Abstract - Z-source neutral-point-clamped (NPC) inverter has been recently proposed as an alternative three-level buck-boost power conversion solution with an improved output wave form quality. In principle, the designed Z-source inverter functions by selectively "shooting through" its power sources, coupled to the inverter using two unique Z-source impedance networks, to boost the inverter three level output wave form. The theme of this paper is to propose a number of enhanced voltage-boost pulse-width modulation (PWM) strategies for controlling the Z-source NPC inverter. Lastly, simulation results are included for validating the performances and practicalities of the presented modulation schemes.

Keywords: Neutral-point clamped (NPC) inverters, Z-source inverters, PWM Schemes, THD.

I. INTRODUCTION
Conventional Voltage Source Inverters (VSI) and Current Source Inverters (CSI) are commonly used as the power electronic circuit for AC machine drives. For applications such as the AC drive system requiring the machine operating over a wide speed range, it is much preferable that the power converter has the buck-boost capability. A new type of power converter, i.e. Z source inverter (ZSI), with buck-boost capabilities has been recently proposed and studied. The AC voltage from ZSI can be controlled theoretically to any value. Simulation results using averaging modeling method. Space vector pulse width modulation (SVPWM) is widely used for variable frequency drive applications because of its various advantages such as the good DC utilization and less harmonics distortion in the output waveform.

II. Z-SOURCE INVERTER
The Z-source inverter consists of a Z-impedance network along with the inverter circuit. Fig.1 shows the circuit diagram of Z-source inverter. The Z-impedance network consists of L and C components connected in an X fashion. The firing control of the Z-source inverter includes the shoot through states. The Z-source inverter advantageously utilizes the shoot-through state to boost the DC bus voltage by gating on both the upper and lower switches of a phase leg. Fig. 3 shows the Z-source network during the shoot-through state. The inductor is energized and the inductor voltage increases due to the increasing current.

The general Z-source converter structure proposed. It employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, load, or another converter, for providing unique features that cannot be observed in the traditional V- and I-source converters where a capacitor and inductor are used, respectively.
The ZSI has three operation modes: normal mode, zero-state mode, and shoot-through mode. In normal mode and zero-state mode, the ZSI operates under the traditional PWM. In the shoot-through mode, the load terminals are shorted both the upper and lower switching devices of any phase legs. The dc capacitor voltage can be boosted to the desired value, and the shoot-through state is forbidden in the traditional inverter. To describe the operating principle and control, this paper focuses on an application. Assume the inductors (L1 & L2) and capacitors (C1 & C2) have the same inductance and capacitance values respectively.

Table 1 State Types of ZSI

<table>
<thead>
<tr>
<th>State Type</th>
<th>ON Switch</th>
<th>ON Diodes</th>
<th>( V_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non Shoot-through</td>
<td>S(_A1), S(_A2)</td>
<td>D(_1), D(_2)</td>
<td>(-V/2)</td>
</tr>
<tr>
<td>Non Shoot-through</td>
<td>S(_A2), S(_A1')</td>
<td>D(_1), D(_2), D(_A1) or D(_A2)</td>
<td>(0)</td>
</tr>
<tr>
<td>Non Shoot-through (not preferred)</td>
<td>S(_A1'), S(_A2')</td>
<td>D(_1), D(_2)</td>
<td>(-V/2)</td>
</tr>
<tr>
<td>Shoot-through (preferred)</td>
<td>S(_A1), S(_A2), S(_A1'), S(_A2')</td>
<td>D(_2), D(_B1)</td>
<td>(0)</td>
</tr>
</tbody>
</table>

III. SPACE VECTOR MODULATION TECHNIQUE
SSVPWM method is an advanced, Computation-intensive PWM method and is possibly the best among all the PWM techniques for variable speed applications. Because of its superior performance characteristics, it has been finding widespread application in recent years. Corresponding to the switching state, \( S_0 = \{ 0 \ 0 \ 0 \} \), \( S_1 = \{ 1 \ 0 \ 0 \} \), …, \( S_7 = \{ 1 \ 1 \ 1 \} \). \( v_1 \), \( v_2 \), \( v_3 \), \( v_4 \), \( v_5 \), \( v_6 \), \( v_7 \) are called active vectors, \( v_{0} \) and \( v_{7} \) are called traditional zero vectors. The length of the active vectors is unity and length of the zero vectors is zero. These two nearest active vectors and the traditional zero vectors are used to synthesize the output voltage vector. \( v_{n} \) and \( v_{n+1} \) (Where \( n = 0, …, 6 \)) vectors are applied at times \( T_1 \) and \( T_2 \) respectively, and zero vectors are applied at \( T_z \) times. For example in sector 1, vector \( V \) can be synthesized as,

\[
v = \frac{T_1}{T_s} v_1 + \frac{T_2}{T_s} v_2 + \frac{T_z}{T_s} (v_0 \text{ or } v_7)
\]

Where \( 2nr \ # i = \text{wt} \ # 2nr + \frac{r}{3} \)

\[
T_1 = \frac{2}{\sqrt{3}} v \cos i + \frac{r}{6} T_s
\]

\[
T_2 = \frac{2}{\sqrt{3}} v \cos i + \frac{3r}{2} T_s
\]

\[
T_z = T_s - T_1 - T_2 = \frac{1}{6} - \frac{2}{\sqrt{3}} v \cos i + \frac{r}{3} T_s
\]

The trajectory of voltage vector \( V \) should be a circular while maintaining pure sinusoidal output line–to-line voltages.

This limitation of the length of the active vector affects the smooth operation of loads like motor drives where overdrive is desired.

IV. MODIFIED VOLTAGE SPACE VECTOR MODULATION FOR Z-SOURCE INVERTERS
For a three-phase-leg two level VSI, both continuous switching (e.g., centered SVM) and discontinuous switching (e.g., 60 – discontinuous PWM) are possible with each having its own unique null placement at the start and end of a switching cycle and characteristic harmonic spectrum. The same strategies with proper insertion of shoot through modes could be applied to the three-phase-leg Z–source inverter with each having the same characteristic spectrum as its conventional counterpart [3]. There are fifteen switching states of a three-phase-leg z-source inverter.

\[
\text{max}(sp) \text{ max off } V = V + V + T
\]

\[
\text{max}(sn) \text{ max off } V = V + V
\]

\[
\text{mid (sp) mid off } V = V + V
\]

\[
\text{mid (sn) mid off } V = V + V - T
\]

\[
V_{\text{min}}(sn) = V_{\text{min}} + V_{\text{off}} - 2T
\]

\{sp, sn\} = \{1, 4\}, \{3, 6\}, \{5, 2\}

Where \( 3 \), \( T \) = shoot through duty ratio.

a) Modulation Development for Three Level Z Source Inverter:
b) Modified Reference Modulated Technique (SVPWM):
In the SPWM scheme for two-level inverters, each reference phase voltage is compared with the triangular carrier and the individual pole voltages are generated, independent of each other. To obtain the maximum possible peak amplitude of the fundamental phase voltage, in linear modulation, a common mode voltage, Voffset1, is added to the reference phase voltages, where the magnitude of Voffset1 is given by

\[ V_{\text{offset1}} = \frac{V_{\text{max}} + V_{\text{min}}}{2} \]  

(4.1)

V. SIMULATION RESULTS
The 3-phase two-level and Three level Z source inverter configurations are simulated using MATLAB-SIMULINK tool box. The parameters used for z source inverter are given in the appendix. Different parameters which are considered for input voltage, voltage across capacitor, Inverter gain output voltage, line voltage and harmonic spectra etc…

i) Non Shoot-Through State for Three Level SPWM At K=0

Fig.9. InputVoltage
Fig.10. Voltage across Capacitor
Fig.11.Inverter Gain Output Voltage
Fig.12. Line Voltage for 3-level ZSI
Fig.13. Line voltage THD

ii) Non Shoot-Through State for Three Level Modified SVPWM at k=0

Fig.14.Voltage across Capacitor
Fig.15.Inverter Gain Output Voltage
Shoot Through PWM control Strategies for Three Level Z source Inverter

Fig.16. Line Voltage for 3-level ZSI

Fig.17. Line voltage THD

iii) Shoot-Through State for Three Level SPWM at K=0.2

Fig.18. Voltage across Capacitor

Fig.19. Inverter Gain Output Voltage

Fig.20. Line Voltage

Fig.21. Line voltage THD

iv) Shoot-Through State for Three Level Modified SVPWM at K=0.2

Fig.22. Voltage across Capacitor

Fig.23. Inverter Gain Output Voltage

VI. COMPARISON OF THD FOR DIFFERENT PWM TECHNIQUES OF 3-PHASE 3-LEVEL Z SOURCE INVERTER

Table 2. Simulation parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Specifications</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC supply</td>
<td>200</td>
<td>V</td>
</tr>
<tr>
<td>Modulation Index</td>
<td>0.866</td>
<td>-</td>
</tr>
<tr>
<td>Output Frequency</td>
<td>50</td>
<td>HZ</td>
</tr>
<tr>
<td>Switching Frequency</td>
<td>1000</td>
<td>HZ</td>
</tr>
<tr>
<td>Shoot through</td>
<td>0.2</td>
<td>-</td>
</tr>
<tr>
<td>$C_1=C_2=C$</td>
<td>1000</td>
<td>μF</td>
</tr>
<tr>
<td>$L_1=L_2=L$</td>
<td>1</td>
<td>mH</td>
</tr>
<tr>
<td>Load</td>
<td>10</td>
<td>Ω</td>
</tr>
</tbody>
</table>

Table 3. comparison of results for 3-level ZSI

<table>
<thead>
<tr>
<th>Switching state</th>
<th>SPWM</th>
<th>Modified SVPWM</th>
<th>Boost factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Non Shoot-through (K=0)</td>
<td>49.78</td>
<td>45.51</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45.1</td>
<td>51.63</td>
<td>44.23</td>
</tr>
<tr>
<td>Shoot-through (K=0.2)</td>
<td>80.44</td>
<td>36.86</td>
<td>83.12</td>
</tr>
<tr>
<td></td>
<td>38.6</td>
<td>83.12</td>
<td>32.00</td>
</tr>
<tr>
<td></td>
<td>32.0</td>
<td>83.12</td>
<td>1.67</td>
</tr>
</tbody>
</table>

Note: By increasing the Switching Frequency THD will decreases. Generally Switching Frequency is chosen in this paper is 1KHZ but by using high switching frequency we will get the THD <5%.

VII. CONCLUSION

A summary of THD and fundamental output voltage for various Z Source inverter topologies with their control strategies are presented. i.e, 3-Level Z source inverter was simulated for SPWM and modified SVPWM with triangular carrier. And it is concluded that 3-level z source inverter has given
good fundamental output voltage (83.12V) with less THD (32.00%).

VIII. REFERENCES


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