Review on Z-Source Inverter

Sattyendrasing A. Seragi
Assistant Professor,
R. C. Patel Institute of Technology Shirpur,
Dist: Dhule (M.S.)

ABSTRACT
This paper presents an impedance-source power converter (abbreviated as Z-source inverter) (ZSI). Z-source have recently been examined and investigated as alternative for traditional inverters. The Z-source converter uses LC impedance network to couple the main converter circuit to the power source, which provides the boosting of input voltage that is not possible in traditional voltage-source (or voltage-fed) inverter (VSI) and current-source (or current-fed) inverter (CSI). The Z-source inverter (ZSI) overcomes the conceptual and theoretical barriers and limitations of the traditional voltage-source converter (abbreviated as V-source converter) and current-source converter (abbreviated as I-source converter) and provides a novel power conversion concept. The Z-source concept is new electronic circuit recently recognized because of its application in all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion.

Keywords
Voltage Source Inverter, Current Source Inverter, Z-Source Inverter.

1. INTRODUCTION
There are two traditional converters: voltage source (VSI) and current source (CSI). Fig.1 shows the traditional single-phase voltage-source converter (abbreviated as V source converter).The main converter circuit, is feeded by dc voltage source with large capacitor .The dc voltage source can be a battery, diode rectifier, fuel-cell stack, and/or capacitor.F2our switches are used in the main circuit; each is composed of a power transistor and freewheeling diode to provide bidirectional current flow and unidirectional voltage blocking capability. The V-source converters are widely used.

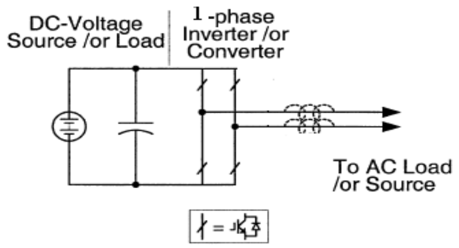


Fig. 1 : Traditional V-Source Inverter

Fig. 2 shows the traditional single-phase current-source converter (abbreviated as I-source converter) structure.

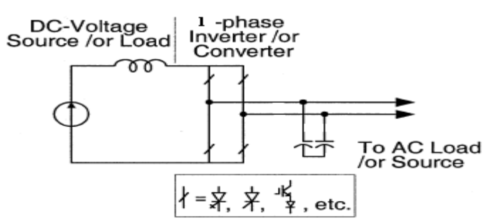


Fig. 2 : Traditional I-Source Inverter

A dc current source can be a relatively large dc inductor fed by a voltage source such as a battery, fuelcell stack, thyristor, rectifier, or diode converter. The main circuit consists of four switches each is composed of a semiconductor switching device with reverse block capability such as SCR and a gate-turn-off thyristor (GTO) or a power transistor with a series diode to provide unidirectional current flow and bidirectional voltage blocking. However, the I-source converter has the following conceptual and theoretical barriers and limitations:

1. The current source inverter acts as boost inverter for dc-to-ac conversion since the output ac voltage is greater than the applied dc voltage .Also current source inverter is a buck converter for ac-to-dc power conversion and the I-source converter is a buck rectifier (or buck converter) for ac-to-dc power conversion when the output dc voltage is smaller than ac input voltage. An additional dc–dc buck (or boost) converter is needed, when wide voltage range is desirable but this conversion stage increases system cost and reduces efficiency.
2. An open circuit of the dc inductor would occur if at least one of the upper devices and one of the lower devices are gated on and maintained on at any time. this destroy the devices. The open-circuit problem causes by EMI noise's. Overlap time for safe current commutation is needed in the I-source converter, which also causes waveform distortion, etc.
3. The main switches of the I-source converter are used to block the reverse voltage that requires a series diode in combination with high-speed and high performance transistors such as insulated gate bipolar transistors (IGBTs). This prevents the direct use of low cost and high-performance IGBT modules and intelligent power modules (IPMs).

In addition, both the V-source converter and the I-source converter have the following common problems:

1. Voltage source and current source inverters are either a boost or a buck converter and cannot be a buck–boost converter.
2. Neither the V-source converter main circuit can be used for the I-source converter, nor vice versa. In other their main circuits cannot be interchangeable.
3. There reliability is affected due to EMI noise.

impedance-fed power converter (abbreviated as Z-source converter) and its control method for implementing dc-toac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. Fig.3 shows the general Z-source converter structure. It uses a unique impedance network (or circuit) to couple the main converter circuit to the power source. The Z-source converter overcomes limitations of the traditional voltage source converter and current source converter and provides a novel power conversion concept.

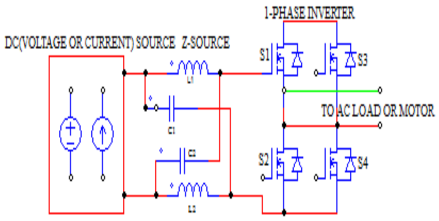


Fig. 3 : General Structure of the Z-Source Inverter

2. Z-SOURCE INVERTER

Z-source inverter (ZSI) which is based on Z-source network can be used to buck and boost the output AC voltage, which is not possible using traditional voltage source or current source inverters. Also the ZSI has the unique ability to short the dc link, which is not possible in the traditional voltage source inverters. This improves the reliability of the circuit .Actually concept of boosting the input voltage is based on the ratio of "shoot-through" time to the whole switching period. Z-source converter is shown in Fig.6 where an impedance network is placed between d.c. link and inverter. Z-source inverter (ZSI) provides a greater voltage than the d.c. link voltage. It reduces the inrush current & hormonics in the current because of two inductors in z source network. It forms a second order filter &handles the undesirable voltage sags of the d.c. voltage source.

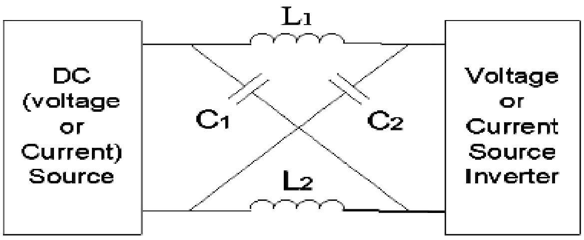


Fig.4 Z-Source Inverter

Fig.4 shows a topology of the single phase Z-source inverter, where the impedance network is placed between the power source and the single phase inverter The presence of 2 inductors & 2 capacitors in Z-source network, allows both switches of same phase leg ON state simultaneously, called as shoot-through state & gives boosting capability to the inverter without damaging the switching devices. During shoot through state energy is transferred From capacitor To inductor & hence Z-source inverter(ZSI) gains the voltage boosting capability Diode is required to prevent the discharge of overcharged Capacitor through the source.

3. SWITICHING STATES

Table 1 Switching States of 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	

As shown in table 1 single phase Z-source inverter 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.

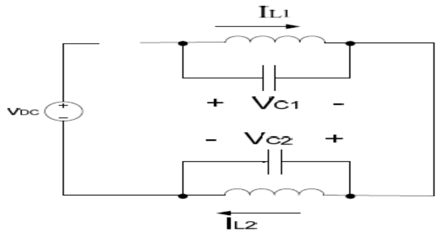


Fig 5 Single Phase ZSI Shoot through Zero State

Fig.5 shows a shoot through switching state of the Z source inverter where two switches of one leg or two legs or all three legs are turned on simultaneously, called as shoot-through state & gives boosting capability to the inverter without damaging the switching devices. During shoot through state energy is transferred from capacitor to inductor & hence ZSI gains the voltage boosting capability . In this state, the diode D at input side is reverse biased and the capacitors, C1 and C2 charge the inductors, L1 and L2 and the voltage across the inductors are VL1=VC1,VL2=VC2 (1)

Assuming a symmetrical impedance network (C1= C2=C and L1=L2=L), it can be observed that VL1=VL2=VL and IL1=IL2=IL the dc-link voltage across inverter bridge during shoot through interval (To) is

$$Vi=0 \qquad (2)$$

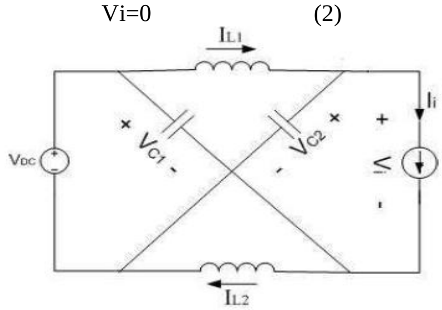


Fig 6 Operating States of Single Phase ZSI

Fig.6 shows ZSI in traditional active and null states and due to symmetrical Z-network, inductors current IL1, IL2 and capacitors current IC1, IC2 are equal. The diode D at the input side conducts and the voltage across the inductors is

$$VL=VDC-VC \qquad (3)$$

The dc-link voltage across inverter bridge during non shoot through interval (T1) is

$$Vi=VC-VL=2VC-VDC \qquad (4)$$

Therefore the average dc-link voltage across Inverter Bridge during one switching cycle (T) is

$$Vi = \frac{To+To(2Vc - Vdc)}{T} = \frac{T1.Vdc}{T1-To} \qquad (5)$$

By applying T1= T -TO in Eq.5

$$Vi = \frac{\frac{1-To}{T}\ (VDC)}{1-2To} \qquad (6)$$

Where Do is the shoot through duty cycle and VDC is the input voltage source.

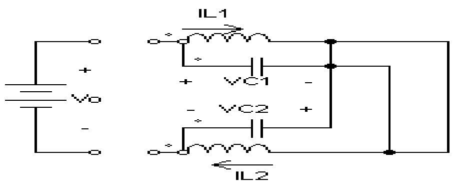
The Z-source inverter may have five different operation modes when viewed from the Z-source network. Modes 1 and 2 have been described in whereas modes 3, 4 and 5 are new modes that may exist for small inductance and high ripple of the inductors.

4. OPERATING MODES

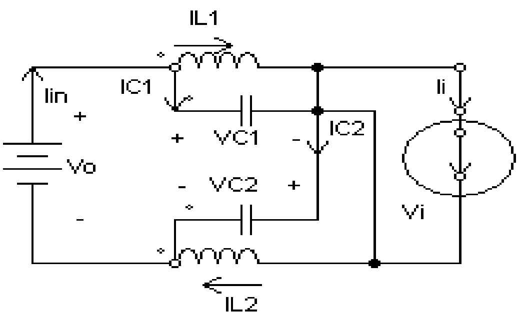
Mode 1 The circuit is in a shoot-through zero state, the sum of the two capacitor voltage is greater than the DC source voltage (VC1+VC2 > V0), the diode is reverse biased, and the capacitors charge the inductors. The voltages across the inductors are:

VL1 = VC1, VL2 =VC2 .

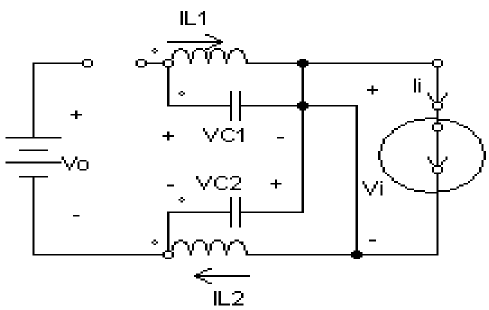
The inductor current increases linearly assuming the capacitor voltage is constant during this period. Because of the symmetry (L1 = L2 = L and C1 = C2 = C) of the circuit, one has VL1 = VL2 = VL, IL1 = IL2 = IL, and VC1 = VC2 = VC.



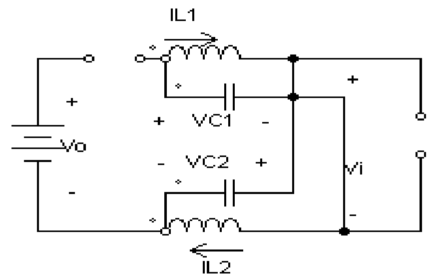
(a) Mode 1 operation



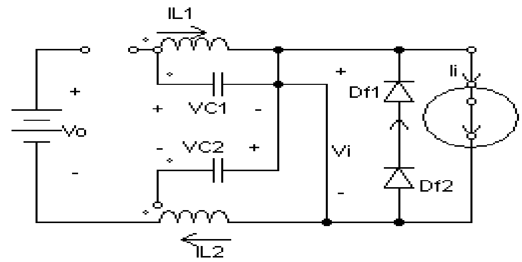
(b) Mode 2 operation



(c) Mode 3 operation



(d) Mode 4 operation



(e) Mode 5 operation

Fig. 7 Possible Operation Modes of Z source Inverter

Mode 2 The inverter is in a non-shoot through state (one of the 6 active states and 2 traditional zero states) and the inductor current meets the following in the equation,

IL > (1/2)*Ii

Again because of the symmetry of the circuit, the capacitor current IC1 and IC2 and the inductor current IL1 and IL2 should be equal to each other respectively. In this mode, the input current from the DC source becomes

Iin = IL1 + IC1 = IL1 + (IL2 - Ii) = 2IL- Ii > 0

Therefore, the diode is conducting and the voltage across the inductor is

VL = V0 - VC

Which is negative (the capacitor voltage is higher than the input voltage during boost operation when there is shoot through states), thus the inductor current decreases linearly assuming the capacitor voltage is constant. As time goes on, the inductor current keeps decreasing to a level that no longer the condition of (2) can be met. At this point, the input current Iin or the diode current is decreased to zero, Mode 2 ends and the inverter enters to a new mode.

Mode 3 The inverter is in one of the 6 active states, and at the end of Mode 2, the inductor current decreases to half of the inverter DC side current, Ii. As a result, the input current becomes zero and the diode becomes reverse-biased. Assuming that the inverter load is inductive and has a much larger inductance than that of the inductor L1 and L2, the inductance of L1 and L2 are negligible and the inductor current and inverter voltage Vi are respectively.

IL = (1/2)*Ii And Vi = VC

Mode 4 The inverter is in one of the 2 traditional zero states (Ii=0) and at the end of Mode 2, the inductor current decreases to zero, thus a new operation mode appears. In Mode 4, the diode stops conducting and the inverter is an open circuit to the Z-source network because of Ii=0. The inductor current becomes zero and maintains zero until the next switching action. Therefore in this mode, the Z-source circuit is isolated from both the DC source and the load.

Mode 5 The inverter is switched to an active state after one of the traditional zero states. The inductor current may decrease to a level that is less than half Ii. After switched to an active state, the inverter cannot enter the active state immediately because that the inductor current is smaller than half of the inverter DC current (the condition of (2) does not hold true) and the inverter enters a freewheeling state described in Fig.3.5 (e). The two diodes in the equivalent circuit are the free -wheeling diodes of the inverter phase legs. This diode free-wheeling state turns the inverter into a shoot through zero state. During this shoot through zero state, all the equations of Mode 1 hold true and the inductor current increases linearly. This mode continues until the inductor current increases to half of the DC side current to the inverter. And the Z-source circuit enters Mode 3 and the inverter enters the intended active state. The difference between this mode and Mode 1 is that this mode is not intentionally created by the control signal and depends on the load current and the inductor current at the time of switching. With different control methods and different circuit parameters and load, the inverter can operate differently with different combination and sequence of the above modes, which yields different circuit characteristics.

Table 2 Comparison of VSI, CSI and ZSI

Current Source Inverter (CSI)	Voltage Source Inverter (VSI)	Impedance Source Inverter (ZSI)
As Inductor is used in the d.c. link, the source impedance is high. It acts as a constant current source.	As Capacitor is used in the d.c. link, it acts as a low impedance voltage source.	As Capacitor and Inductor is used in the d.c. link, it acts as a constant high impedance voltage source.
Momentary short circuit on load and mis-firing of switches are acceptable.	A VSI is more dangerous situation as the parallel capacitor feeds more powering to the fault.	In ZSI mis-firing of the switches sometimes are also acceptable.
This is used in only buck or boost operation of inverter.	This is also used in only a buck or boost operation of inverter.	This is used in both buck and boost operation of inverter.
The main circuit cannot be interchangeable.	The main circuit cannot be interchangeable here also.	Here the main circuits are interchangeable.
It is affected by the EMI noise.	It is affected by the EMI noise.	It is less affected by the EMI noise.
It has a considerable amount of Harmonic distortion.	It has a considerable amount of Harmonic distortion.	Harmonic distortion is low.
Power loss should be high because of filter.	Power loss is high.	Power loss is less.
Lower efficiency because of high power loss.	Lower efficiency because of high power loss.	Higher efficiency because of less power loss.

5. CONCLUSION

The Z-source converter uses an impedance source network to replace the limitations of traditional voltage source and current source inverters while working with the light load. Z source inverter is used for buck and boost operation so that it increases the efficiency with low cost and less power loss. Recently Z Source inverter is in demand because of its attractive power conversion.

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