Abstract - The Z-source inverter is an alternative power conversion topology that can both buck and boost the input voltage using passive components. With its unique structure, Z-source inverter can utilize the shoot through states to boost the output voltage, which improves the inverter reliability greatly, and provides an attractive single stage dc to ac conversion that is able to buck and boost the voltage. The shoot-through duty cycle is used for controlling the dc link voltage boost and hence the output voltage boost of the inverter. This paper focuses on step by step development of MATLAB/SIMULINK model of Z-source inverter followed by their harmonics study as compared to traditional inverters i.e. voltage and current source inverter. Analysis and simulation results will be presented to demonstrate that it reduces harmonics, electromagnetic interference noise and it has low common mode noise.

Index Terms - Shoot-through states, simulation, duty cycle and Z-source inverter.

I. INTRODUCTION

There exist mainly two types of traditional inverters:

- Voltage source (fed) inverters
- Current source (fed) inverters

Fig.1 shows the topology of the voltage source inverter. The input to the inverter is a dc voltage source usually with a capacitor in parallel to absorb the high frequency ripple. The inverter bridge consists of six switches with a freewheeling diode in parallel with each of them. The voltage source inverter has several limitations as listed below:

The output voltage range is limited; the inverter cannot output a higher voltage than the dc bus voltage. For many applications, when the input dc voltage is not always constant, like a fuel cell, photovoltaic array, and during voltage sag etc, a dc/dc boost converter is often needed to boost the dc voltage to meet the required output voltage. This increases the system complexity and the cost and reduces the system reliability.

The two switches on the same phase leg cannot be gated on the same time, otherwise a short-circuit will occur and destroy the inverter. The mistrigger caused by electromagnetic interference (EMI) is a major killer of the inverter. For safety reasons, there is always a dead time to make sure that the two switches will not be turned on simultaneously. However, the dead time can cause output voltage distortion and harmonic problems. The harmonic problem can be solved by implementing a current/voltage feedback control; however, this increases the system complexity.

The current source inverter is shown in Fig. 2. A dc current source feeds the main converter circuit, a three-phase bridge. The dc current source can be a relatively large dc inductor fed by a voltage source such as a battery, fuel-cell stack, diode rectifier. The inverter bridge consists of six switches with a reverse blocking diode in series or switches with reverse blocking capability. Three capacitors are connected at the ac side of the inverter to provide a leading power factor load.

The current source inverter has several limitations as listed below:

Current source inverter is basically a boost converter. For applications where a wide voltage range is required, extra circuitry has to be used to obtain the required voltage. However, this increases the circuit complexity and reduces the efficiency as well as the reliability.

At least one switch in the upper three devices and one in the lower three devices has to be turned on at the same time, or an open circuit will occur and destroy the inverter. Mistrigger caused by the EMI noise could significantly reduces the system reliability.

To make sure that there will be no open circuit, overlap time is often needed, which will cause output waveform distortion and low frequency harmonic problem. The switches of the current source converter have to block reverse voltage that requires a series diode to be used in combination with high-speed and high-performance transistors such as insulated gate bipolar transistors (IGBTs).
II. Z SOURCE INVERTER – AN INTRODUCTION

To overcome the problems associated with the traditional voltage source and current source inverters, this paper presents an impedance-source inverter (abbreviated as Z-source inverter) and its control method for implementing dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. Fig. 3 shows the general structure of Z-source inverter.

The traditional voltage and current source inverter has six active vectors (or switching states), 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. These total eight switching states and their combinations have spawned many PWM control schemes.

The Z-source inverter has an additional zero vector, the shoot-through switching state, which is forbidden in the traditional voltage and current source inverters. How to insert this shoot-through state becomes the key point of the control methods. It is obvious that during the shoot-through state, the output terminals of the inverter are shorted and the output voltage to the load is zero. The output voltage of the shoot-through state is zero, which is the same as the traditional zero states, therefore the duty ratio of the active states has to be maintained to output a sinusoidal voltage, which means shoot-through only replaces some or all of the traditional zero states. To describe the operating principle and control of the Z-source inverter consider the Z-source inverter structure shown in Fig. 4.

Fig. 4 Z-source inverter

Fig. 5 shows the equivalent circuit of the Z-source inverter shown in Fig. 4 when viewed from the dc link.

The inverter bridge is equivalent to a short circuit when the inverter bridge is in the shoot-through zero state, as shown in Fig. 6, whereas the inverter bridge becomes an equivalent current source as shown in Fig. 7 when in one of the six active states.
As described in [1], the voltage gain of the Z-source inverter can be expressed as,

\[ V_{ac} = M \cdot B \cdot \frac{V_0}{2} \]  

(1)

Where \( V_{ac} \) is the output peak phase voltage, \( V_0 \) is the input dc voltage, \( M \) is the modulation index, and \( B \) is the boost factor, which is determined by,

\[ B = \frac{1}{1 - 2D_0/T} \]  

(2)

Where \( T_0 \) is the shoot-through time interval over a switching cycle \( T \), or \((T_0/T) = D_0\) is the shoot-through duty ratio. The switching states sequence is shown in Fig. 8 and can be generated through carrier-based implementation.

Table I shows all the fifteen switching states of a three-phase-leg Z-source inverter.

<table>
<thead>
<tr>
<th>State (Output Voltage)</th>
<th>( S_1 )</th>
<th>( S_2 )</th>
<th>( S_3 )</th>
<th>( S_4 )</th>
<th>( S_5 )</th>
<th>( S_6 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active [100] (finite)</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Active [110] (finite)</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Active [010] (finite)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Active [001] (finite)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Active [011] (finite)</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Null [000] (OV)</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Null [111] (OV)</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Shoot-Through E1 (OV)</td>
<td>1</td>
<td>1</td>
<td>( S_1 )</td>
<td>( S_1 )</td>
<td>( S_6 )</td>
<td>( S_8 )</td>
</tr>
<tr>
<td>Shoot-Through E2 (OV)</td>
<td>( S_1 )</td>
<td>( S_1 )</td>
<td>1</td>
<td>1</td>
<td>( S_6 )</td>
<td>( S_8 )</td>
</tr>
<tr>
<td>Shoot-Through E3 (OV)</td>
<td>( S_1 )</td>
<td>( S_1 )</td>
<td>( S_1 )</td>
<td>( S_1 )</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Shoot-Through E4 (OV)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>( S_6 )</td>
<td>( S_8 )</td>
</tr>
<tr>
<td>Shoot-Through E5 (OV)</td>
<td>1</td>
<td>1</td>
<td>( S_1 )</td>
<td>( S_1 )</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Shoot-Through E6 (OV)</td>
<td>( S_1 )</td>
<td>( S_1 )</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Shoot-Through E7 (OV)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

III. SIMULINK MODEL AND RESULTS

The Matlab/Simulink software has used for the simulation of Z source inverter. The Simulink model has shown in Fig. 9 &10. The simulation results have shown in Fig. 11 & 12.
IV. PERFORMANCE ANALYSIS OF Z-SOURCE INVERTER

The method of comparing the effectiveness of modulation is by comparing the unwanted components i.e. the distortion in the output voltage or current waveform, relative to that of an ideal sine wave, it can be assumed that by proper control, the positive and negative portions of the output are symmetrical (no DC or even harmonics). The total harmonics distortion factor reduces to,

$$\text{THD} = \sqrt{\sum_{n=3,5,7} \left( \frac{V_n}{V_1} \right)^2}$$

(3)

Normalizing this expression with respect to the quantity (V₁) i.e. fundamental, the weighted total harmonic distortion (WTHD) becomes defined as

$$\text{WTHD} = \sqrt{\sum_{n=3,5,7} \left( \frac{V_n}{n \cdot V_1} \right)^2}$$

(4)

Taking the advantage of MATLAB, Z source inverter control system is built up, and the output line voltages are obtained by simulation.

Then the total harmonics distortion (THD) rate of those schemes is obtained by FFT method. In simulation the switching period is taken as 0.2ms, and the inverter output frequency is designed as 50Hz. The results of the simulation are shown in figure 12.

Fig. 12 shows the harmonic spectrum for the filtered output voltage for phase ‘a’. The spectrum shows that there is a fundamental component of the output voltage obtained at 50 Hz frequency and the magnitude is 114.427 r.m.s. (161.8242 peak) voltage. The THD is 0.02% of the fundamental and the WTHD is 0.02% of the fundamental. It shows that the quality of the output voltage is pure sinusoidal.
In this paper Z source inverter has studied and simulated and harmonic analysis has studied. Then with the help of Matlab/Simulink the scheme is simulated and their simulation results are obtained. The simulation results show that the output contains fundamental component at the 50 Hz frequency. The output voltage spectrum shows that the output contains single component at 50 Hz frequency. The performance of the scheme has evaluated on the basis of THD & WTHD and found that the output voltage quality is good and pure sinusoidal.

VI. REFERENCES


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