reference signals and two constant voltage envelopes with the carrier triangular wave. In simple boost the voltage stress is very high and when we operate z source inverter and shoot through state occur all switches gets on and the losses of switching becomes higher.

In maximum boost control the Shoot through duty cycle changes each cycle. All the zero states of the Z source inverter are change to shoot through state and we are getting improved voltage gain. In order to produce switching signals, three sinusoidal reference waveforms having with great with modulation index (M) are contrasted and a similar high recurrence triangular wave. In this method active states remain same and zero states change to shoot through state [5]. The main advantage of maximum boost control is voltage stress is low and switching loss also reduce but drawback is that that the duty cycle ratio of shoot through vary in each cycle [6].

Now we see maximum constant boost control method in it the main benefit is that duty cycle ratio of shoot through state remains constant. If we keep shoot through duty constant size and cost reduces a lot. In order to get pulses by constant boost control method, which also gets voltage gain max while maintaining the shoot-through duty ratio constant. In maximum boost control there are three sinusoidal phase reference signals and two shoot through envelopes [7].

3. Space Vector PWM Control Strategy

Space vector control modulation used a lot in different applications of power inverters because it produces low current harmonics. It also has high index of modulation and the transient response is very fast. It's a great actually best PWM technique. Space vector control refers to unique switching sequence of the three switches which are upper of phase leg of the inverter. In order to get less harmonic distortion in the output voltage and also low THD factor and to provide more use of supply voltage compared with sine PWM technique. In this paper we apply this concept to Z- source inverter, a space vector pulse width modulation needed to introduce the shoot-through states into the zero vectors without changing the active states. In space vector control there are total eight space vectors V0 to V7 are used, where V1 to V6 are active vectors, V0 and V7 are zero vector [8].

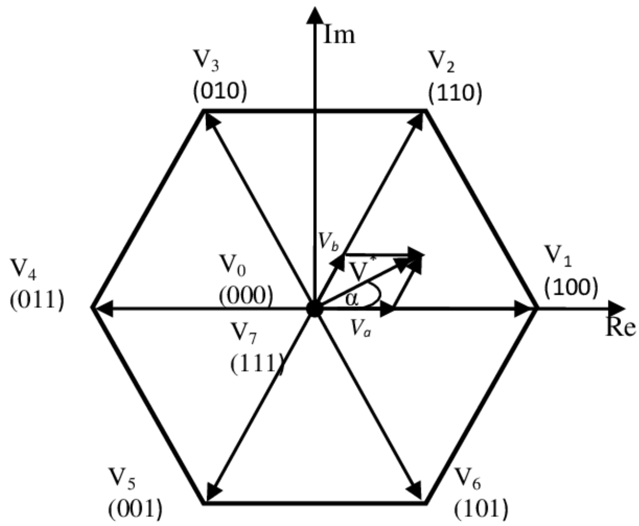

Figure 2. *Hexagon of Voltage vectors for SVPWM.*

Voltage vector V0 & V7 are present at the center of the hexagon in Figure 2 & Vector V1 to V6 are present at the corners of the Hexagon. These eight vectors are basically forming the boundary of this imaginary hexagon. By imagination the hexagon around the vectors, we can divide the hexagon in the eight sectors. These sectors are triangular in nature.

The maximum voltage is obtained when the inscribed circle touches the hexagon in the Figure 2. As the inscribed circle in the hexagon touches the boundary at the center of the sector line so the angle in 30° & magnitude of the triangle is 2/3.

So,

$$VRmax = \frac{2}{3}\, Vd\, cos\frac{\pi}{6}$$

$$VRmax = 0.577Vd \qquad (1)$$

So, the maximum voltage in space vector PWM is 0.577Vd. If we compare it with Sine PWM technique where the maximum voltage from linear modulation can be obtained is 0.5Vd, which means we are obtaining 15% more from the same DC bus voltage [9].

The modulation index is:

$$M = \frac{Vref}{\frac{2}{3} * Vd} \qquad (2)$$

Let's discuss the switching times for active states and zero states [7]. The switching time for the active states at any sector are;

$$T1 = \frac{\sqrt{3}\, Ts\, Vref}{Vdc} sin(\frac{n}{3}\boldsymbol{\pi} \text{ -}\alpha) \quad (3)$$

Now for T2

$$T2 = \frac{\sqrt{3}\, Ts\, Vref}{Vdc} sin(\alpha - \frac{n-1}{3}\boldsymbol{\pi}) \quad (4)$$

Now we discuss the switching time duration for zero states

$$\text{T0} = \text{TS- (T1+T2)} \quad (5)$$

Space Vector PWM is great method to control the output voltage of the Z-source inverter. In order to get the voltage boost at the output stage, the shoot-through states are need to introduce. Shoot through states are properly distributed to each switching period. As we know duty ratio of shoot through state control the DC link voltage [10, 11].

$$D = \frac{4.Tst}{Ts} \quad (6)$$

The voltage vectors for the space vector PWM is shown in figure below.

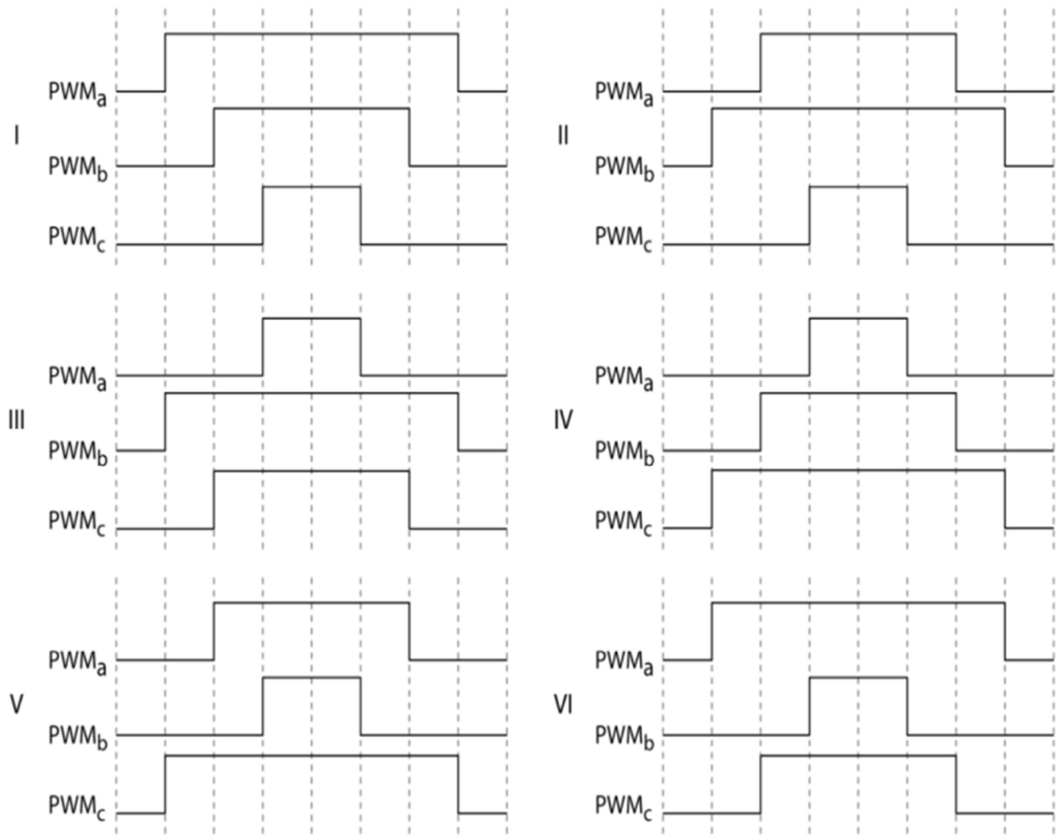

Figure 3. *The space vector PWM in sectors.*

In sine triangle PWM actually there is a problem of utilization of DC bus voltage. Utilization of DC bus voltage is a challenge here generally if you consider modulation index of the PWM and the voltage gain that is actually fundamental by VDC, up to some level it is linear. With space vector modulation we have less stress of switches and higher utilization of DC bus voltage [12].

Space Vectors Three phase voltages are;

$$V_{A0}\,(t) + V_{B0}(t) + V_{C0}(t) = 0 \quad (7)$$

Two phase voltages;

$$\begin{bmatrix} V\alpha & (t) \\ V\beta & (t) \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos 0 & \cos\frac{2\pi}{3} & \cos\frac{4\pi}{3} \\ \sin 0 & \sin\frac{2\pi}{3} & \sin\frac{4\pi}{3} \end{bmatrix} \begin{bmatrix} V_{A0} & (t) \\ V_{B0} & (t) \\ V_{C0} & (t) \end{bmatrix}$$

Space Vector Representations

$$\vec{V}(t) = V_\alpha(t) + j\, V_\beta(t) \quad (8)$$

$$\vec{V}(t) = \frac{2}{3}\, [V_{A0}(t)e^{j0} + V_{B0(t)}e^{j\frac{2\pi}{3}} + V_{C0}(t)e^{j\frac{4\pi}{3}}] \quad (9)$$

We are discussing switching states here in Table 1. V_0 is the zero-state vector. $\overrightarrow{V_1}$ to $\overrightarrow{V_6}$ are the active state vectors. Upper three switches + abc are S1, S3, S5 and that will be represented here as all the positive phase is that PPP and ultimately you will get a null vector and once all the lower switches are on that means 000 or OOO that is S4, S6, S2 you will get essentially zero voltage [13, 14].

By designing the model of space vector PWM on MATLAB the duty cycle comes as shown in the Figure 4.

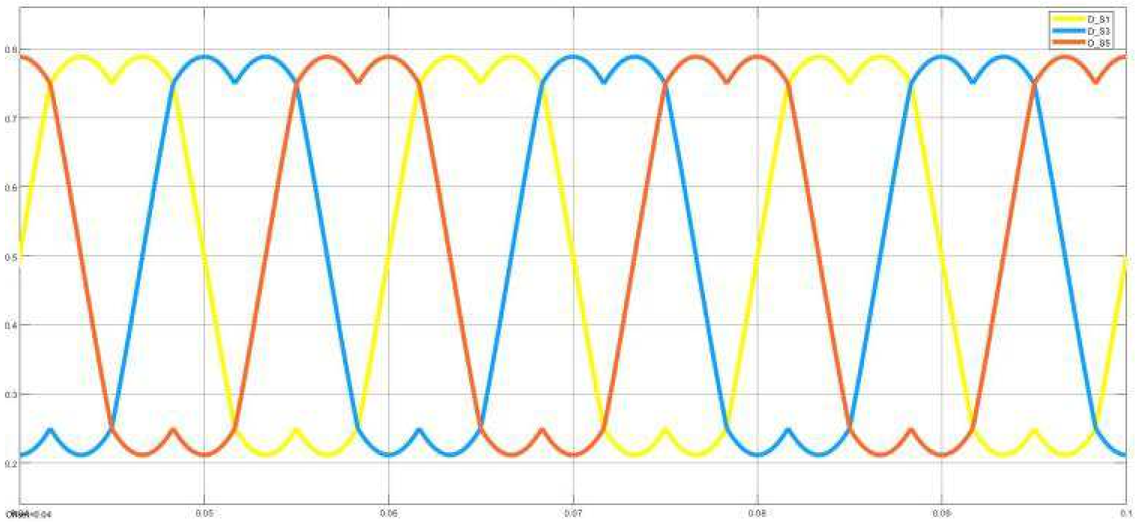

Figure 4. *Duty Cycle of SVPWM.*

Table 1. *Switching States.*

Space Vector	Switching state (Three phase)	On state switch	Vector Definition
$\vec{V_0}$	[PPP] / [OOO]	S1,S3,S5 / S4,S6,S2	$\vec{V_0}$=0
$\vec{V_1}$	[POO]	S1,S3,S2	$\vec{V_1}=\frac{2}{3}V_d e^{j0}$
$\vec{V_2}$	[PPO]	S1,S3,S2	$\vec{V_2}=\frac{2}{3}V_d e^{j\frac{\pi}{3}}$
$\vec{V_3}$	[OPO]	S4,S3,S2	$\vec{V_3}=\frac{2}{3}V_d e^{j\frac{2\pi}{3}}$
$\vec{V_4}$	[OPP]	S4,S3,S5	$\vec{V_4}= V_d e^{j\frac{3\pi}{3}}$
$\vec{V_5}$	[OOP]	S4,S6,S5	$\vec{V_5}=\frac{2}{3}V_d e^{j\frac{4\pi}{3}}$
$\vec{V_6}$	[POP]	S1,S6,S5	$\vec{V_6}=\frac{2}{3}V_d e^{j\frac{5\pi}{3}}$

4. LC Filter Designing

LC filters refer to circuits consisting of a combination of inductors (L) and capacitors (C) to cut or pass specific frequency bands of an electric signal.

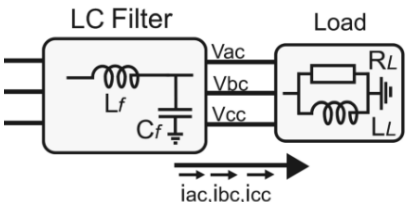

Figure 5. *Simple LC Filter with 3-phase Load.*

Capacitors block DC currents but pass AC more easily at higher frequencies. Conversely, inductors pass DC currents as they are, but pass AC less easily at higher frequencies.

In other words, capacitors and inductors are passive components with completely opposite properties. By combining these components with opposite properties, noise can be cut and specific signals can be identified.

A low pass filter is designed to reduce the harmonics or ripples generated by the voltage waveform at the output side. For the designing of low pass filter, its cut-off frequency is such that it eliminates the low order harmonics at the output voltage and under load variations the impedance should be kept zero.

As. we attach parallel RLC load of 100kw at the output. The value of inductor and capacitor for LC filter is obtained by hit and trial method, by changing the different values of inductor and capacitor to get the right rectified waveform on output. The values of L & C by using this method comes to be 1000uF for capacitor and 7.2mH for inductor. The dc L&C connector is used to reduce the ripple voltage output of the single phase bridge fixer. Its values are selected in such a way that the ripple factor is less than 10%. Consequences where no loading function is performed because the total harmonic distortion THD is high. Two volatility index values (90% and 50% of the estimate) were calculated to give all possible categories of THD variability.. The no load test of SVPWM inverter drive induction motor is obtained by applying the higher value of modulation index (90%) and the lower possible value (50%). The phase voltage and phase current SVPWM inverter are analyzed by using Fourier series.

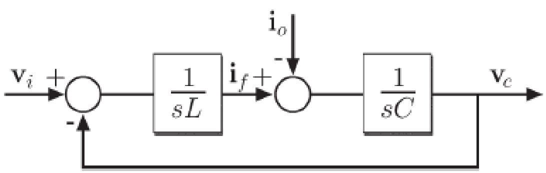

Figure 6. *LC Filter Model.*

State Space model for LC filter and RL Load

$$\frac{di_{Lf}}{dt} = \frac{V_{inv\_LL} - V_{Cf}}{L_f}$$

$$\frac{dV_C}{dt} = \frac{I_{Lf} - I_{load}}{C_f}$$

$$\frac{dI_{Load}}{dt} = \frac{V_{Cf} - R_{load} I_{Load}}{L_{load}} \quad (10)$$

A passive LC filter is suitably designed to improve the waveform quality obtained from the Z-source inverter. The LC filter is used to limit the rate of rise of the inverter output voltage and reduce common mode noise to the motor. In typical applications where dv/dt is limited to 100-500 V//spl mu/s, the resonant frequency of the filter is above the switching frequency. The purpose of the filter is to eliminate both high-frequency common-mode and normal-mode voltages from the three-phase output voltages of the inverter. In order to improve the power quality and reduce the harmonics of the output voltage, a filtering branch can be added to the existing Z-source inverter circuit in engineering practice [15].

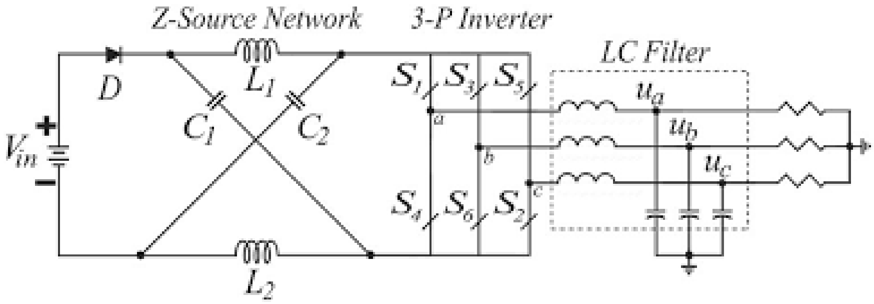

Figure 7. *Z-Source inverter with LC Filter.*

Table 2. *Parameters used for simulation.*

Parameters	Value
Input DC voltage	260
Z source Inductance (L1 & L2)	4.5mH
Z source Capacitance (C1 & C2)	5.5uC
Active Power of RLC Load	100kW
Inductive Reactive Power Q_l	100var
Capacitive Reactive Power Q_c	100var
Fundamental Frequency	50Hz

5. Simulation and Experimental Results

To demonstrate the validity of SVPWM technique simulation and experimental results are conducted on the system of 100kW. The results are compared with the No load voltage and with and without LC filter. MATLAB/Simulink is used for the simulation. The parameters used for simulation and experiment are given in the Table 2.

The output voltage of the inverter without any load and filter is shown in the figure below.

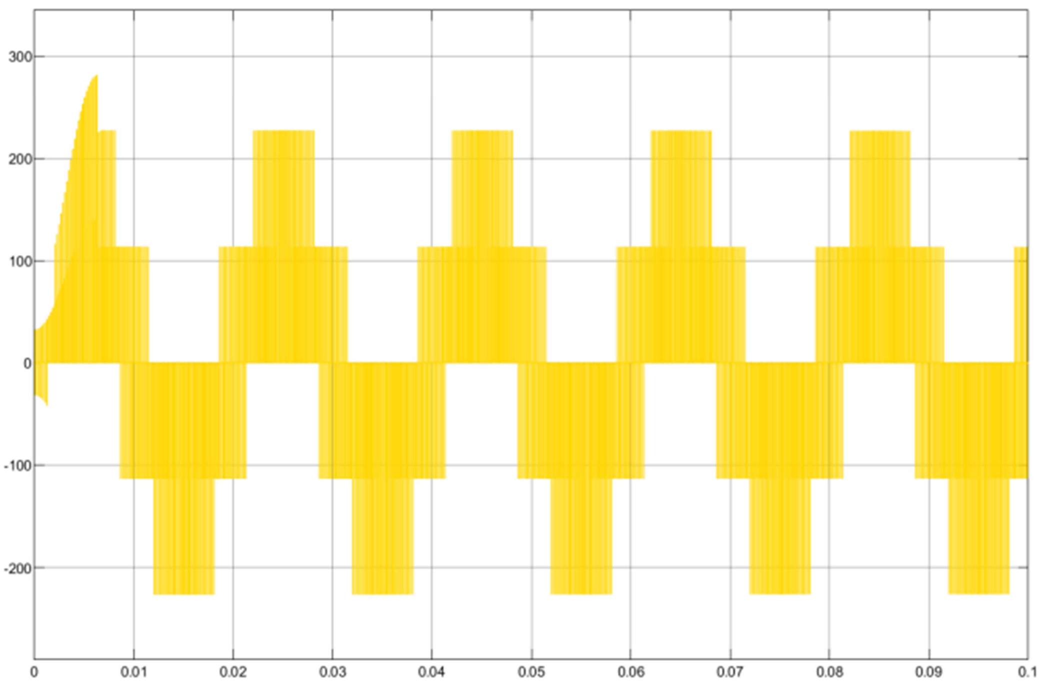

Figure 8. *Output Phase Voltage of Inverter.*

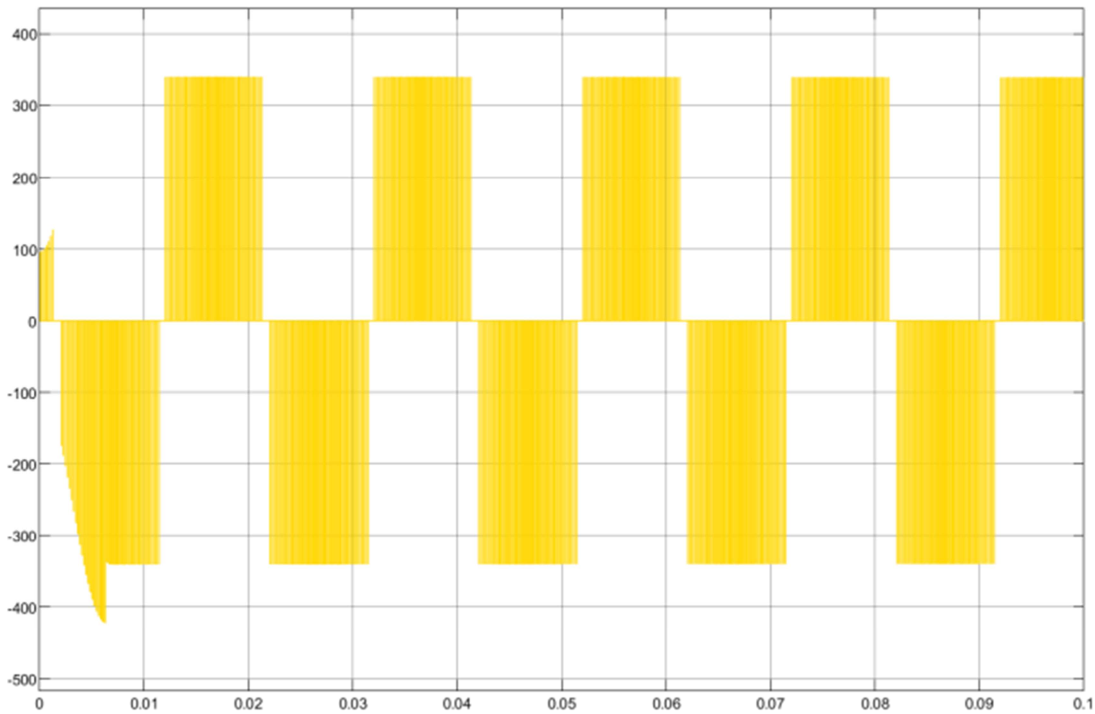

Figure 9. *Output Line Voltage of Inverter.*

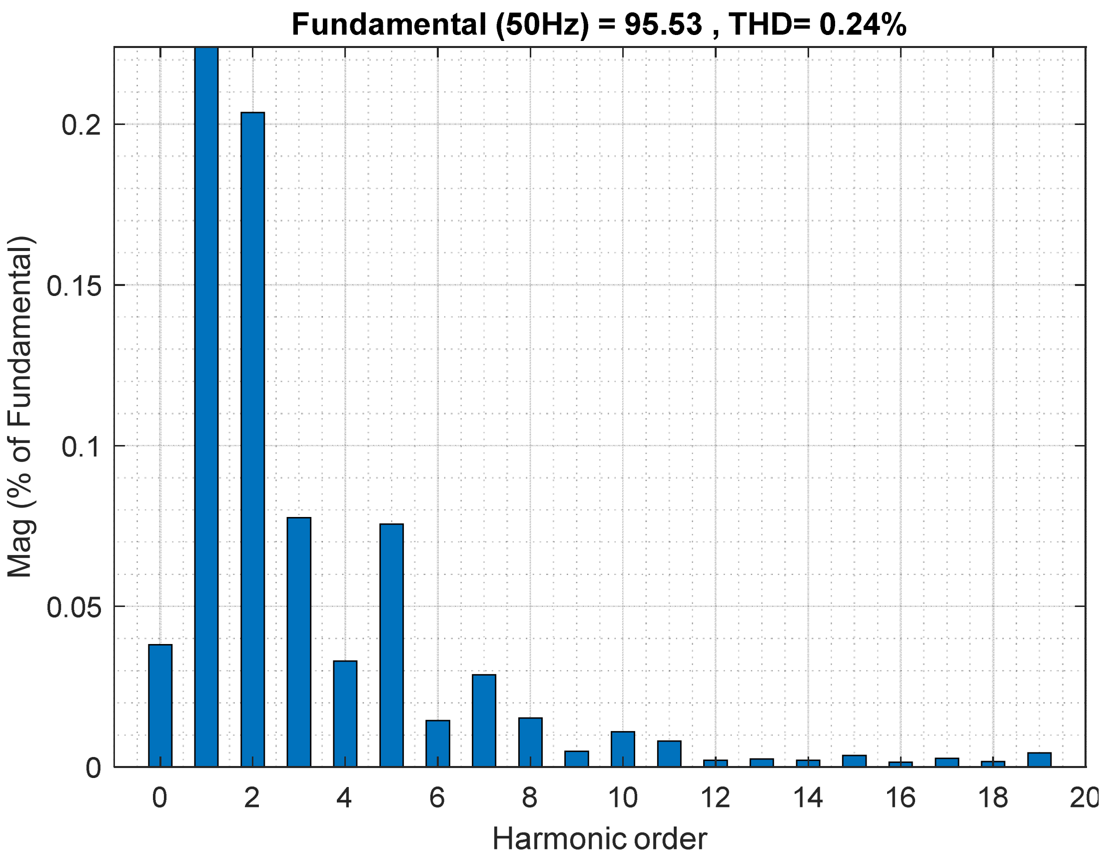

Figure 10. *THD of Inverter.*

Figure 10 showing the THD after without any load which comes to be 0.24%. By filtering the output of the inverter with the LC filter and attaching the three phases Parallel RLC load with it. The output voltage comes as shown in the Figure 11 & Total harmonic distortion comes to be 3.42% as shown in the Figure 12 below.

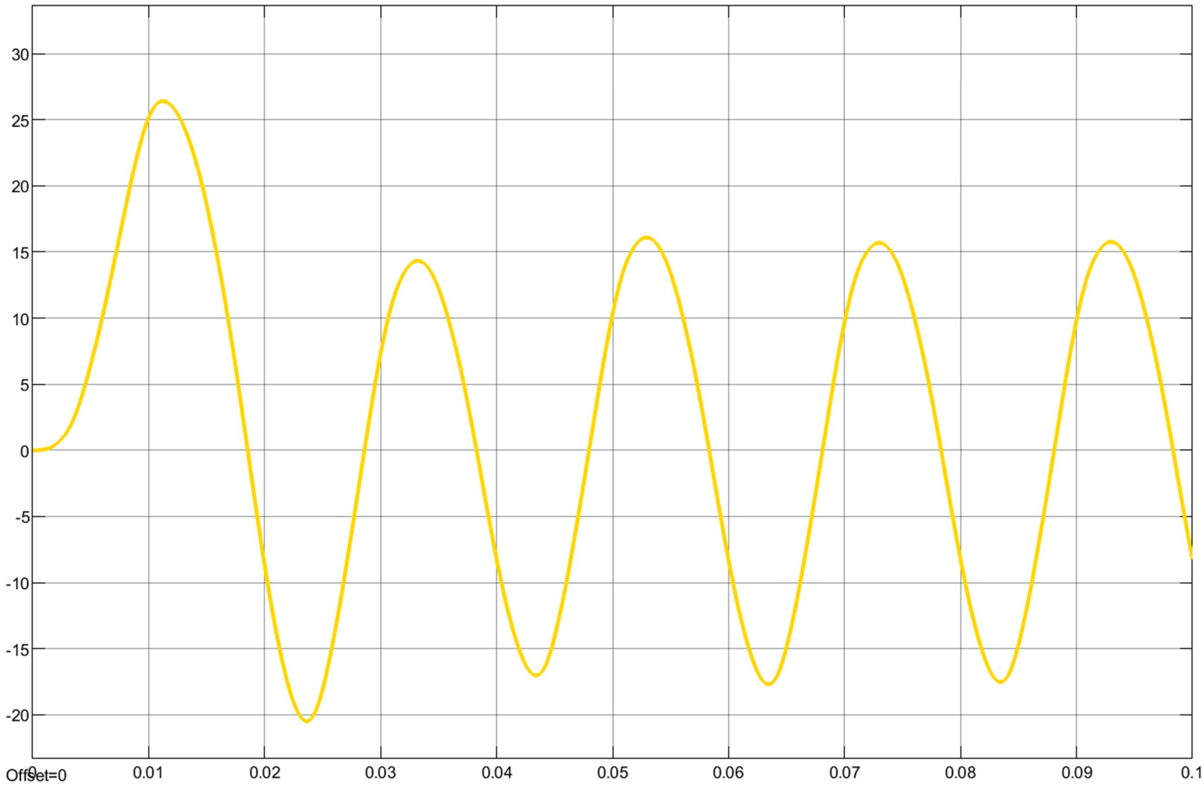

Figure 11. *Output Voltage with Load.*

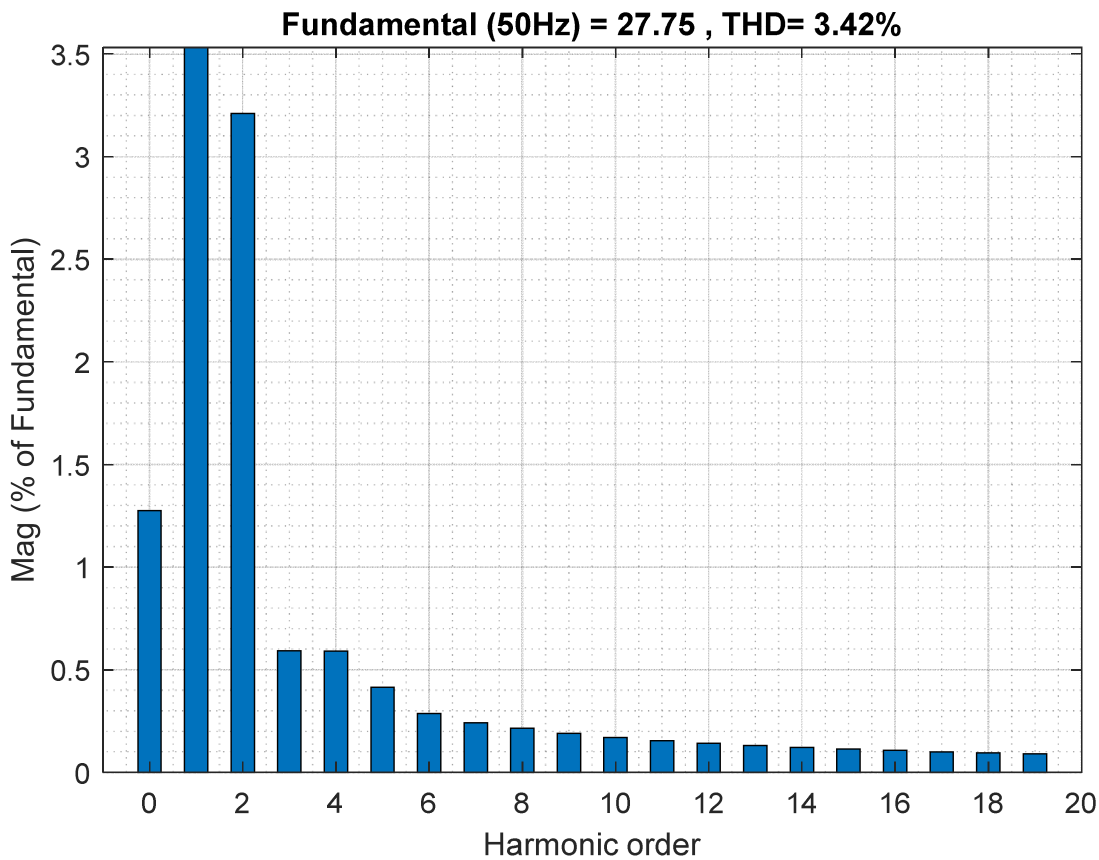

Figure 12. *THD with Load.*

The current across the inductor of the Z network is shown in Figure 10.

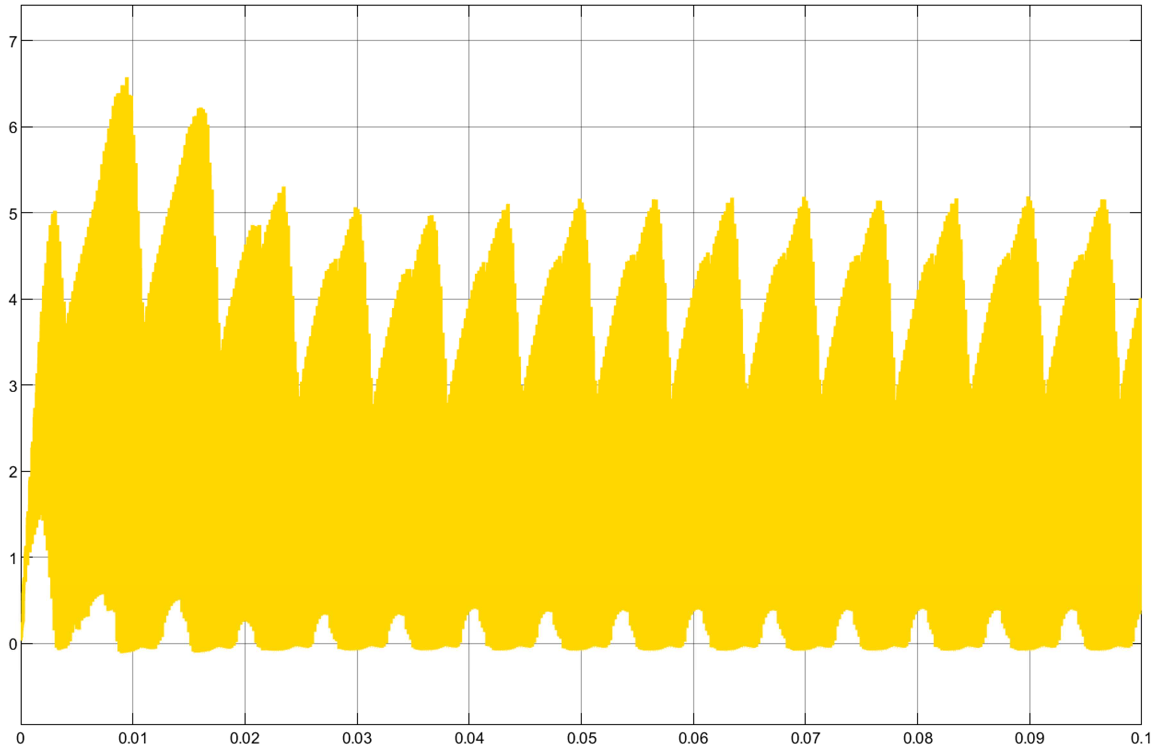

Figure 13. *Current across the inductor of Z network.*

6. Conclusion

In this paper, SVPWM techniques have been investigated. During the investigations, we realized harmonic density, power factor & switching losses in both techniques. A simple MATLAB/Simulink model is presented to implement SVPWM for three-phase ZSI. A brief review of the ZSI model is also reported based on space vector representation. A MATLAB/Simulink based model for implementation of SVPWM is presented. The step-by-step model development is reported. The presented model gives an insight into the SVPWM. By varying the magnitude of the input reference different modulation index can be achieved. To this end, we have also implemented a comprehensive simulation of these methods using the MATLAB tools. It has been observed that SVPWM has shown higher performance due to smaller THD, greater PF and less switching losses because SVPWM uses a fast switching method in advance to reduce THD. It also minimizes switching losses due to switching of any switching condition that results in a single phase power switch at all times. In addition, at higher switching frequencies SVPWM provides better results compared to SPWM. Therefore, based on all the results obtained, we concluded that the SVPWM process provides maximum overall performance and efficiency.

References

[1] F. Z. Pang, "Z-source inverter," *IEEE Transactions on Industry Applications,* vol. 39, pp. 504 - 510, 2003.

[2] A. J. J. W. F. P. D. A. M. Shen, "Comparison of Traditional Inverters and Z-Source Inverter," in *2005 IEEE 36th Power Electronics Specialists Conference*, Dresden, Germany, 2005.

[3] F. Z. Pang, "Maximum boost control of the Z-source inverter," *IEEE Transactions on Power Electronics,* vol. 20, pp. 833 - 838, 2005.

[4] T. Li and Q. Cheng, "A comparative study of Z-source inverter and enhanced topologies," in CES Transactions on Electrical Machines and Systems, vol. 2, no. 3, pp. 284-288, September 2018, doi: 10.30941/CESTEMS.2018.00035.

[5] H. Fathi and H. Madadi, "Enhanced-Boost Z-Source Inverters With Switched Z-Impedance," in IEEE Transactions on Industrial Electronics, vol. 63, no. 2, pp. 691-703, Feb. 2016, doi: 10.1109/TIE.2015.2477346.

[6] P. T. T. P. D. Gayathri, "Design and Performance Analysis of Transformerless Z Source Inverter In PV Systems," in *2021 3rd International Conference on Signal Processing and Communication (ICPSC)*, Coimbatore, India, 2021.

[7] O. Ellabban and H. Abu-Rub, "Z-Source Inverter: Topology Improvements Review," in IEEE Industrial Electronics Magazine, vol. 10, no. 1, pp. 6-24, March 2016, doi: 10.1109/MIE.2015.2475475.

[8] M. -K. Nguyen, Y. -C. Lim and S. -J. Park, "A Comparison Between Single-Phase Quasi- Z-Source and Quasi-Switched Boost Inverters," in IEEE Transactions on Industrial Electronics, vol. 62, no. 10, pp. 6336-6344, Oct. 2015, doi: 10.1109/TIE.2015.2424201.

[9] S. W. H. X. J. G. Yinhai Zhang, "A Novel SVPWM Modulation Scheme," in *2009 Twenty-Fourth Annual IEEE Applied Power Electronics Conference and Exposition*, Washington, DC, USA, 2009.

[10] R. K. T. S. P. Singh, "Performance comparison of SPWM and SVPWM technique in NPC bidirectional converter," *2013 Students Conference on Engineering and Systems (SCES),* 2013.

[11] P. A. M. Valan Rajkumar, "Simulation and an experimental investigation of SVPWM technique on a multilevel voltage source inverter for photovoltaic systems," *International Journal of Electrical Power & Energy Systems,* vol. 52, pp. 116-131, 2013.

[12] W. X. M. L. Y. S. Z. H. Jia YingYing, "Application and Simulation of SVPWM in three phase inverter," in *Proceedings of 2011 6th International Forum on Strategic Technology*, Harbin, China, 2011.

[13] D. C. Anup Kumar, "A survey on space vector pulse width modulation technique for a two-level inverter," in *2017 National Power Electronics Conference (NPEC)*, Pune, India, 2018.

[14] J. T. Y. G. J. L. Zeliang Shu, "An Efficient SVPWM Algorithm With Low Computational Overhead for Three-Phase Inverters," *IEEE Transactions on Power Electronics,* vol. 22, no. 5, pp. 1797 - 1805, 2007.

[15] S. F. B. W. K. H. Ahmed, "Passive Filter Design for Three-Phase Inverter Interfacing in Distributed Generation," in *2007 Compatibility in Power Electronics*, Gdansk, Poland, 2007.