Comparison of Traditional Inverters with ZSI and Simulation of Maximum Boost Control Method of ZSI

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Abstract— In this paper, two traditional inverters (Voltage source inverter & Current source inverter) are compared with newly introduced Zero Source Inverter (Zsi).As per the topology of Converters, Voltage source converter has a capability of increasing the output as per requirement of condition and it works as a boost converter. Also voltage source inverter has a capability of step-down the output and works as a buck inverter. On other hand, Opposite to the voltage source converter topologies, current source converter has a capability of step-down the output and works as a buck converter. Where Current source inverter has a capability that it can be increasing the output as per requirement. This newly introduced design which is Zero source converter design has a capability of both voltage source and current source converter. That mean, it can be step up and step down the output as per design consideration and requirement and providing unique features that cannot be obtained in the traditional voltage-source(or voltage-fed) and current-source (or current-fed) inverters where a capacitor and inductor are used, respectively In traditional voltage source converter and current source converter a capacitor and inductor are used respectively. But in ZSI, both capacitor and inductor are used for Buck and Boost process. The Z Source converter overcomes the conceptual and theoretical barriers and limitations of Traditional voltage source and current source converter. The Z-Source concept can be applied to all DC-TO-AC, AC-TO-DC, AC-TO-AC, DC-TO-DC power conversion. This paper describes Inverter mode of voltage source converter, current source converter and Zero source converter. Also the comparison of three of them. There are three control modes of ZSI out of which analysis and simulation of Simple boost control method of ZSI is demonstrated in this paper.

Key words: ZSI, Traditional Inverters

I. Introduction

The main objective of static power converters is to produce an AC output waveform from a dc power supply. There are two traditional converters:

1) Voltage source converter
2) Current source converter

Voltage source converter: - Fig. 1.1 shows the traditional three-phase voltage source inverter structure. There are six switches are used in the main circuit. Each is traditionally composed of a power transistor and an anti parallel (or freewheeling) diode to provide bidirectional current flow and unidirectional voltage blocking capability. A dc voltage source supported by a relatively large capacitor feeds the main converter circuit, a three-phase bridge. The dc voltage source can be a battery, fuel-cell stack, diode rectifier, and/or capacitor. Widely voltage source inverter is used. [1]

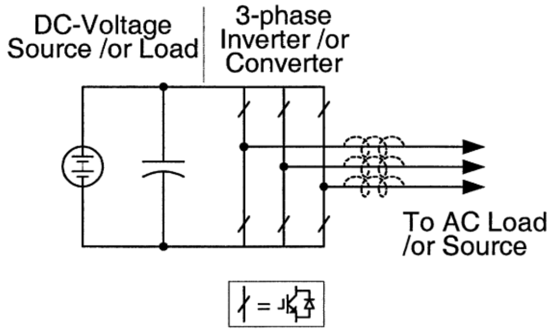


Fig. 1: Traditional Voltage source converter

Current source converter: - Fig. 1.2 shows the traditional three phase current-source inverter structure. 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, or thyristor converter Six switches are used in the main circuit, each is traditionally composed of a semiconductor switching device with reverse block capability such as a gate-turn-off thyristor (GTO) and SCR or a power transistor with a series diode to provide unidirectional current flow and bidirectional voltage blocking.[1]

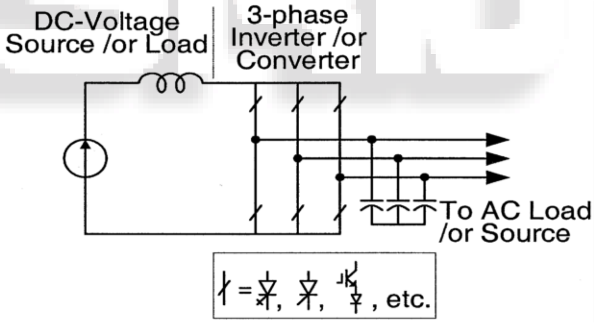


Fig. 2: Traditional Current source converter

II. Limitations

A. Limitation of traditional V-Inverter:

1) The ac output voltage is limited below and cannot exceed the dc-rail voltage or the dc-rail voltage has to be greater than the ac input voltage. Therefore, the V-source inverter is a buck (step-down) inverter for dc-to-ac power conversion and the V-source converter is a boost (step-up) rectifier (or boost converter) for ac-to-dc power conversion.
2) An additional dc-dc boost converter is needed to obtain a desired ac output. Where a wide voltage range is desirable, the additional power converter stage increases system cost and lowers efficiency.
3) An output LC filter is needed for providing a sinusoidal voltage compared with the current-source inverter, which causes additional power loss and control complexity.

4) Main limitation is that, the upper and lower devices of each phase leg cannot be gated on simultaneously either by purpose or by EMI noise. Otherwise, a shoot-through would occur and destroy the devices. The shoot-through problem by electromagnetic interference (EMI) noise's mis-gating-on is a major killer to the converter's reliability. Dead time to block both upper and lower devices has to be provided in the V-source converter, which causes waveform distortion, etc.[1]

B. Limitation of traditional V-Inverter:

1) The ac output voltage has to be greater than the original dc voltage that feeds the dc inductor or the dc voltage produced is always smaller than the ac input voltage. Therefore, the current source converter is a boost inverter for **dc-to-ac** power conversion and the current source converter is a buck rectifier (or buck converter) for **ac-to-dc** power conversion.
2) An additional dc-dc boost converter is needed to obtain a desired ac output. Where a wide voltage range is desirable, the additional power converter stage increases system cost and lowers efficiency.
3) The main switches of the I-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). This prevents the direct use of low-cost and high-performance IGBT modules and intelligent power modules (IPMs).
4) At least one of the upper devices and one of the lower devices have to be gated on and maintained on at any time. Otherwise, an open circuit of the dc inductor would occur and destroy the devices. The open-circuit problem by EMI noises mis-gating-off is a major concern of the converter's reliability. Overlap time for safe current commutation is needed in the I-source converter, which also causes waveform distortion, etc.[1]

In addition, both the V-source converter and the I-source converter have the following common problems.

They are either a boost or a buck converter and cannot be a buck–boost converter. That is, their obtainable output voltage range is limited to either greater or smaller than the input voltage.

Their main circuits cannot be interchangeable. In other words, neither the V-source converter main circuit can be used for the I-source converter, or vice versa.

They are vulnerable to EMI noise in terms of reliability

III. Z SOURCE INVERTER

To overcome the above problems of the traditional V-source and I-source converters, this paper presents an impedance source (or impedance-fed) power converter (abbreviated as Z-source converter) and its control method for implementing dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion.

The configuration of Z-source inverter is shown in fig. 3. It consists of 2 identical inductors and 2 identical capacitors in X shape are employed to provide an impedance source (Z-source) coupling the converter (or inverter) to the dc source, load, or another converter.

The dc source or load can be either a voltage or a current source or load. Therefore, the dc source can be a battery, diode rectifier, Thyristor converter, fuel cell, an inductor, a capacitor, or a combination of those. Switches used in the converter can be a combination of switching devices and diodes such as the anti parallel combination as shown in Fig.

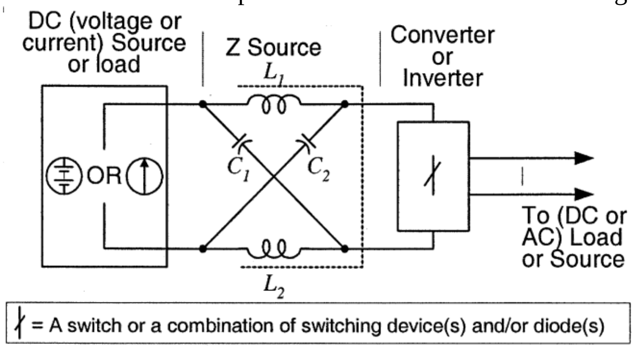


Fig. 3: General structure of Z-Source inverter

It employs a unique impedance network 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. Z-source inverter can boost dc input voltage with no requirement of dc-dc boost converter or step up transformer, hence overcoming output voltage limitation of traditional voltage source inverter as well as lower its cost.

A comparison among conventional PWM inverter and Z-source inverter shows that Z-source inverter needs lowest semiconductors and control circuit cost, which are the main costs of a power electronics system. The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion.

The traditional VSI has six active vectors and two zero vectors. However, Z-source Inverter Bridge has one extra zero state vector. The unique feature of Z-source inverter is that it can be used as buck-boost inverter that as wide range of obtainable voltage. The traditional V- and I-source inverters cannot provide such feature. For the traditional V-source inverter, the dc capacitor is the sole energy storage and filtering element to suppress voltage ripple and serve temporary storage.

For the traditional I-source inverter, the dc inductor is the sole energy storage/filtering element to suppress current ripple and serve temporary storage. The Z-source network is a combination of two inductors and two capacitors. This combined circuit, the Z-source network is the energy storage/filtering element for the Z-source inverter. The Z-source network provides a second-order filter and is more effective to suppress voltage and current ripples than capacitor or inductor used alone in the traditional inverters. Therefore, the inductor and capacitor requirement should be smaller than the traditional inverters.[1]

Current Source Inverter (CSI)	Voltage Source Inverter (VSI)	Impedance Source Inverter (ZSI)
As inductor is used in the d.c link, the source Impedance is high; a constant current source is realized.	As capacitor is Used in the d.c link, it acts as allow impedance voltage source.	As capacitor and Inductor are used in the d.c link, it acts as a constant high impedance voltage source.

A current source inverter is capable of withstanding short circuit across any two of its output terminals hence momentary short circuit on load and mis-firing of switches are acceptable.	A VSI leads to more dangerous situation as the parallel Capacitor could feed more power in to the fault.	In ZSI mis-firing of the switches may be acceptable.
Used in boost operation of the inverter.	Used in a buck mode of operation of the inverter.	Used in both buck and boost operating modes of the Inverter.
Affected by the EMI noise.	Affected by the EMI noise.	Less affected by the EMI noise. Impedance Source act as a filter
Considerable amount of harmonic distortion	Considerable Amount of harmonic Distortion	Harmonics distortion is low

IV. CONTROL METHODS

There are a number of control methods which have been presented so far to control Z-source inverter, mainly there are three control methods for Z-source inverter.

1) Simple boost control method
2) Maximum boost control method
3) Maximum constant boost control method

Now, new mordant control method also used

1) Space vector pulse with modulation
2) Modified space vector pulse with modulation

Here is the Maximum boost control method of Z-source inverter and its analysis with simulation.

V. MAXIMUM BOOST CONTROL METHOD [2]

Fig.4 shows the maximum boost control strategy. It is similar to the traditional carrier-based PWM control method. The point is this control method maintains the six active states unchanged and turns all zero states into shoot-through states. Thus maximum *to* and *B* are obtained for any given modulation index *M* without distorting the output waveforms.

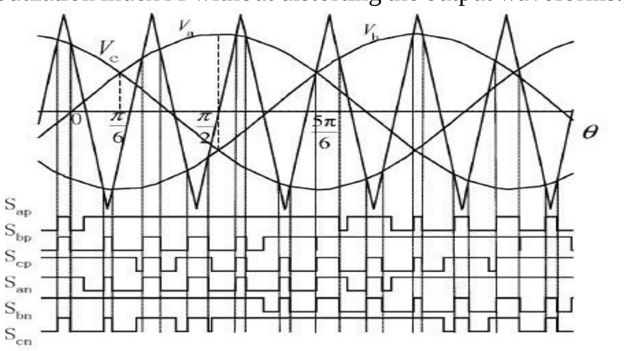


Fig. 4: Maximum boost control method

As can be seen from Fig, the circuit is in shoot-through state when the triangular carrier wave is either greater than the maximum curve of the references (*V*a, *V*b, *V*c) or smaller than the minimum of the references. The shoot-through duty cycle varied search cycle. To calculate the voltage gain, what we are interested in is the average shoot-through duty cycle. The shoot-through state repeats periodically every (π /3).Assume that the switching frequency is much higher than the modulation frequency, the shoot-through duty ratio over one switching cycle in the interval (π / 6,π / 2) can be expressed as

$$\frac{\overline{T_o}}{T} = \int_{\frac{\pi}{6}}^{\frac{\pi}{2}} \frac{2-(M\sin\theta - M\sin(\theta - \frac{2\pi}{3}))}{2}\, d\theta$$

$$= \frac{2\pi - 3\sqrt{3}M}{2\pi}$$

One equation of simple boost control is

$$B = \frac{1}{1-2D_0}$$

From the above two equations,

$$B = \frac{1}{1-(2\overline{T_o}/T)} = \frac{\pi}{3\sqrt{3}M - \pi}$$

The maximum shoot-through duty ratio (D_0) is

$$D_0 = \frac{2\pi - 3\sqrt{3}M}{2\pi}$$

The inverter voltage gain (G) is obtain as,

$$G = BM \frac{\pi}{3\sqrt{3}M - \pi} = \frac{\pi M}{3\sqrt{3}M - \pi}$$

This above equation gives relation between G and M.
The voltage stress across the inverter's devices is,

$$Vinv = BVo = \frac{\pi}{3\sqrt{3}M - \pi} Vo$$

Where,
B = Boost factor
M = Modulation Index
Vo = DC Input voltage
G = Inverter voltage gain
D_0 = Maximum shoot-through duty ratio
T0 = Shoot Through Time
T = Switching Period
D0 = Shoot through Duty Ratio

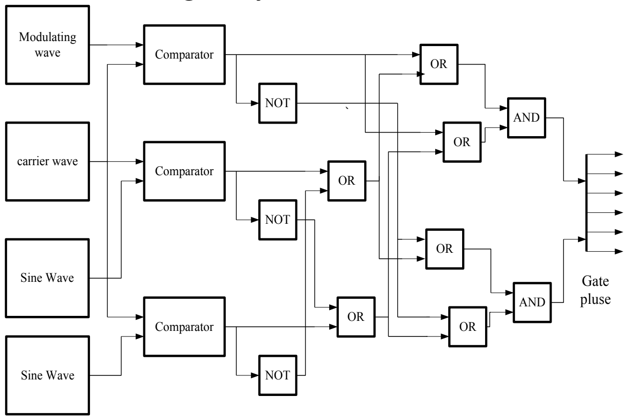


Fig. 5: Control circuit of MBC method in Matlab/Simulink

VI. SIMULATION OF Z-SOURCE INVERTER WITH MBC METHOD

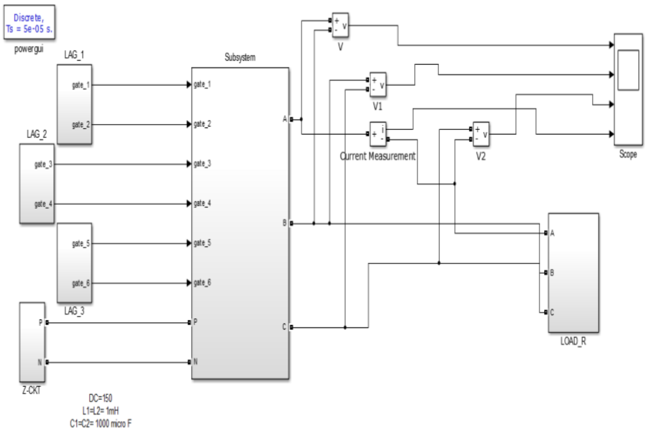
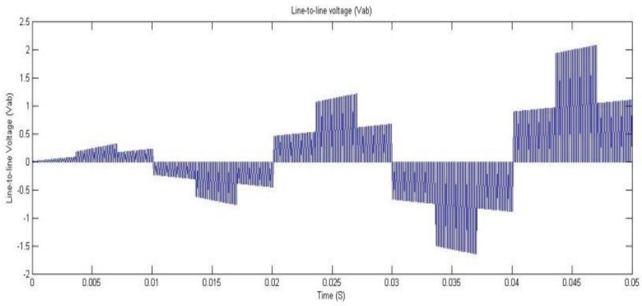


Fig. 6: Power Circuit of Three phase Inverter

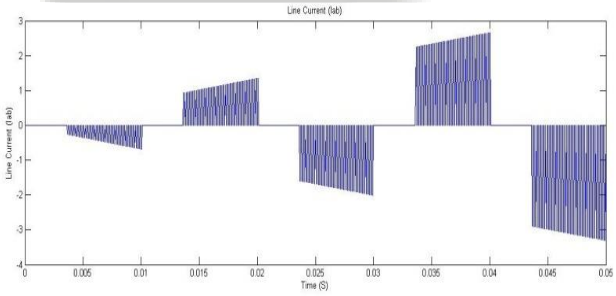
VII. WAVEFORM & THD ANALYSIS FOR R-LOAD WITHOUT FILTER.

VIII. SIMULATION RESULT

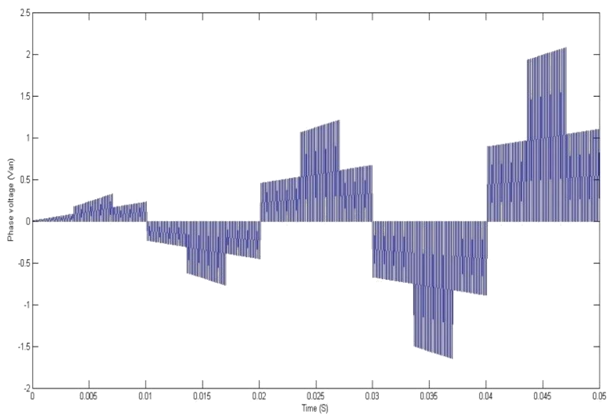
A. *Waveform of Line to Line Voltage:*



B. *Waveform of Line to line current:*



C. *Waveform of Line to phase voltage:*



D. *R = 100 Ohm with mBC method:*

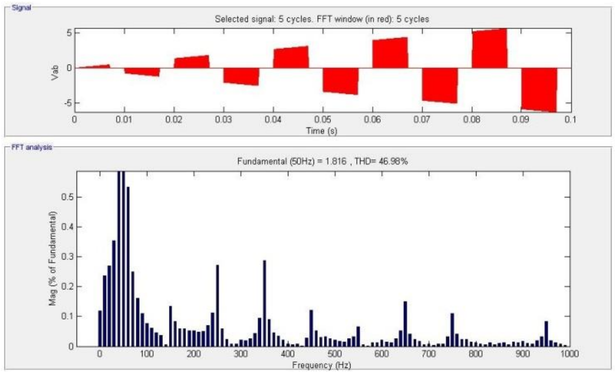


Fig. 9: THD of Line to Line Voltage Vab

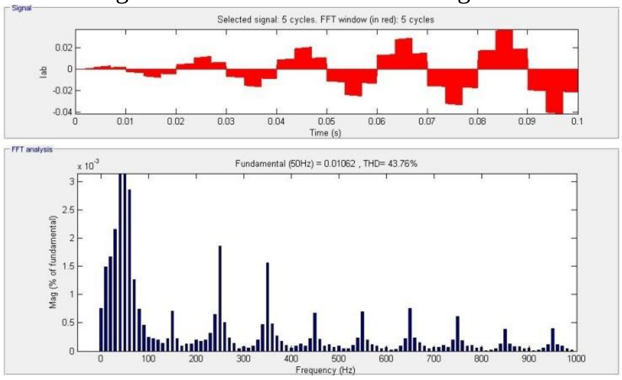


Fig. 10: THD of Line Current

For different frequencies result of Maximum boost control method.

MAXIMUM BOOST CONTROL METHOD			
Name of output	49.5Hz	50Hz	50.5Hz
Vab	35.60%	31.31%	29.39%
Vbc	35.50%	34.48%	34.07%
Vca	32.88%	30.61%	30.97%
Iab	33.87%	29.80%	28.93%

IX. CONCLUSION

This paper gives information and comparison about traditional inverter and Z-source inverter. The simulation of MBC method is done in MATLAB and waveforms are verified according to it. The Maximum boost control method is used to overcome the THD losses. It also shows that as frequency increases THD reduced and this factor is not available in traditional V-source and I-source inverter. Traditional losses are reducing in ZSI because there is no need of any filter circuit. The ZSI contain two identical inductors and capacitors which acts as impedance source as well as filter circuit.

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