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STUDY AND ANALYSIS OF SINGLE PHASE Z-SOURCE INVERTER

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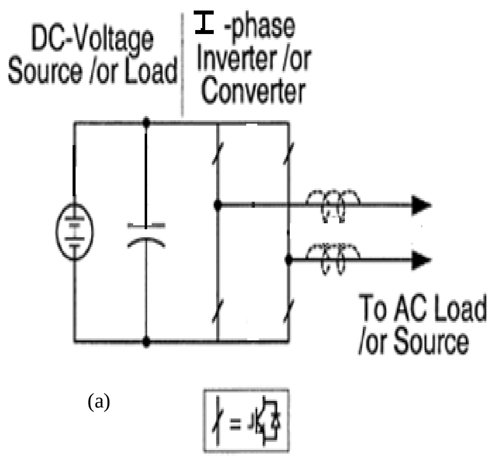
ABSTRACT:
This paper presents an Impedance Source Inverter (Z-Source Inverter) for Resistive Load. The Z-source inverter employs a unique impedance network (or circuit) to couple the inverter main circuit to the power source, thus providing unique features that cannot be obtained in the traditional voltage-source (or voltage-fed) and current-source (or current-fed) inverters where a capacitor and inductor are used, respectively. It 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, also provide ride-through capability during reduces harmonics, improves power factor and high reliability, and extends output voltage range. The effect of filter on inverter load voltage and current is studied. The detailed comparison of Z-Source inverter with Traditional inverter is discussed and simulation results will be presented to demonstrate these new features.

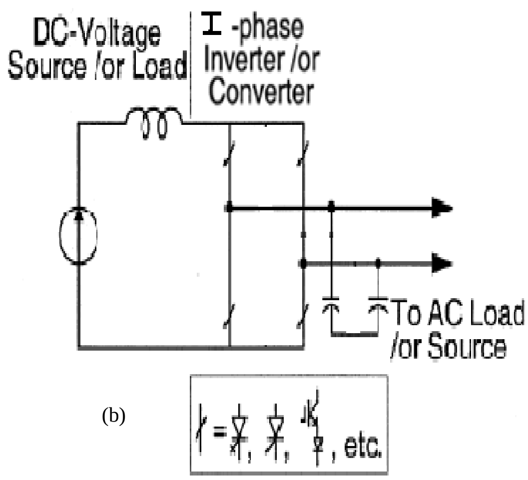
Keywords: *Simulation, Total Harmonic Distortion, Traditional inverter, Z-Source Inverter.*

1. INTRODUCTION:

There exist two traditional inverters [1],[11]: voltage-source (or voltage-fed) (Fig. 1(a)) and current-source (or current-fed) inverters (Fig. 1(b)) (or inverters depending on power flow directions).



(a)



(b)

Fig.1 (a) Traditional single-phase voltage-source inverter structure
Fig.1 (b) Traditional single-phase current-source inverter structure

A dc voltage source (or a current source) can be a relatively large capacitor (or a relatively large dc inductor) feed the main inverter circuit, a single-phase bridge. The dc voltage source can be a battery, fuel-cell stack, diode rectifier, capacitor or a thyristor inverter.

Four switches are used in the main circuit; each is composed of a power transistor and a diode. In voltage source inverter, an anti-parallel (or freewheeling) diode is used to provide bidirectional current flow and unidirectional voltage blocking capability, whereas in current source a diode in series is used to provide unidirectional current flow and bidirectional voltage blocking.

However, the V-source and I-source inverter has the following conceptual and theoretical barriers and limitations.

- They are either a boost or a buck inverter and cannot be a buck–boost inverter. That is, their obtainable output voltage range is limited to either greater or smaller than the input voltage.
- Their main circuits cannot be interchangeable. In other words, neither the V-source inverter main circuit can be used for the I-source inverter, or vice versa.
- They are characterized by relatively low efficiency because of switching losses and considerable EMI generation.

2. Z-SOURCE INVERTER (ZSI):

To overcome the problems of the traditional V-source and I-source inverters, this paper presents a Z (impedance)-source power inverter (Z-source inverter)[1][2]. Fig. 2 shows the general ZSI structure proposed.

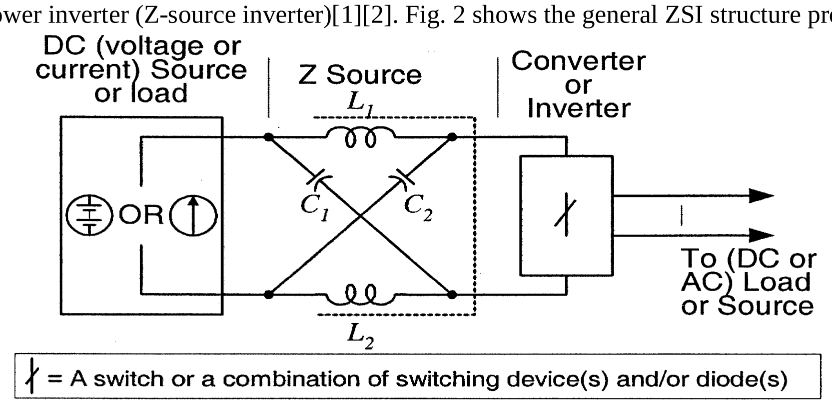


Fig.2 General Z-source inverter structure

It employs a unique impedance network to couple the inverter main circuit to the power source, load, or another inverter, for providing unique features that cannot be observed in the traditional V- and I-source inverters where a capacitor and inductor are used, respectively.

It has three stages:

(i) *DC voltage source of the rectifier supply*- fed to the impedance network.

(ii) *Impedance network-*

This is a two-port network (Fig (3)) that consists of split inductors L1 and L2 (L1=L2) and capacitors C1 and C2 (C1 = C2) connected in X-shape. L1 and L2 are series arm's inductances; C1 and C2 are diagonal arm's capacitances. This network is coupled with the main circuits and the source.

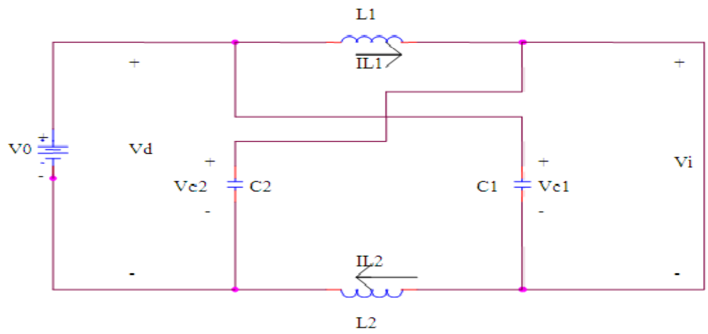


Fig. 3 Impedance network

The impedance network used buck or boost the input voltage depends upon the boosting factor. This network also acts as a second order filter .This network should require less inductance and smaller in size. Similarly capacitors required less capacitance and smaller in size. This impedance network, the constant impedance output voltage fed to the single phase inverter main circuit.

(iii) *Single phase inverter*- traditional inverter (section I).

ZSI has three operation modes [1] [4] [6]:

(i) normal mode,
(ii) zero-state mode, and
(iii) Shoot-through mode.

In normal mode and zero-state mode, the ZSI operates as a traditional Pulse-width modulation (PWM) inverter. The ZSI advantageously utilizes the shoot-through states (not in traditional inverter) to boost the dc bus voltage. In addition, the reliability of the inverter is greatly improved because the shoot-through state can no longer destroy the circuit. Thus it provides a low-cost, reliable, and highly efficient single-stage structure for buck and boost power conversion [5] [7].

This paper presents the detailed design analysis, utilization of the shoot through zero states to boost voltage, the effect of Z network and output LC filter on inverter load voltage and current. MATLAB simulations results are presented in order to verify the features of ZSI over Traditional Inverter.

3. DESIGNING OF Z (IMPEDANCE)- NETWORK:

A two-port impedance network is a symmetrical lattice network, connected between the dc source (voltage source in this paper) and the inverter (Fig (4)). The full bridge inverter consists of two legs. Each leg consists of two switches and their anti parallel diodes. The two switches in each leg are switched in such a way that when one of them is in OFF state, the other will be in ON state. Due to this switching operation, output current flows continuously through the load and output voltage is solely dictated by the status (ON/OFF) of the switches.

3.1 Significance of Inductors and Capacitors:

The impedance source network is the energy storage or filtering element for the ZSI. This network provides a second order filtering. This is more effective to suppress voltage and current ripples. The inductor and capacitor requirement should be smaller compare than the traditional inverters. The two inductors (L1 and L2) are small and approach zero, the Impedance source network reduces to two capacitors (C1 andC2) in parallel and becomes a traditional voltage source. Therefore, a traditional voltage inverter’s capacitor requirement and physical size is the worst-case requirement for the Impedance source inverter. Similarly, when the two capacitors (C1 and C2) are small and approach zero, the Impedance source network reduces to two inductors (L1 and L2) in series and becomes a traditional current source [1][5][6]. Therefore, a current source inverter’s inductor requirements and physical size are the worst case requirement for the Impedance source inverter.

The normal operation mode is same as the traditional inverter. The output voltage depends upon the voltage across the inverter bridge and on the modulation index. In the boost mode however, the Z-source inverter boosts the voltage of C1 and C2 (see figs 2 and 3), thereby raising the voltage at the inverter bridge. The capacitor voltage of the Z-source network is a function of shoot- through states.

Table 1 shows, how the shoot through state of a single phase Z-source inverter can be controlled. It has five possible switching states: two active states (vectors) when the dc voltage is connected across the load, two zero states (vectors) when the load terminals are shorted through either the lower or the upper two switches and one shoot through state (vector) when the load terminals are shorted through both the upper and the lower switches of any one leg or two legs. Z-source inverter utilizes the shoot through zero states to boost voltage in addition to traditional active and zero states.

Table 1 Switching states of a single phase 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	

Assume the inductors (L1 & L2) and capacitors (C1 & C2) have the same inductance and capacitance values respectively. So from Fig (3), we have,

$$V_{C1} = V_{C2} = V_C \qquad \text{…………1 (a)}$$

$$V_{L1} = V_{L2} = V_L \qquad \text{…………1 (b)}$$

$$V_d = 2\,V_C \qquad \text{…………1 (c)}$$

During switching cycle T,

$$V_L = V_O - V_C \;\&\; V_d = V_O \qquad \text{…………2 (a)}$$

$$V_i = V_C - V_L \qquad \text{…………2 (b)}$$

$$V_i = V_C - V_L \qquad \text{…………2 (c)}$$

Where, V_O *is DC voltage source and* ,

$$T = T_O + T_1$$

The average voltage of the inductors over one switching period (T) should be zero in steady state:

$$V_L = \frac{T_O \times V_C + T_1(V_O - V_C)}{T} = 0 \qquad \text{…………3}$$

$$\frac{V_C}{V_O} = \frac{T_1}{T_1 - T_O}$$

$$V_i = 2V_C - V_O = \frac{2V_O T_1}{T_1 - T_O} - V_O$$

$$V_i = \left(\frac{2T_1 - T_1 + T_O}{T_1 - T_O}\right)V_O = \frac{(T_1 + T_O)V_O}{T_1 - T_O}$$

$$V_i = \frac{T \times V_O}{T_1 - T_O} = B \times V_O \qquad \ldots\ldots\ldots\ldots 4$$

Where, $\mathbf{B} = \frac{T}{T_1 - T_O}$ is the boost factor resulting from the shoot-through zero state. The shoot through duty cycle is given by $(D_o) = T_o/T$.

So, $B = \frac{T}{T_1 - T_O} = \frac{1}{1 - 2D_O}$ …………5

The peak dc-link voltage 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 if modulation index is m,

$$V_{ac} = m\frac{V_i}{2} \qquad \ldots\ldots\ldots\ldots 6$$

From equation (4)

$$V_{ac} = mB\frac{V_O}{2} \qquad \ldots\ldots\ldots\ldots 7$$

Whereas for, traditional inverter [3][11], $V_{ac} = mV_O$

The output voltage V_{ac} can be stepped-up or stepped-down depending upon the product mB commonly known as *buck-boost factor (B_B)*.

The capacitor voltage can be given by,

$$V_{c1} = V_{c2} = V_c = \frac{(1 - \frac{T_O}{T})V_O}{1 - \frac{2T_O}{T}} \qquad \ldots\ldots\ldots\ldots 8$$

From equation (5)

$$V_c = \frac{(1 - D_O)V_O}{1 - 2D_O} \qquad \ldots\ldots\ldots\ldots 9$$

$$V_c = mBV_O \qquad \ldots\ldots\ldots 10$$

Where, $m = 1 - D_O$

4. SIMULATION AND RESULTS

4.1 Single Phase Z-Source Inverter Matlab-Simulink model:

To verify the proposed design strategies, a MATLAB-simulink model of single phase Z-source inverter and Single phase Traditional inverter are presented (Fig 4 & Fig 5). The design parameters are given in table 2. Theoretical and practical values of fundamental load voltage and current are measured and tabulated in table 3 and table 4, respectively.

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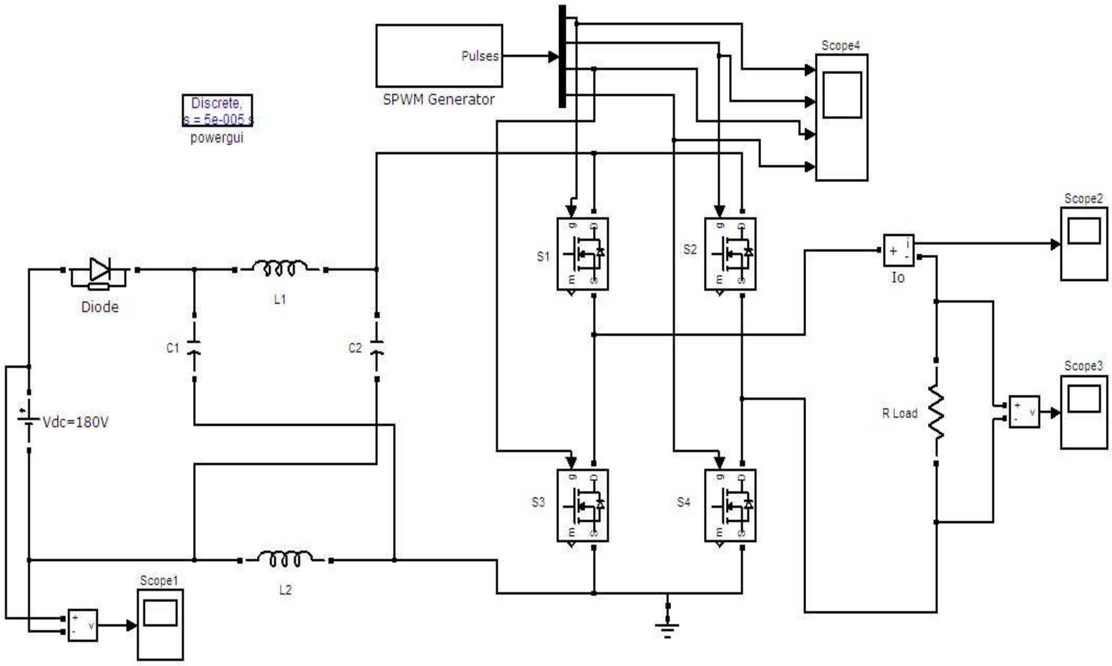


Fig. 4 Single phase Z-source inverter MATLAB-simulink model

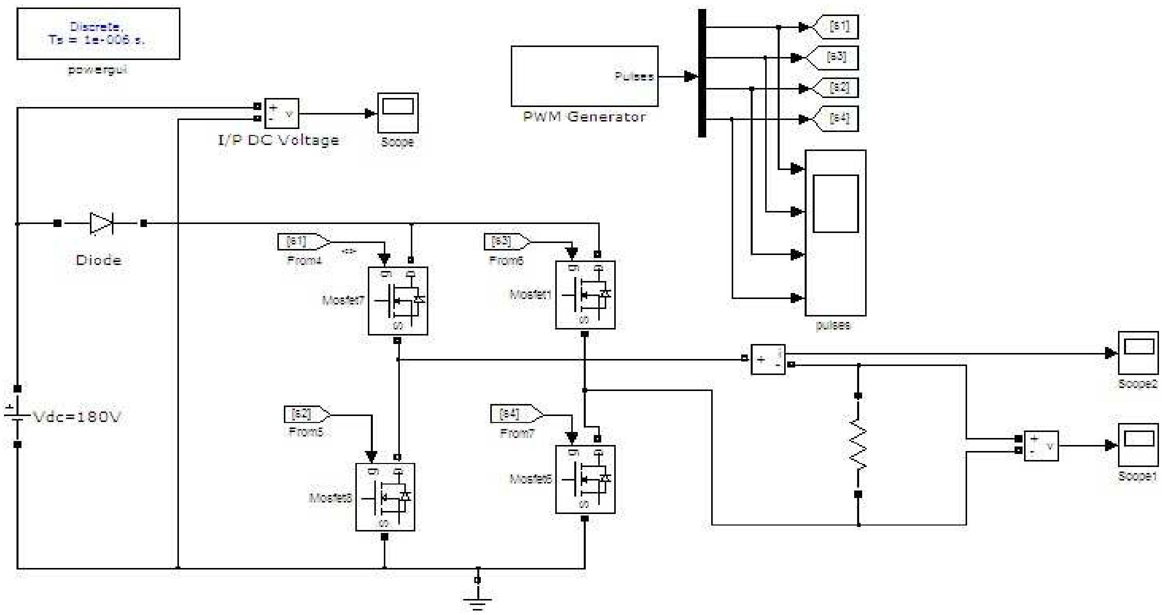


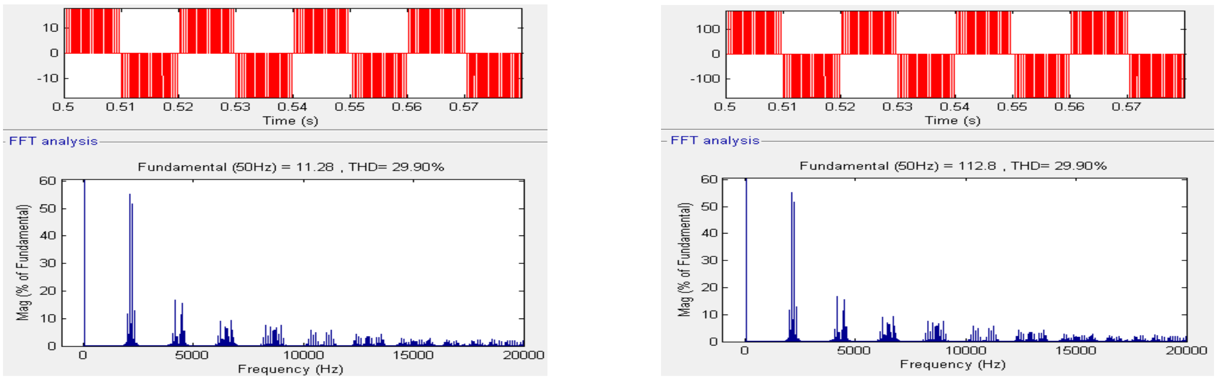
Fig. 5 Single phase Traditional inverter MATLAB-simulink model

Table 2: Design parameters

S.N.	Parameters/ components	Values
1.	$L_1 = L_2$	4.5 µH
2.	$C_1 = C_2$	100 µF
3.	Switching frequency and Modulation Index	10 kHz and 0.642
4.	Input DC voltage	180V
5.	Load Resistance	10 ohm

4.2 Traditional Inverter Matlab-Simulink Model:

To compare the Z-source inverter with traditional inverter, the MATLAB- simulink model has been also simulated (Fig 5) and theoretical and practical values of fundamental load voltage and current are measured and tabulated in table 3 and table 4, respectively. The output waveforms for load voltage and current are shown in Fig 5(a) and Fig 5(b).

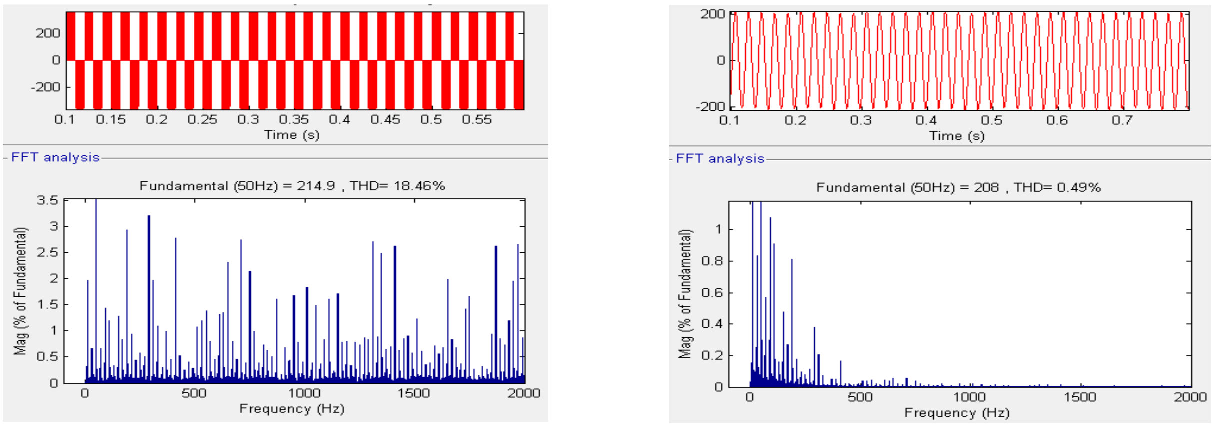


(a) (b)

Fig 5 Traditional inverter harmonics spectra of (a) load voltage and (b) load current

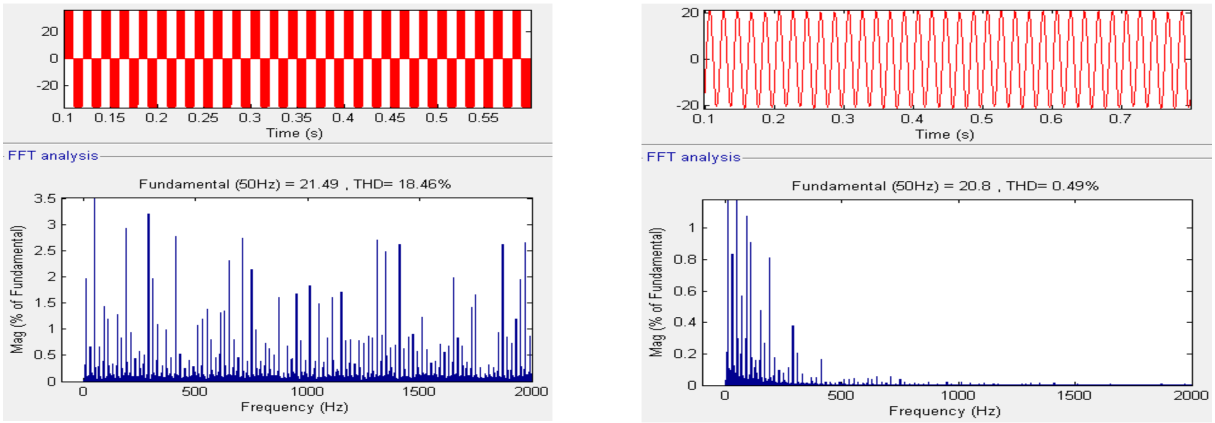
4.3 Effect of Filter on Inverter load voltage and current:

To improve the response of the inverter, LC filter is used at output side. The simulation result (table 4) shows that Total harmonic distortion in the response is greatly reduced with filter. The output waveforms without and with filters are shown in Fig (6) and Fig (7).



(a) (b)

Fig 6: Z-source Inverter load voltage and harmonics spectra (a) without filter and (b) with filter



(a) (b)

Fig 7: Z-source Inverter load current and harmonics spectra (a) without filter and (b) with filter

Table 3 Comparison of inverter response (Theoretical)

Type Parameter	**Traditional inverter**		**Z-source inverter**	
	No Load	**Full Load**	**No Load**	**Full Load**
Fundamental V_L (V)	115.56	121.46	203.39	215.87
Fundamental I_L (A)	23.11	12.15	40.67	21.58

Table 4 Comparison of inverter response with and without filter (Practical)

Type Parameter	Traditional inverter		Z-source inverter without filter		Z-source inverter with filter	
	No Load	Full Load	No Load	Full Load	No Load	Full Load
Fundamental V_L (V)	104.5	112.8	199.7	214.9	192.7	208
%THD of V_L	29.90	29.94	18.01	18.46	0.85	0.49
Fundamental I_L (A)	22.12	11.28	39.85	21.49	38.53	20.8
%THD of I_L	29.90	29.94	18.01	18.46	0.85	0.49

5. CONCLUSION:

In this paper, the theoretical analysis and design of Z-source inverter is studied. The control methods with the insertion of shoot-through states of Z-source inverter have been studied. The shoot through switching state in the Z-source inverter shows that input voltage is boosted .The proposed scheme is simulated with the help of MATLAB/SIMULINK. Simulation results show that the sinusoidal load voltage and current can be achieved by the Z-source inverter using filter which is compared to the traditional inverter (Table 4). It proves that output voltage matches with the design analysis.

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