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

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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, a comparison 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: Startup inrush 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 the voltage at the input. So Z-capacitors having high 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 and finally, in section-6, the concluding remarks are provided.

![Figure-1 Basic structure of a Z-Source Inverter](image-url)

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 capacitors \( C_1 \) and \( C_2 \) connected in X-shape is designed to have an impedance source (Z-source) coupled to the converter (or inverter) to the dc source, load. Antiparallel combination is provided to the switches
A. Voltage Stress on Capacitor of Z-Source inverter

Let that the two inductors $L_1$ and $L_2$ and two capacitors $C_1$ and $C_2$ 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

$$V_i = B V_o = \frac{1}{1 - 2D_0} V_o \quad (1)$$

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

$$V_{c1} = V_{c2} = V_c = \frac{1 - D_0}{1 - 2D_0} V_o \quad (2)$$

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 $C_2$ connected 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.

![Improved Z-Source Inverter Topology](image)

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 $V_2 = V_{l1} = V_{l2}$, $V_c = V_{c1} = V_{c2}$ (4)

Figure.3(a) is the equivalent circuit in the shoot-through state, the inverter side is shorted and is expressed as $V_c = V_o + V_c$ (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

$$V_l = -V_c \quad (6)$$

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

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

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

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

$$V_p = M \frac{V_o}{2} = MBV_o \quad (9)$$

where $B$ is the boost factor determined by $D_o$ is determined from the boost factor $M$ is the modulation ratio. It can be seen from (8) derivation, the output is determined by the boost factor $B$ ($B \geq 1$), that is the same as the traditional ZSI topology.
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 \( i_1 \), and the current at the input side is given by

\[
\dot{i}_{in} = 2i_L - i_1 \tag{15}
\]

The current at the input is zero in the shoot-through state. The zero state of traditional \( i_1 \) is zero, \( i_{in} \) is 2\( i_L \), \( i_1 \) is 1 and 2 which are the active states 1 and 2 respectively, \( i_{in} \) is 2\( i_L \)-\( i_1 \) and 2\( i_L \)-\( i_2 \), 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 2\( i_L \) for the improved topology. The input current is zero in the zero state; in active state 1 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**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Description</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Input voltage, ( V_o )</td>
<td>200 volts</td>
</tr>
<tr>
<td>2</td>
<td>Z-Source inductor, ( L_1 = L_2 )</td>
<td>500( \mu )H</td>
</tr>
<tr>
<td>3</td>
<td>Z-Source capacitor, ( C_1 = C_2 )</td>
<td>500( \mu )F</td>
</tr>
<tr>
<td>4</td>
<td>Output inductive filter, ( L_f )</td>
<td>500( \mu )H</td>
</tr>
<tr>
<td>5</td>
<td>Output capacitive filter, ( C_f )</td>
<td>10( \mu )F</td>
</tr>
<tr>
<td>6</td>
<td>Resistive load, ( R )</td>
<td>5( \Omega )</td>
</tr>
<tr>
<td>7</td>
<td>Switching Frequency</td>
<td>10KHz</td>
</tr>
</tbody>
</table>

Figure-4 shows 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 \( V_L \) and current of Z-inductor \( i_L \). In the topology of traditional, observation of \( V_c \) is equal to \( V_o \) in the state of 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.

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