

A Comparative Study on the various topologies used for Z-source Inverter

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Abstract

-There has been several research leading to the development of the new topologies that overcomes the existing drawbacks of the 3-phase Voltage source Inverters. Z-source Inverters has an aided advantage over the traditional VSIs. Apart from the advantages, there has been certain concerns regarding the Z-source Inverter, which, has been handled by the improved Z-source inverter topology. Realization of the Improved Z-source Inverter shall be conducted with the implementation of the various control methods with the different PWM techniques so as to enhance and maximize the efficiency of the topology and to reduce the voltage stress and minimize the inrush current at start-up. This paper will give an insight of the proposed work that has to be done during the course of the time.

Keywords: ZSI, IZSI, boost control

I. INTRODUCTION

Due to the limitations of the Voltage and Current Fed Inverter topologies, Z-source Inverters has come to existence. As described and shown in fig 1, the Voltage Source or a Voltage fed Inverters uses a parallelly connected Capacitor along with a constant Voltage Source. Whereas the Current source or Current fed Inverter uses a power source that has a constant current which is filtered by a series inductor as shown in fig 2.

Considering the voltage fed Inverters, each switch has to able to withstand the unidirectional voltage generated and has to permit the bidirectional current flow and hence an antiparallel combination of transistor and diode is commonly implemented which has been illustrated in the fig 1.

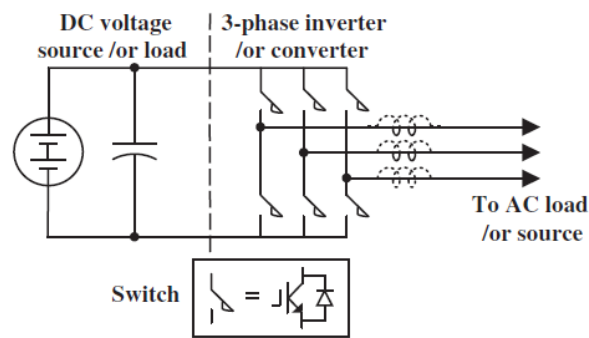


fig 1: Traditional 3-Phase VSI

And in case of Current fed Inverters, each switch has to withstand the Bidirectional Voltage generated and permit the unidirectional current and for this purpose, a reverse blocking switch or a series combination of transistor and diode can be implemented as shown in fig 2.

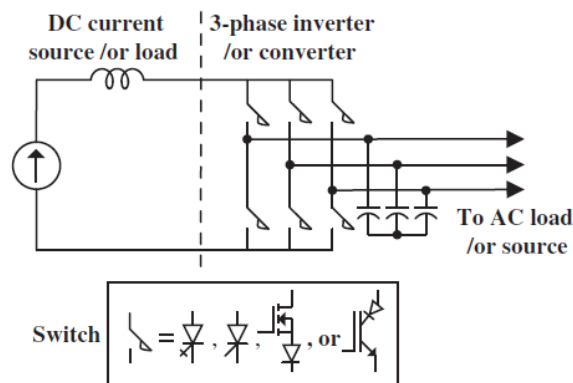


fig 2: Traditional 3-Phase CSI

On the basis of the Analysis, it is imperative to notice that both these topologies of Inverters has failed to achieve certain parameters such as their intolerance towards Electromagnetic Interference (EMI) making them un-reliable and the ability to operate as both Buck-Boost and thereby limiting their output voltage range from either lower to higher.

A generalized Z-source inverter has been shown in fig 3., which has been introduced to the field of power electronics which is able to eradicate the major drawbacks of the traditional VSIs and CSIs and can operate for both Buck-Boost Operations so thereby making the system more reliable.

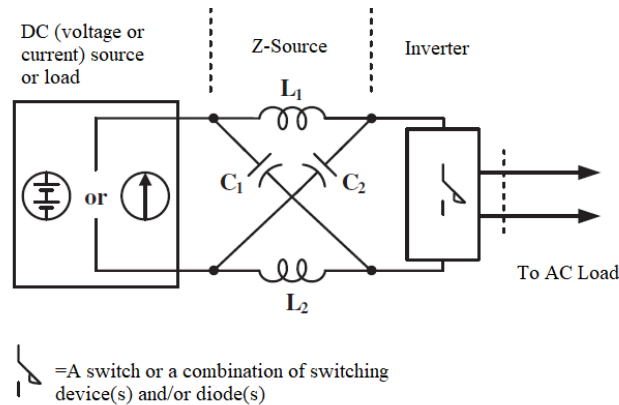


fig 3: Generalized representation of Z-Source Inverter

On the basic understanding, Z-source is a two-terminal network which is composed of two inductors and two capacitors connected as shown in the fig 3, in such a way that it can provide an impedance network connected in between the DC source to the inverter bridge. The great and significant trait of a Z-source inverter is that unlike the traditional voltage source or current-source inverters, it can be short and open circuited that provides a mechanism for the main converter circuit to step-up (boost) and step-down (buck) voltage as desired.

The Z-source network provides great flexibility for coupling the source, main switch network, and load:

- a. A Z-source converter can be injected by using a voltage source or a current source. Therefore, a battery, diode rectifier, thyristor converter, fuel cell stack, inductor, capacitor, a source with a switch network, or a combination of the above can be used as the DC source for the network.
- b. A voltage-source configuration (fig 1) or a current-source configuration (fig 2) can act as the main switch network of a Z-source converter.
- c. A inductive, capacitive, or another Z-source network can be implemented as the load of a Z-source converter as shown in fig 4.[1-20]

Limitations of the Voltage fed Inverters and Current Fed inverters can be tabulated as shown below:

Parameters	Voltage Fed Inverters	Current Fed Inverters
Type of Load or Source	An AC Inductive Load or AC inductive Source has to be used for proper functioning.	An AC Capacitive Load or Capacitive AC Source is a must for proper operation.
Amount of Voltage Generated	AC output voltage is diminished in comparison to the magnitude of the DC input voltage (i.e., Only performs the Step down or Buck Operation)	AC output voltage is always more than the input DC source (i.e., Only performs the Step up or Boost Operation)

Switching Patterns	Simultaneous triggering of both lower and upper switches of each phase may incur shoot-through which may in turn destroy the switches.	To prevent the open circuit across the DC inductor and to prevent the devices from being damaged, atleast one switch from both the upper and lower has to be turned on simultaneously.
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Table 1: Comparison between the VSI and CSI.

The voltage fed Z-source Inverter can be explained as follows:

- a. Compared to the traditional VSI, ZSI with DC voltage source has 9 switching states, while a traditional 3-phase VSI will have eight switching states.

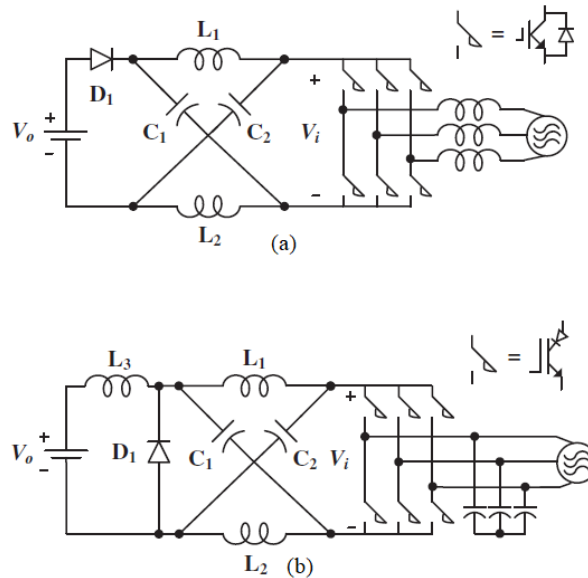


fig 4: (a) Voltage-fed ZSI with discontinuous input current. (b) Current-fed ZSI with continuous input current.

- b. The ZSI bridge will have one extra zero state when the load terminals are shorted through both upper as well as lower switches of phase branches. This third null state is called the shoot-through zero state, which may be achieved by seven unique methods:
 - i. Short circuit any one phase branch,
 - ii. any two-phase branches, and
 - iii. all three-phase branches.
- c. In the traditional voltage-source inverter, the shoot-through zero state is taken into consideration because it would cause a shoot-through and damage the switches, but in case of the Z-source Inverter configuration, the shoot-through zero state is possible for use, which provides the additional buck-boost feature to the inverter.

When the ZSI bridge is in the third null state, its equivalent configuration can be depicted as shown in Figure 5, whereas when the ZSI bridge operates in any other switching states rather than the shoot-through state, the configuration can be depicted as shown in Figure 6.

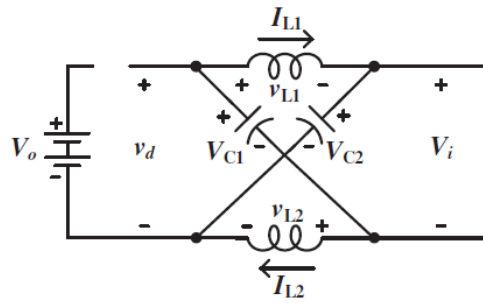


fig 5: Equivalent circuit of the Z-source inverter viewed from the DC side when the inverter bridge is in the shoot-through zero state.

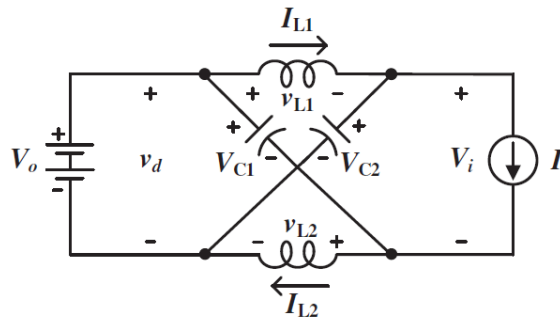


fig 6: Equivalent circuit of the Z-source inverter viewed from the DC side when the inverter bridge is in one of the eight traditional (nonshoot-through) switching states.

Pulse width modulation (PWM) switching methods can be implemented to control the Z-source inverter as implemented over traditional VSI and input output correlation remains the same.

With the passage of time, certain modifications have been made to enhance the overall quality, cost and efficiency of the Z-source Inverters. And this report will show the enhancements and modifications and an effort will be made to determine the most efficient and cost effective model till date, and finally sorting the enhancements that can be done on the model for further upholding of the model.[21-32]

II. OVERVIEW OF TOPOLOGIES

1. **Fang Zheng Peng**, in his paper “Z-Source Inverters” describes about all the different types of control methods of Z-Source Inverters along with some of the practical implementations of this Inverters, along with the implementation of Quasi-Z-Source Inverter and its implementations.[1]
2. **Fang Zheng Peng**, in his paper “*Maximum Boost Control of the Z source Inverter*” discusses the maximum Boost control scheme for the Voltage fed Z-source Inverter and compares the variations of voltage boost with respect to modulation index and voltage stress versus voltage gain are analysed and verified. He varied the modulation index from 0.88 to 1.1(attained by using Third harmonic injection) with the input voltage from 170V to 250V and the observations were made during the period $\pi/6$ to $\pi/2$ as the shoot through state was repeating periodically every $\pi/3$.[2]
3. **Miaosen Shen**, in his paper “*Constant Boost Control of the Z source Inverter to minimize Current Ripple and Voltage stress*” introduces the Maximum constant boost control method, by which one can achieve maximum voltage boost at any modulation index without any introduction of low-frequency disturbances in the configuration and in turn reduces the voltage stress on the switches as well as the

capacitors. The requirement of lesser number of passive elements is also one of the major advantages of the Constant Boost control Method.[3]

4. **Yuan Li**, in his paper “*Quasi Z-source Inverter for Photovoltaic Power Generation Systems*” discusses implementation of qZSI for the photovoltaic Systems due to its lower component ratings and constant dc current from the source. As per the control topologies, qZSI can be triggered similarly to the ZSI. qZSI can operate both buck-boost operation working as an inverter, and power conditioning can be done in its single stage with higher reliability. [4]
5. **Yu Tang**, in his paper *Improved Z-Source Inverter with reduced Z-source Voltage Stress and Soft start Capability* introduces a new topology which can minimize the Z-source capacitor voltage stress as well limit the inrush current at start-up, for the same voltage boost. Even a soft-starting strategy has been proposed to limit inrush current and the resonance of Z-Source capacitors and inductors without not much further changes in the operating principles and modulation techniques, which is exactly the same with the traditional ZSI.[5]
6. **Yu Tang**, in his paper “Pulse width Modulation Z-source Inverters with minimum Inductor Current ripple” introduces the PWM technique implemented to the Z-source inverters which holds the minimal inductor current transients. The shoot-through time period of three phase branches are calculated in the technique and accordingly, they are rearranged to obtain the
7. minimal current transients across the Z-source inductor, without affecting the total shoot-through time interval.[6]
8. **Himanshu Sharma**, in his paper “*Comparative analysis of a novel topology for single-phase Z-source inverter with reduced number of switches*” proposed a new topology for the Z-source Inverter so as to reduce the number of passive elements and active switches in order to achieve a low cost and compact size of the ZSI.
9. **Aman Sharma**, in his paper “*Buck-Boost Operation Using a Z-Source Inverter*” explains the Buck-Boost operation of the Z-source Inverter.
10. **Quang-Vinh Tran**, in his paper *Algorithms for Controlling Both the DC-Boost and AC Output Voltage of Z-Source Inverter* introduces an algorithm that is implemented to linearly control the Z-source capacitor voltage in turn to the overall transient response

Type of topology	Number of passive elements and switches	Remarks
Z-source Inverter	2L,2C,1D,6S	Better voltage regulation and reduced voltage stress compared to the Traditional Multilevel Inverters
Improved Z-source Inverter	2L,2C,1D,6S	Improved reliability and low inrush inductor current at startup due to the specific change in the configuration.
Quasi Z-source Inverter	2L,2C,1D,6S	Has continuous input current, reduced source stress, and

		lower component ratings and hence the cost
Novel topology of Single phase Z-source Inverter	2L,1C, 2S	Due to the lesser number of components the topology is cost effective

where L, C, D and S denotes Inductor, Capacitor, Diode and switch respectively

III. COMPARISION OF THE CONTROL METHODOLOGIES

The control methodologies that are implemented for the control of the switching in the ZSI topologies are Simple-boost Control, Maximum-boost Control and Maximum-constant Boost Control Method.

- 1. Simple Boost Control:**It uses two references whose magnitudes is either greater than or at par with the maximum value of three phase reference for controlling shoot-through duty ratio in a sinusoidal PWM. The simple boost control waveforms can be depicted by:

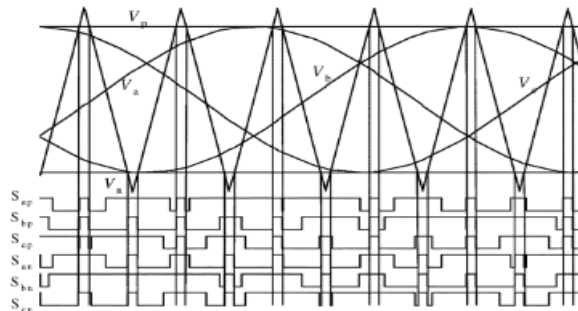


fig 7: simple boost control waveforms

- 2. Maximum Boost Control:** In this method of control, all active states remain unchanged while the null states get altered into shoot-through zero states. The waveforms for this control can be depicted by:

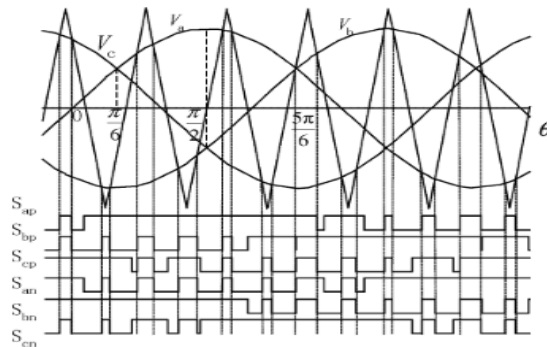


fig 8: Maximum Boost Control Waveforms

- 3. Maximum Constant Boost Control:** This control method implements the use of three reference signals along with two shoot-through envelope signals. The waveforms relating the Maximum constant boost control method can be depicted in figure 9.

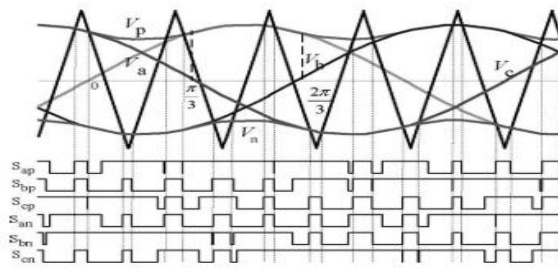


fig 9: Maximum constant boost control waveforms

The Voltage boost vs. Modulation index curves for the control methods implemented for the ZSI is depicted in the figure 10.

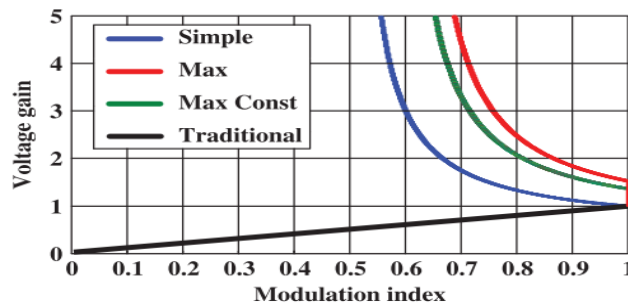
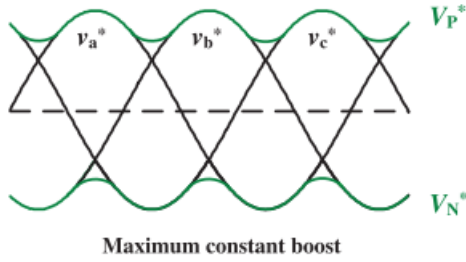


fig 10: comparison of Voltage gain vs. Modulation Index curves for the different topologies of ZSI

The comparison of the control methods can be tabulated as

Control Method	No. of reference signals	Reference signals used in the method	Modulation Index at 50% shoot-through state
Simple Boost Control	Two constant reference signals whose magnitude is either greater than or at par with the peak values of the voltage references	<p>Simple boost</p>	0.50
Maximum Boost Control	It uses the peak envelope of the three phase voltage references, which, results in the short circuit of the entire zero-states to achieve the maximum voltage boost corresponding to every modulation index.	<p>Maximum boost</p>	$\frac{\sqrt{3}\pi}{9} = 0.605$

<p>Maximum Constant Boost Control</p>	<p>It uses two envelope signals to produce the maximum and constant shoot-through duty cycle.</p>		<p>$\sqrt{3}/3=0.577$</p>
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IV. FUTURE ASPECTS OF RESEARCH

It is evident to check out all the advantages and disadvantages of the several topologies that are proposed for the Z-source Inverter. Even with all the research on this topic, there has been lacking of research on certain sections of the topologies, its implementation.

The implementation of the simple boost control has only been implemented over the improved Z-Source Inverter and the outcomes almost up to the content provided by the traditional Z-Source with minimal cost and reliability in accordance with minimal voltage stress, for the same boost capability.

There is a possibility of further research on

- a. decreasing the voltage stress on the switches by implementing the maximum boost control method and maximum constant boost control methods with the improved Z-source Inverter topology.
- b. Enhancing the reliability of the improved Z-source Inverter by using the PWM modulation technique to minimize the inductor current and thereby accompanied by the several control methods to enhance the overall performance of the topologies, in terms of economics, switch count and reliability.

V. CONCLUSION

Implementations of the Improved Z-source Inverters has been implemented over the MATLAB simulation software to understand Traditional Z-Sourced inverter and the Improved Z-source inverter with the various control methods:

- a. Simple-boostcontrol Method
- b. Maximum-boostcontrol Method
- c. Constant-boost control Method

Apart from this Quasi Z-source Inverters topologies, were also implemented to, so, as to check the significant changes and modifications that can be either the topologies so as to make a change to the for achieving the certain Goals:

- a. Higher Reliability of the Z-source Inverter.
- b. Minimum inrush inductor current at start-up.
- c. Minimize the overall cost of the Inverter.

Moreover, it can be concluded that Improved Z-source Inverter, can be preferred for the overall cost effectiveness, but certain progress can be made by the implementation of the various control methods as cited above.

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