International Journal of ChemTech Research
CODEN(USA): IJCRGG ISSN : 0974-4290
Vol.5, No.2, pp 993-1002, April-June 2013

ICGSEE-2013[14th – 16th March 2013]
International Conference on Global Scenario in Environment and Energy

Impedance Source Buck- Boost converter for linear and Non-Linear load using MATLAB simulation

Sudhir Ranjan[1], Sushma Gupta[2], Ganga Agnihotri[2]*

[1]Department of Electrical Engg, IPEC GZB UP, India,
[2]Department of Electrical Engineering, MANIT Bhopal, India.

*Corres.author: ganga1949@gmail.com

Abstract: This paper presents an alternative power conversion topology that can buck or boost the input voltage/current with linear and non-linear load depending upon duty ratio and modulation index in a single stage conversion with the help of Impedance source passive Network (L and C), which is usually known as Z-Source. The buck and boost capabilities of inverters are operated in the shoot through state. The objective of this Paper is to demonstrate a low-cost, efficient, and reliable inverter for linear and non-linear load. This paper verified the simulation result for Z-Source PWM inverter with MATLAB and implementation to any linear and non-linear three phase load. The unique feature of Z-Source network is shoot-through duty cycle and it acts as a filter which reduces the line harmonics, improves power factor, increases reliability and extends the output AC voltage range of inverter.

I. Introduction

The classic boost converter is not a good choice for the high step-up conversion[1] due to following three reasons. Firstly, an extremely high duty-cycle must be used to obtain the steep conversion ratio, which causes serious losses on the power devices due to their parasitic parameters. Secondly, low on-resistance active switches and good performance diodes cannot be adopted due to the high voltage stress. Third, the reverse-recovery problem of the output diode is severe due to its short conduction time. All these three factors degrade the efficiency and limit the power level. So, after invention of power semiconductor devices these problems can be overcome. Consequently a large number of inverters are invented but key components in all these power electronic devices. Particularly in hybrid, electric, and fuel cell vehicles, the Insulated Gate Bipolar Transistors (IGBTs), freewheeling diodes and advanced power module technology are used[2]. After that a Novel PWM scheme was invented for controlling the output of an inverter with improved fundamental component value. The main advantage of this approach is that it adopts a consistent strategy for the entire range of modulation index i.e. it does not require any mode change and also causes exactly same number of switching per cycle[3]. The appreciable improvement in THD in the lower range of modulation depth attracts drive applications where low speed operation is required. Traditional VSI and CSI inverter are frequently used for speed control of machine.
The well known three-phase Traditional inverter VSI and CSI have also some limitation as below: -
(I) The two switches of same phase can't be gated on simultaneously which can be damage the inverter.
(II) Buck and Boost both phenomenons can't be take from single topology.

In the literature[4-11], a new impedance-source inverter had proposed. The newly proposed inverter had overcome the problems which were occurred in traditional inverter. Following are additional advantages of Z-Source inverter over traditional inverter.

(I) In VSI and CSI, power loss is high because of additional filter so the efficiency is low but in Z-source Inverter Impedance Network (Z-Source) itself acts as a filter.

(II) The VSI is a buck (down) inverter whereas CSI is a boost (up) inverter. For applications exceeding available voltage range an additional boost (or buck) DC/DC converter is needed. This increases the system cost and decreases the efficiency.

(III) The VSI (CSI) requires dead time (overlap time) to provide safe commutation which causes waveform distortion.

(IV) The main circuit is not being interchangeable. In other words, neither the VSI main circuit can be used for the CSI and nor CSI as a VSI.

(V) Vulnerable to EMI noise.

(VI) In CSI and VSI buck-boost gain are finite but in Z- Source it lies between (0≈∞).

In this paper, a design of Z-source PWM inverter is proposed. A mathematical modeling is done for Z-source inverter and simulation is carried out to find out the performance of the same. Total harmonic distortion (THD) is calculated to know the quality of the Z-source inverter.

II. System Description

A. Z-Source Inverter

The Z-source Inverter (ZSI) is a new topology in power conversion, Fig. 3 shows the ZSI implemented as a 3-phase DC/AC converter (inverter). Although DC/AC conversion is the most common application of the Z-source topology, it can also be applied to AC/DC and AC/AC power conversions[1].

The ZSI used to overcome the problems in the traditional source inverters. The ac voltage is rectified to dc voltage by the rectifier. The rectifier output dc voltage fed to the impedance network, which consists of two split inductors and two split capacitors equal in magnitude.

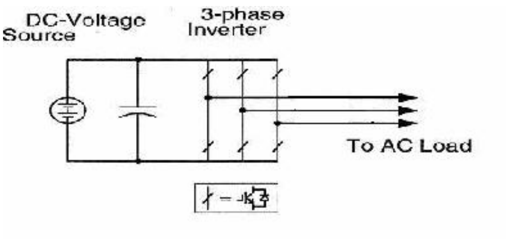

Fig-1: VSI inverter

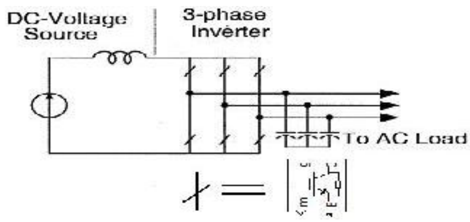

Fig-2: Current source Inverter

The network inductors are connected in series arms and capacitors are connected in diagonal arms. The impedance network is used to buck or boost the input voltage depend upon buck or boost factor. This network also act as a second order filter and it should required less inductance and less capacitance. The inverter main circuit consists of active switches. These inverters use a unique impedance network, coupled between the power source and converter circuit, which cannot be achieved with conventional VSI and CSI [1].

The unique feature of the Z- source inverter is that the output ac voltage can be any value between zero and infinity regardless of dc voltage. That is, the Z-source inverter is a buck-boost inverter that has a wide range of voltage.

The traditional three-phase voltage source inverter shown in fig-1 has six active vectors when the DC voltage is impressed across the load and two zero vectors when the load terminals are shorted through either the lower or upper three devices, respectively.

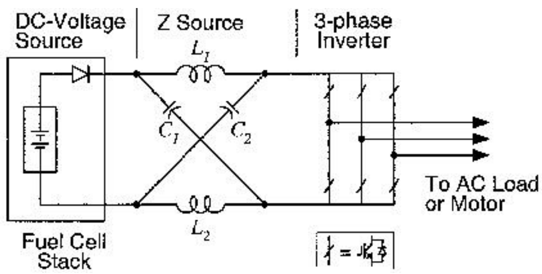

Fig-3: Z-source inverter

However, three phase Z source inverter bridge has one extra zero state when the load terminals are shorted through both the upper and lower devices of any one phase leg, any two phase legs, or all three phase legs. This shoot-through zero state is forbidden in the traditional voltage source inverter, because it would cause a shoot-through. The Z- source network makes the shoot-through zero state possible. This shoot-through zero state provides the unique features to the Z-Source Inverter are:
(i) The ZSI provides the buck-boost function by one-stage conversion.
(ii) In this technology unwanted on and off by EMI noise will not destroy the converter.
(iii) The ZSI has the advantages of both VSI and CSI.
(iv) It solves the problems of the traditional converters.
(v) The ZSI has low or no in-rush current as compared to the VSI and CSI.
(vi)Due to low losses efficiency of the system is improved.

B. Shoot-Through PWM Control

There are several control methods such as: simple boost control[1], maximum boost control[2], and maximum constant boost control.[3]

In traditional PWM switching sequence based on the triangular carrier method. In every switching cycle, the two non-shoot-through zero states are used along with two adjacent active states to synthesize the desired voltage. When the dc voltage is high enough to generate the desired ac voltage, the traditional PWM is used.

The shoot-through period is generated by comparing the same triangular wave with straight lines or envelopes of the modulating signal or sinusoidal signal depending upon the technique used and inserted in the switching waveform with the help of OR gate.

The working principle is almost the same as the one that traditional carrier based PWM has. In addition to six working states and two zero states the shoot through states will be added.

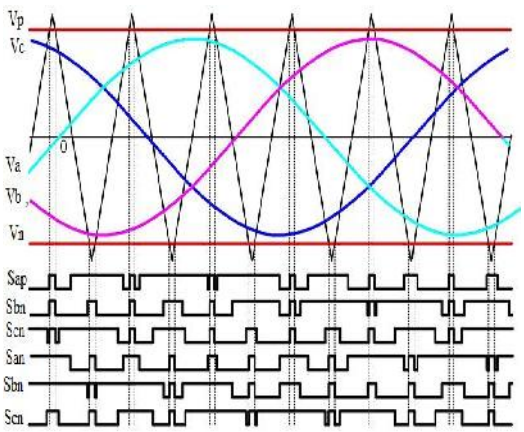

Fig-4: Control method for Simple boost control

The shoot-through impulses will be generated when the triangular carrier signal is greater than the upper shoot-through signal or lower than the lower shoot-through signal shown in fig-4.

While the dc voltage is not enough to directly generate a desired output voltage, a modified PWM with shoot-through zero states will be used as shown in Fig. 5 to boost voltage. It should be noted that each phase leg still switches on and off once per switching cycle. Without change the total zero-state time interval, shoot-through zero states are evenly allocated into each phase. That is, the active states are unchanged. However, the equivalent dc-link voltage to the inverter is boosted because of the shoot-through states.

The maximum shoot-through duty ratio is limited to

$$D_s = 1- M_a$$

Where.M_a is modulation index which indicates the ratio of modulating signal to amplitude of carrier signal. And duty ratio is defined as total time period taken in shoot during one cycle to total time period.

The maximum shoot-through duty ratio reaches to zero when the modulation index one is. When the modulation index increases, the switching frequency of the inverter will also increase, as well as switching losses.

State of switching of Z-source inverter

State (output voltage)	S1	S4	S3	S6	S5	S2
Active{100} (finite)	1	0	0	1	0	1
Active{110} (finite)	1	0	1	0	0	1
Active{010} (finite)	0	1	1	0	0	1
Active{011} (finite)	0	1	1	0	1	0
Active{001} (finite)	0	1	0	1	1	0
Active{101} (finite)	1	0	0	1	1	0
Null{000} (0 V)	0	1	0	1	0	1
Null{111} (0 V)	1	0	1	0	1	0
Shoot through E1(0V)	1	1	S3	!S3	S5	!S5
Shoot through E2(0V)	S1	!S1	1	1	S5	!S5
Shoot through E3(0V)	S1	!S1	S3	!S3	1	1
Shoot through E4(0V)	1	1	1	1	S5	!S5
Shoot through E5(0V)	S1	!S1	1	1	1	1
Shoot through E6(0V)	1	1	S3	!S3	1	1
Shoot through E7(0V)	1	1	1	1	1	1

Above table shows the switching sequence of Z- source PWM inverter with simple boost control method. There are total 15 state in which six active state, two zero state and seven shoot-through state which can be obtained by different combination of switching sequence.

III. Mathematcal Modeling Of Z-Source Inverter

Assuming that the inductors L_1 and L_1 capacitors C_1 and C_2 have the same inductance & capacitance, respectively, the Z-source network becomes symmetrical. From the symmetry and the equivalent circuit, voltages across capacitors and inductors are as follows:

$$V_{C1} = V_{C2} = V_C \qquad V_{L1} = V_{L2} = V_L \tag{1}$$

Given that the inverter bridge is in the shoot - through zero state for an interval of T_0, during a switching cycle, T and from the equivalent circuit as shown in Fig.6**.**

$$V_L=V_C, \qquad V_d=2V_C, \qquad V_i=0 \tag{2}$$

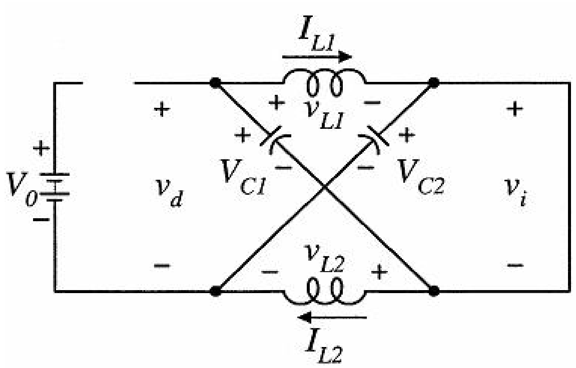

Fig. 5. Z-source Inverter Bridge in the shoot- through zero state.

Now consider that the inverter bridge is in one of the eight non-shoot-through states for an interval of T_1, during the switching cycle, T. From the equivalent circuit, Fig.7, one has-

$V_L=V_0 – V_C$, $V_d= V_0$,
$V_i= V_C – V_L = 2V_C –V_0$ (3)

where V_0 is the DC source voltage and $T=T_0+T_1$.

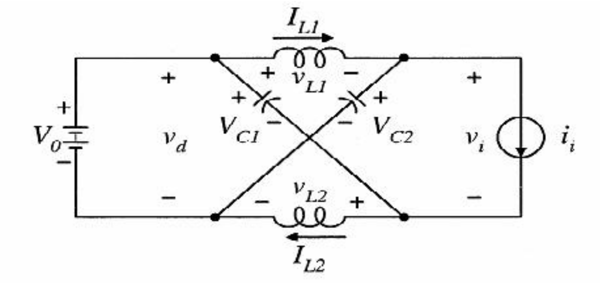

Fig. 6. Z-source Inverter Bridge in one of the eight non shoot-through states.

The average voltage of the inductors over one switching period T should be zero in steady state. From Eq. 2 and Eq. (3) voltage across inductor and capacitor are obtained as:
$V_L= [T_0 V_C + T_1 (V_0 – V_C)] / T =0$ (4)
$V_C / V_0 = T_1/ (T_1- T_0)$ (5)

Similarly, the average DC-link voltage across the inverter bridge can be found as follows:

$V_i = [T_0 * 0 + T_1 (2V_C –V_0)] / T = [T_1/ (T_1- T_0)] V_0$ (6)

The peak DC-link voltage across the inverter bridge is expressed in Eq. 3 can be rewritten as:
$V_i= V_C - V_L = 2V_C –V_0 = [T/ (T_1- T_0)] = BV_0$ (7)

Where,
$B = T/ (T_1- T_0) = 1/ (1-2T_0 /T) \geq 1$ (8)

The DC-link voltage is the boost factor resulting from the shoot-through zero state. The peak DC-link voltage V_i is the equivalent DC-link voltage of the inverter.
On the other side, the output peak phase voltage from the inverter can be expressed as:

$Vac= M V_i/2$ (9)

where M is the modulation Index. Using Eq. 7 and Eq. 9 can be further expressed as:
$Vac= M* B* V_0 /2$ (10)

For the traditional V-source PWM inverter, we have the well known relationship: $Vac= M* V_0 /2$. Eq. 10 shows that the output voltage can be stepped up and down by choosing an appropriate buck–boost factor BB,
$BB = M* B= (0\approx\infty)$ (11)

From Eq. 1, Eq. 5 and Eq. 8, the capacitor voltage can expressed as
$V_{C1}= V_{C2}= V_C = [1-(T_0 /T)] /[1-(2T_0 /T)] V_0$ (12)

The buck–boost factor BB is determined by the modulation index M and boost factor B. The boost factor B as expressed in Eq. 8 can be controlled by duty cycle (i.e., interval ratio) of the shoot-through zero state over then on shoot-through states of the inverter.

Note that the shoot-through zero state does not affect the PWM control of the inverter, because it equivalently produce the same zero voltage to the load terminal. The available shoot-through period is limited by the zero-state period that is determined by the modulation index.

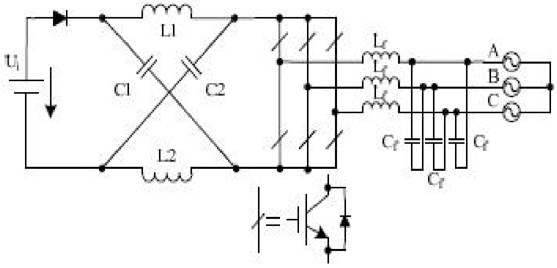

Fig. 7. Simplified prototype circuit

IV. Simulation Of Z-Source PWM Inverter

Here we simulate Z-source PWM inverter with two separate load linear and non linear. The linear loads are passive load i.e. R-load, R-L load, R-C load and R-L-C load but in this circuit we consider only R- load. And in non-linear load we consider a diode rectifier.

A. Z-Source PWM Inverter with linear load

Z-source inverter with linear load is shown in fig-9.The applied DC input voltage is 150 volt and it gives the output AC line to line RMS voltage approx 396 volt.

The parameter of inverter is chooses like this: - amplitude of carrier signal is Ac=1 unit, amplitude of modulating signal Am=0.5655 unit, Impedance network have inductance L= 150 µH and capacitance C=1000 µf for linear and non linear load also, sinusoidal signal with frequency 50 Hz and carrier frequency 10 kHz in a logical operator.

The experimental result of proposed work will validate with MATLAB software. THDs (Total harmonic distortions) analysis are also validate with FFT analysis of MATLAB software for linear and non linear also.

B. Mathematical Analysis

Let Amplitude of modulating signal (Sinusoidal signal) $A_m = .5655$ and Amplitude of carrier signal (Triangular signal) $A_c = 1$ So, Modulation Index

$$M = A_m / A_c = 0.5655$$

And, Duty ratio D is calculated as

$$D = 1 - M = 1\text{- } 0.5655 = 0.4345$$

Now Boost-factor B is calculated as:-

$$B = \frac{1}{1-2D}$$

$$B = \frac{1}{1-2*0.4345} = 7.6365$$

Now, Capacitor voltage is boosted to

$$V_{c1} = V_{c2} = V_c = \frac{1-D}{1-2D}$$

= 647.76 Volt.

So, Peak Phase voltage,

$\hat{V}_{ac} = 323.88$ Volt.

So, RMS Phase Voltage,

$V_{rms} = \hat{V}ac / \sqrt{2}$

$= 229.05$ Volt

So, RMS Line to Line voltage

$V_{rmsL-L} = \sqrt{3} * V_{rms} = 396.75$ Volt

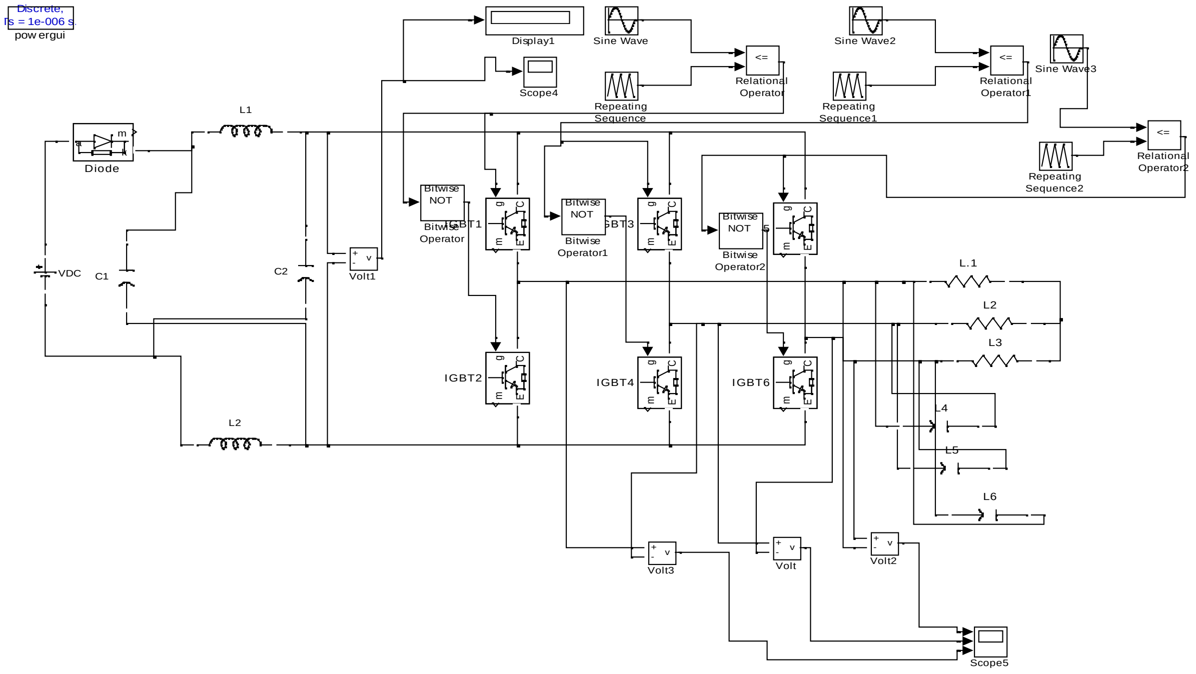

Fig-9 Z-Source simulation model with linear load

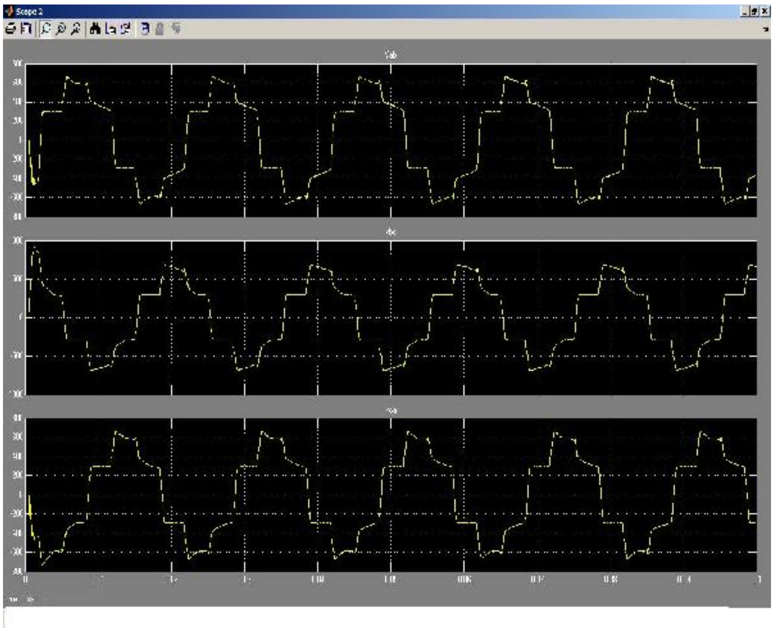

Fig. 10 Simulated output line voltage with linear load

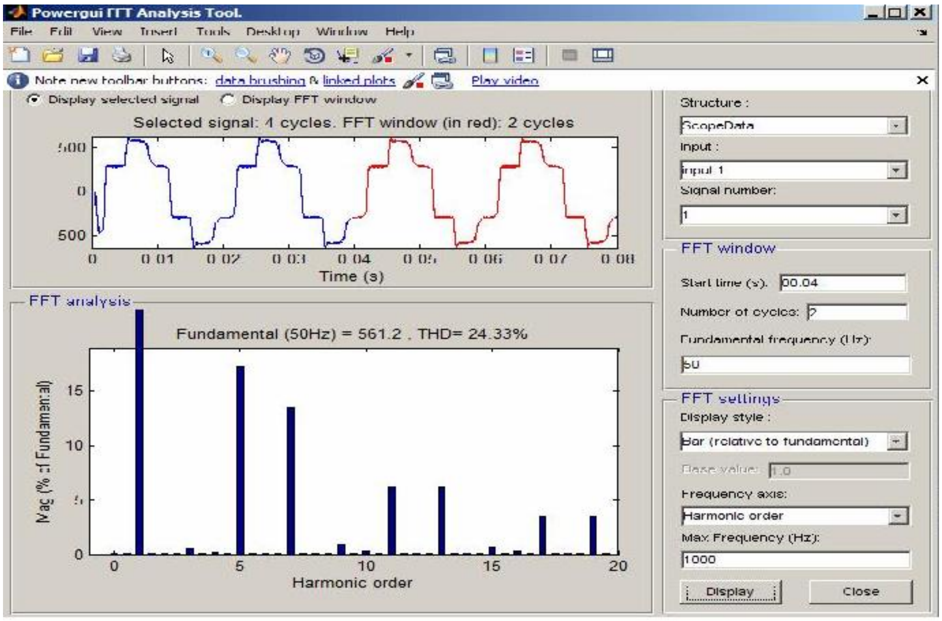

Fig. 11. FFT Analysis of Simulated Waveform

C. Z-Source PWM Inverter with non-linear load

Z -source inverter with non- linear load which consist of a non linear device like diode, transistor, FET, MOSFET etc. In this work, a three phase rectifier circuit is connected as load and shown in fig. 12.
The applied DC input voltage is 150 volt and it gives the output AC line to line RMS voltage approx 419 volt.

The parameter of inverter is chooses like this: - amplitude of carrier signal is Ac=1 unit, amplitude of modulating signal Am=0.5655 unit, Impedance network have inductance L= 150 µH and capacitance C=1000 µf for linear and non linear load also, sinusoidal signal with frequency 50 Hz and carrier frequency 10 KHz in a logical operator.
The experimental result of proposed work will validate with MATLAB software. THDs (Total harmonic distortions) analysis are also validate with FFT analysis of MATLAB software .
D. Mathematical Analysis:
Let Amplitude of modulating signal(Sinusoidal signal) $A_m = .5655$ and Amplitude of carrier signal (Triangular signal)
$A_c = 1$ So, Modulation Index

$$M = A_m / A_c = 0.5655$$

$$M = 0.5655$$

And, Duty ratio D is calculated as

$$D = 1 - M$$

$$D = 1 - .5655 = 0.4345$$

Now Boost-factor B is calculated as:-

$$B = \frac{1}{1 - 2D}$$

$$B = \frac{1}{1 - 2 * 0.4345} = 7.6365$$

Now, Capacitor voltage is boosted to

$$V_{c1} = V_{c2} = V_c = \frac{1 - D}{1 - 2D}$$

$$= 647.76 \text{ Volt.}$$

So, Peak Phase voltage,

$$\hat{V}_{ac} = B * M * V_o / 2$$

$\hat{V}_{ac} = 323.88$ Volt.

So, RMS Phase Voltage,

$V_{rms} = \hat{V}ac / \sqrt{2}$

= 229.05 Volt

So, RMS Line to Line voltage

$$V_{rmsL-L} = \sqrt{3} * V_{rms}$$

= 396.75 Volt

But due to non-linearity it will be 419v Approx from simulation result.

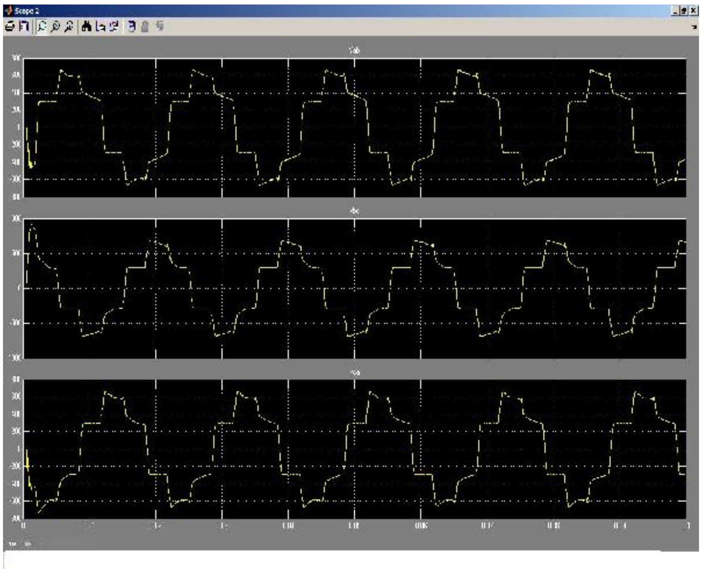

Fig. 12 Output voltage of Z-Source Inverter with non-linear load

Harmonics analysis of above window is explain as below:-

Fundamental frequency,

F= 50 Hz

THD for Non-linear load is 30%

THD for Linear is 24.33%

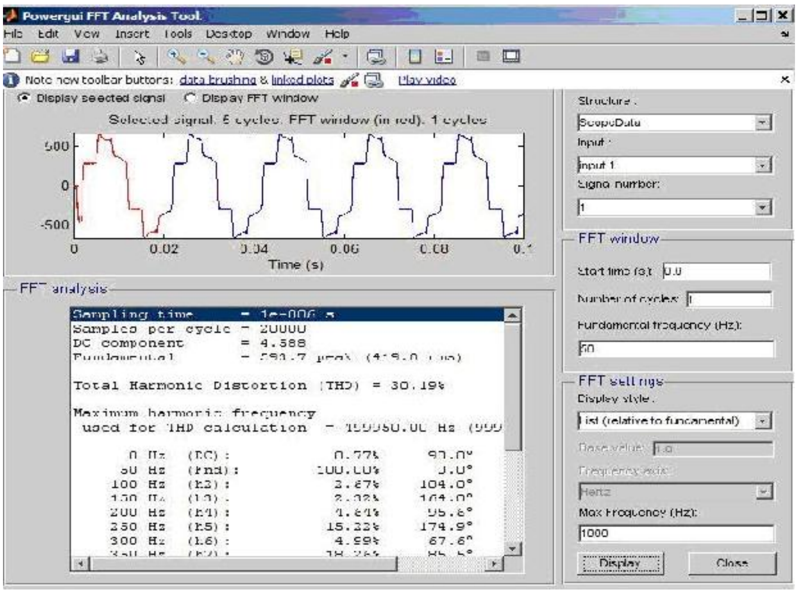

Fig. 13 FFT Analysis of Simulated Waveform

V. Conclusion

In present work, a design is carried out of Z-Source PWM Inverter for linear and non-linear load. Further mathematical model has been developed and simulated with MATLAB software. In this case, 150 volt DC signals is applied and get the inverter output voltage 396.7 volt (RMS) and the THD for linear is 24 % (calculated). For the non-linear load, inverter voltage of 419 volt (RMS) is obtained and THD approximately 30 % is calculated for frequency 50 Hz.

References

1. Yi Zhao, Wuhua Li, Yan Deng, Xiangning He, Simon Lambert, Volker Pickert “High step-up boost converter with coupled inductor and switched capacitor”, Power Electronics, Machines and Drives (PEMD 2010), 5th IET International Conference on , Vol.,No., pp.1-6, 19-21 April 2010.
2. Z. John Shen and Ichiro Omura “Power Semiconductor Devices for Hybrid, Electric, and Fuel Cell Vehicles”, Proceedings of The IEEE - PIEEE, vol. 95, no. 4, pp. 778-789, 2007
3. S. Jeevananthan1, R. Nandhakumar1, P. Dananjayan1 Inverted Sine Carrier for Fundamental Fortification in PWM Inverters and FPGA Based Implementations Serbian Journal of Electrical Engineering, Vol. 4, No. 2, November 2007, 171-187
4. Fang Zheng Peng, "Z- Source Inverter" IEEE Trans. Industry Applications, Vol.39, No. 2, March/April 2003.
5. Yu Tang, Shaojun Xie,, Chaohua Zhang, and Zegang Xu, “Improved Z-Source Inverter with Reduced Z-Source Capacitor Voltage Stress and Soft-Start Capability”, IEEE Trans. on Power Electronics, Vol. 24, NO. 2, February 2009.
6. Miaosen Shen, Jin Wang, Alan Joseph, Fang Z. Peng, Leon M. Tolbert, and Donald J.Adams, “Maximum constant boost control of the Z-source inverter”, Volume: 3, pp:1329 – 1333, Dec. 4-7, 2000**.**
7. M. Shen, A. Joseph, , J. Wang, F. Z. Peng, D. J. Adams, “Comparison of Traditional Inverters and Z-Source Inverter for Fuel Cell Vehicles”, IEEE Transactions on Power Electronics, vol. 22, no. 4, July 2007, pp. 1453-1463.
8. B. Justus Rabi and R. Arumugam “Harmonics Study and Comparison of Z-source Inverter with Traditional Inverters” International Journal of Automotive Technology, Vol. 10, No. 4, pp. 431−439
9. M.Sasikumar et al. / (IJAEST) International Journal of Advanced Engineering Science and Technologies, Vol No. 1, Issue No. 2, 096 – 101.
10. S. Thangaprakash and A. Krishnan,“Comparative evaluation of modified pulse width modulation schemes of Z-source inverter for various applications and” International Journal of Engineering, Science and Technology Vol. 2, No. 1, 2010, pp. 103-115.
11. Ram Prasad Panda, R. K. Tripathi, “A Novel Sine Wave Inverter with PWM DC Link” 2008 IEEE Region 10 Colloquium and the Third ICIIS, Kharagpur, INDIA December 8-10.

*****