An Improved Z-Source Inverter for Reduction in Inrush Current and Stress on Capacitor

Barla Pavani[1], Kanuri Venkatesh[2], Pudi Sekhar[3]
[1,2]*Department of Electrical and Electronics Engineering, VIIT, JNTUK University, INDIA*
[3]*Associative Professor, VIIT, JNTUK University, INDIA*

Abstract

The Z-Source inverter is used to perform the buck-boost functions, however an increase the startup inrush current and stress on the capacitor is observed. In order to overcome these problems, an improved Z-source inverter(ZSI) topology is presented. The startup inrush current is reduced and the resonance between the Z-inductors and Z-capacitors is prevented in the improved ZSI topology. Further, acomparison is made between the improved ZSI and the traditional ZSI topology. To realize the performance of improved ZSI, simulations are carried out using MATLAB/Simulink. It has been observed that the startup inrush current is reduced and the resonance at the Z-inductors and Z-capacitors is avoided.

Keywords: - *Startupinrush current, Z-Source inverter, traditional Z-source inverter topology, modulation techniques.*

1. INTRODUCTION

Now-a-days, Z-Source inverters (ZSI) which are the power electronics converters have various topologies. The ZSI mainly focuses on the buck-boost characteristic which is done in a single stage conversion from dc-ac. A ZSI provide an impedance source network which is coupled with the inverter to a dc input source, and is connected in X-shape which consists of two capacitors and two inductors. As compared to the traditional voltage–source inverter, ZSI can perform buck-boost functions. There is no need of dead time when gating on of the two switches of the same phase leg occurs simultaneously which leads to the reduction in output distortion. Figure-1 shows the structure of Z-source inverter topology. The focus of most recent topologies these days are on mainly strategies of modulation [1]-[4],[13] fields application [5]-[7], and the Z-source inverter modeling [9],[14]. Though these topologies have merits, but also have demerits and are given below.

1) Performance of the functioning of the voltage boost in the Z-source stage, the voltage across the capacitor of Z-source is greater than thevoltage at the input.So,Z-capacitors havinghigh voltage are used, which causes to rise in the cost and system's volume.

2)The Z-source inverter cannot control the rush current and resonance at the Z-inductors and the Z-capacitors in the beginning, which produces surges in voltage and current and the device maybe destroyed.

The literature in this area focused mainly on strategies of modulation. To eliminate these limitations this paper presents a new ZSI topology known as Improved ZSI topology.

This paper is organized as follows: Section-1 presents introduction whereas section-2 presents traditional Z-Source Inverter Topology. Section-3 presents an Improved Z-Source Inverter Topology whereas section-4 presents comparative study of both ZSI Topologies. Section-5 presents simulation results and discussion andfinally, in section-6, the concluding remarks are provided.

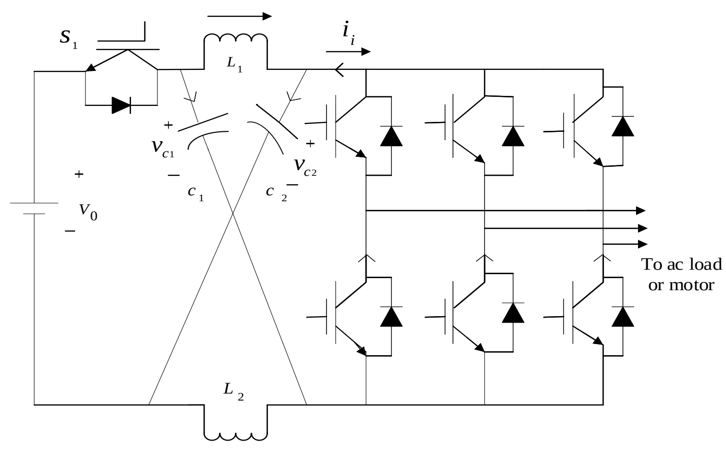

Figure-1 Basic structure of a Z-Source Inverter

II. TRADITIONAL Z-SOURCE INVERTER TOPOLOGY

A traditional Z-source inverter is a network of two-port that contains two inductors $L_1$and L_2 and two capacitorsC_1 and C_2connected in X shape is designed to have an impedance source (Z-source) coupled tothe converter (or inverter) to the dc source, load. Antiparallel combination is provided to the switches used in the converter can be a combination of diodes and switching devices.

A. Voltage Stress on Capacitor of Z-Source inverter

Let that the two inductors L_1andL_2 and two capacitorsC_1 andC_2 have the same inductance (L)and capacitance (C) values then the Z-source inverter becomes symmetrical.
The dc link voltage which is peak is described in [1], is expressed as

$$V_i = BV_o = \frac{1}{1-2D_o} V_o \quad (1)$$

Where the dc input voltage is V_o, B stands for the boost factor, Boost factor is given from the shoot-through ratio D_o. Voltage of the Z-capacitor is given by

$$V_{C1} = V_{C2} = V_C = \frac{1-D_O}{1-2D_O} V_O \quad (2)$$

From (2), V_c is not less than V_o, so voltage stress across Z-capacitor is high.

B. Startup Inrush Current

At the beginning of the ZSI, a huge inrush current occurs. The initial voltage of the Z-capacitors is zero, so the huge inrush current will charge the Z-capacitors immediately to 0.5V_o and starts the resonance at the Z-capacitors and the Z-inductors. This causes a large Z-inductor current and Z-capacitor voltage surge.

To overcome the limitations of the traditional ZSI, an improved Z-source inverter is presented in this paper. The figure-2 shows the topology of an improved Z-source inverter.

III. AN IMPROVED Z-SOURCE INVERTER TOPOLOGY

Figure-2 is the improved Z-Source Inverter topology. There are two inductors $L_1$and L_2 and two capacitors C_1 and C_2connected in X shape and is designed to have an impedance source (Z-source) present in the improved Z-source inverter same as in the traditional Z-source inverter. The diode and position of the inverter is exchanged and the direction is reversed. Stress of voltage across the Z-capacitor can be reduced when the polarity of voltage of the Z-capacitors in the improved ZSI is kept same as the voltage input polarity and obtain the boost voltage.

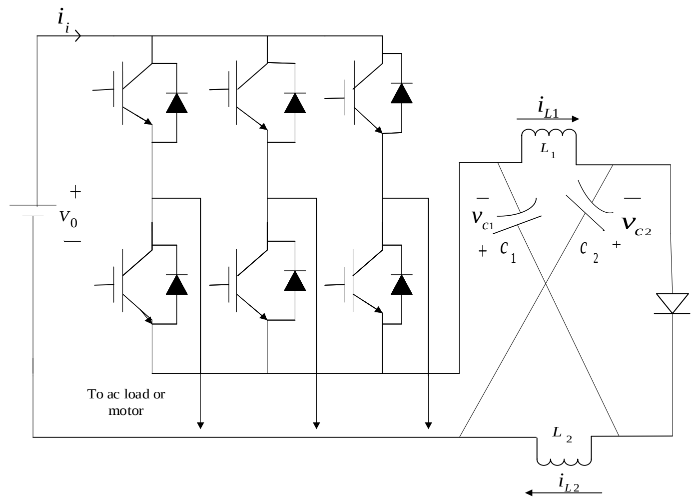

Figure-2 Improved Z-Source Inverter Topology

A. Operation Principle

As shown in figure-3 is the equivalent circuit of the improved Z-source inverter.
If $L = L_1 = L_2$,

$C = C_1 = C_2$(3)

Then $V_L = V_{L1} = V_{L2}, V_c = V_{c1} = V_{c2}$ (4)

Figure.3(a)is the equivalent circuit in the shoot-through state, the inverter side is shorted and is expressed as
$V_L = V_o + V_c$(5)
Figure.3(b) the equivalent source current at the side of an inverter is simplified in the non-shoot-through state. The inductor voltage is expressed as

$V_L = -V_c$(6)

The duty ratio in the shoot through state is $D_o$and on one switching period the average value of v_L is zero, the equation is given by

$$V_c = \frac{D_o}{1-2D_o} V_o (7)$$

The Z-source capacitor voltage $V_c$is equal to zero, when the duty ratio D_o in the shoot-through state is zero.
The peak dc-link voltage across the inverter phase legs and peak output phase voltage can be expressed as

$$V_{PN} = V_o + 2V_c = \frac{1}{1-2D_o} V_o = Bv_o (8)$$

$$V_p = M\frac{V_i}{2} = MB\frac{V_o}{2} (9)$$

where B is the boost factor determined by $D_o$is determined from the boost factor. Mis the modulation ratio. It can be seen from (8) derivation, theoutput is determined by the boost factor B ($B \geq 1$), thatis the same as the traditional ZSI topology.

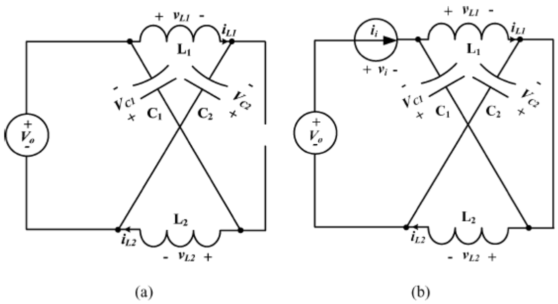

Figure-3 Equivalent circuit of an Improved Z-source inverter
3(a) Shoot-through state.
3(b) Non-shoot-through state.

IV. COMPARATIVE STUDY OF BOTH ZSI TOPOLOGIES

A. Voltage Stress and Ripple of Z-capacitor

The dc-link peak voltage can be determined as the duty ratio D_o in shoot-through state is given as

$V_i = \frac{1}{1-2D_O} V_O$ (10)

It is equal as in the traditional topology, and, V_C is determined as

$V_C = \frac{D_O}{1-2D_O} V_O$ (11)

When compared with (11), V_C is decreased by V_O when the same voltage boost is maintained. The conditions for the traditional ZSI and the improved ZSI are the same during the shoot -through state is that the current of Z-inductor discharges the Z-capacitor and the voltage ripple of the Z-capacitors is determined by

$\Delta V_C = \frac{I_L D_O T}{C}$ (12)

B. Current Ripple of Z-Inductor

The average currentof the Z-inductor is equal to the average input current, therefore, the average current of the Z-inductor for both topologies is same. At the non-shoot-through state, the current of the Z-inductor is reduced in the improved topology. The current ripple of Z-inductor is given by

$\Delta i_L = \frac{(1-D_O)TV_C}{L} = \frac{D_O(1-D_O)T V_C}{(1-2D_O)L}$ (13)

In shoot-through state, the current of theZ-inductor current is increased in traditional ZSI topology. The ripple current is given by

$\Delta i_L = \frac{D_O T V_C}{L} = \frac{D_O(1-D_O)T V_C}{(1-2D_O)L}$ (14)

From equations (13) and (14), it is observed that the ripple current is same for both traditional and improved topologies.

C. Input Current Ripple

The current at the input side of the ZSI is different for different control. For the traditional ZSI, the inverter bridge current is i_i, and the current at the input side is given by

$i_{in} = 2i_L - i_i$ (15)

The current at the input is zero in the shoot-through state. The zero state of traditional i_i is zero, i_{in} is $2i_L$. i_i is i_1 and i_2 which are the active states 1 and 2 respectively, i_{in} is $2i_L - i_1$ and $2i_L - i_2$, respectively, and the input current whose average is i_L.

The current fed to the inverter bridge is the input current and the input current in shoot-through state is $2i_L$ for the improved topology. The input current is zero in the zero state; in active state1 and 2, the input current is i_1 and i_2, respectively and the input current average is i_L in traditional ZSI.

V. SIMULATION RESULTS AND DISCUSSIONS

To realize the performance of improved Z-source inverter, the topology is simulated in MATLAB/Simulink environment. The Table-1 shows the system parameters.

Table – 1 System Parameters

S.No.	Description	value
1	Input voltage, V_o	200 volts
2	Z-Source inductor, $L_1 = L_2$	$500\mu H$
3	Z-Source capacitor, $C_1 = C_2$	$500\mu F$
4	Output inductive filter, L_f	$500\mu H$
5	Output capacitive filter, C_f	$10\mu F$
6	Resistive load, R	5Ω
7	Switching Frequency	10KHz

Figure-4shows the simulation waveforms of traditional ZSI topology and figure-4 shows the simulation waveforms of an improved ZSI topology, when $D_O = 0$ and $M = 0.8$. The waveforms shown are the current at the input side i_{in}, voltage of Z-capacitor V_c, voltage of dc-link V_i and current of Z-inductor i_L. In the topology of traditional, observation of V_c is equal to V_o in the stateof steady. In the beginning, severe inrush current occurs. A resonance at the Z-inductor and Z-capacitor occurs when V_c is charged and voltage and current surges occurs which cause damage to the converter.

In figure-5, at starting inrush current is avoided and in steady state V_c is equal to 0. The resonance at the Z-inductor and Z-capacitor are not considered.

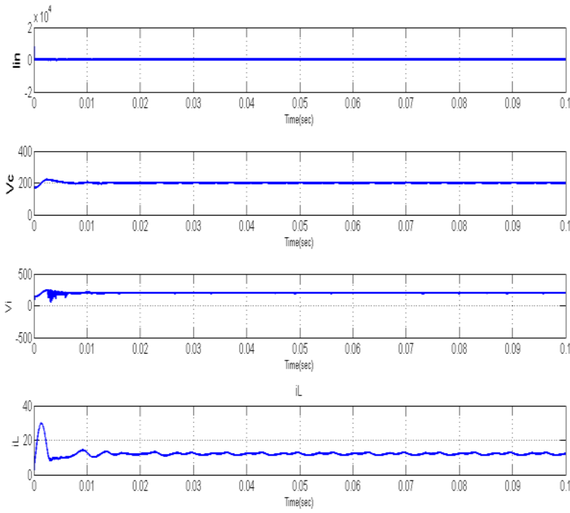

Figure-4 Output waveforms of the traditional ZSI topology

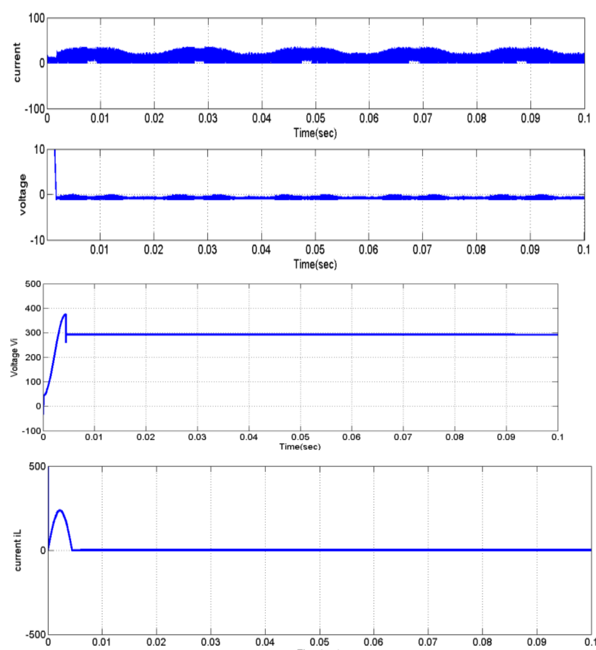

Figure-5 Output waveforms of an improved ZSI topology

VI. CONCLUSION

This paper presents an improved Z-source inverter topology in order to eliminate the drawbacks of traditional ZSI. From the simulation results it has been observed that the startup inrush current and the stress of voltage on the Z-capacitor has been reduced, which leads to reduction in volume and system cost.

REFERENCES

[1] F. Z. Peng, "Z-source inverter," *IEEE Trans. Ind. Appl.*, vol. 39, no. 2, pp. 504–510,Mar./Apr. 2003.

[2] F. Z. Peng, M. S. Shen, and Z. Qian, "Maximum boost control of the Z-source inverter," *IEEE Trans. Power Electron.*, vol. 20, no. 4, pp. 833–838, Jul. 2005.

[3] M. S. Shen, J.Wang, A. Joseph, F. Z. Peng, L. M. Tolbert, andD. J.Adams, "Constant boost control of the Z-source inverter to minimize current ripple and voltage stress," *IEEE Trans. Ind. Appl.*, vol. 42, no. 3, pp. 770–777, May/Jun. 2006.

[4] P. C. Loh, D. M.Vilathgamuwa,Y. S. Lai, G. T. Chua, andY.W. Li, "Pulsewidth modulation of Z-source inverters," *IEEE Trans. Power Electron.*, vol. 20, no. 6, pp. 1346–1355, Nov. 2005

[5] F. Z. Peng, A. Joseph, J.Wang, M. Shen, L. Chen, Z. G. Pan, E. O. Rivera, and Y. Huang, "Z-source inverter for motor drives," *IEEE Trans. PowerElectron.*, vol. 20, no. 4, pp. 857–863, Jul. 2005.

[6] F. Z. Peng, M. Shen, and K. Holland, "Application of Z-source inverter for traction drive of fuel cell-battery hybrid electric vehicles," *IEEE Trans.Power Electron.*, vol. 22, no. 3, pp. 1054–1061, May 2007.

[7] Y. Huang, M. Shen, F. Z. Peng, and J. Wang, "Z-source inverter for residential photovoltaic systems," *IEEE Trans. Power Electron.*, vol. 21, no. 6, pp. 1776–1782, Nov. 2006.

[8] P.C. Loh, D. M.Vilathgamuwa,G. J.Gajanayake,Y. R. Lin, andC.W. Teo, "Transient modeling and analysis of pulse-width modulated Z-source inverter," *IEEE Trans. Power Electron.*, vol. 22, no. 2, pp. 498–507, Mar. 2007.

[9] Y. Tang, S. J. Xie, and C. H. Zhang, "Z-source AC-AC converters solving commutation problem," *IEEE Trans. Power Electron.*, vol. 22, no. 6, pp. 2146–2154, Nov. 2007.

[10] M. S. Shen and F. Z. Peng, "Control of the Z-source inverter for fuel cell-battery hybrid vehicles to eliminate undesirable operation modes," in *Proc. IEEE IAS*, Oct. 2006, pp. 1667–1673.

[11] N. Muntean, L. Tutelea and I. Boldea, "A modified carrier - based PWM modulation technique in Z - source inverters," *2007 International Aegean Conference on Electrical Machines and Power Electronics*, Bodrum, 2007, pp. 174-180.

[12] Muhammad H. Rashid, "Power Electronics Handbook ", by Academic Press 2001.

[13] V Nagarjuna, M Phani Raju "Z-Source Inverter with Vector Control Strategy for Ac Drive Applications", SSRG International Journal of Electrical and Electronics Engineering (SSRG - IJEEE), V3(4), 26-30 April 2016. ISSN:2348 – 8379.

[14] Himanshu, Dr. Rintu Khanna, Dr. Neelu Jain "A Survey on Various Topologies of Z-Source Inverters", SSRG International Journal of Electrical and Electronics Engineering (SSRG - IJEEE), V3(7), 5-9 July 2016. ISSN:2348 - 8379.