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Comparison of Z-Source Inverter Fed Induction Motor with Traditional Source Inverter Systems

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Abstract: This study presents an impedance-source inverter fed (or Z-source converter) induction motor and its control characteristics compared with other traditional inverters. The impedance source inverter employs a unique impedance network coupled with inverter and rectifier; it overcomes the conceptual barriers and limitations of the traditional voltage-source converter (abbreviated as V-source converter) and current-source converter (abbreviated as I-source converter). By controlling the shoot-through duty cycle, the z-source inverter system provide ride-through capability during voltage sags, reduces line harmonics, improves power factor and extends output voltage range. Analysis and simulation results are presented to demonstrate these features.

Key words: Harmonic distortion, induction motor drives, voltage sag, Z-source inverter

INTRODUCTION

There exist two traditional converters: voltage-source (or voltage-fed) and current-source (or current-fed) converters (or inverters depending on power flow directions). Figure 1 shows the traditional three-phase voltage-source converter (abbreviated as V-source converter) structure. 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. Six switches are used in the main circuit; each is traditionally composed of a power transistor and an antiparallel (or freewheeling) diode to provide bidirectional current flow and unidirectional voltage blocking capability. The V-source converter is widely used. It, however, has the following conceptual and theoretical barriers and limitations.

- 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. For applications where drive is desirable and the available DC voltage is limited, an additional DC-DC boost converter is needed to obtain a desired AC output. The additional power converter stage increases system cost and lowers efficiency.
- 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 misgating-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.
- 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.

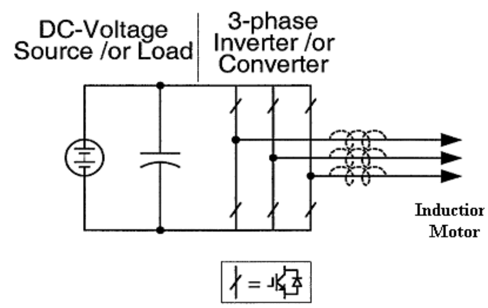

Fig. 1: Traditional V-source inverter

Figure 2 shows the traditional three-phase current-source converter (abbreviated as I-source converter) 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

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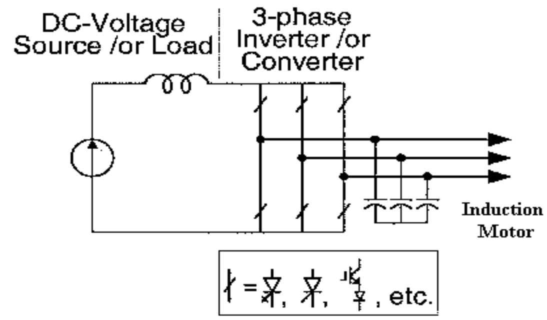


Fig. 2: Traditional I-source inverter

gate-turn-off thyristor (GTO) and SCR or a power transistor with a series diode to provide unidirectional current flow and bidirectional voltage blocking.

However, the current (I) -source converter has the following conceptual and theoretical barriers and limitations.

- 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 I-source inverter is a boost inverter for DC-to-AC power conversion and the I-source converter is a buck rectifier (or buck converter) for AC-to-DC power conversion. For applications where a wide voltage range is desirable, an additional DC–DC buck (or boost) converter is needed. The additional power conversion stage increases system cost and lowers efficiency.
- 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 (IGBT's). This prevents the direct use of low-cost and high-performance IGBT modules and intelligent power modules (IPM's).

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, nor vice versa. The objective is to develop an inverter system which can work at low voltage.

The concept of Z-source inverter was proposed (Peng, 2003). Comparison of traditional inverters and Z-source inverter was presented (Miaosen *et al*., 2005). The Pulse-width modulation of Z-souce inverters was presented in Loh *et al*. (2005). Constant boost control of the Z- Souce inverter to minimize current ripple and voltage stress was presented by Shen *et al*. (2006). Identification of an Effective control scheme for Z-source Inverter was presented by Meenakshi and Rajambal (2010). Performance Analysis of Reduced switch Z-source inverter fed IM drives was presented Srinivasan and Dash (2010). Comparison of ZSI and Traditional two stage boost inverter in grid tried renewable energy generation is presented by Li and Liu (2010).

Z-SOURCE CONVERTER

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. Figure 3 shows the general Z-source converter structure.

In Fig. 3, a two-port network that consists of a split-inductor and capacitors connected in X shape is 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 antiparallel combination as shown in Fig. 1, the series combination as shown in Fig. 2, etc. The inductance can be provided through a split inductor or two separate inductors.

The Z-source 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 Z-source converter overcomes the above-mentioned conceptual and theoretical barriers and limitations of the traditional V-source converter and I-source converter and provides a novel power conversion concept. The Z-source concept can be applied to all DC-to-AC, AC-to-DC, AC-to-AC, and DC-to-DC power conversion. To describe the operating principle and control, this paper focuses on an application example of the Z-source converter fed induction motor: a Z-source inverter for DC-AC power conversion needed for induction motor.

OPERATION AND CONTROL

Z-source inverter is thought to be a one - stage boost - buck inverter and one - stage topology is

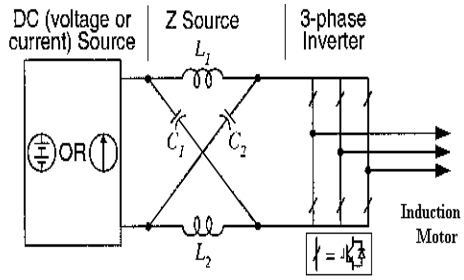


Fig. 3: Z-source inverter structure using the antiparallel combination of switching device and diode

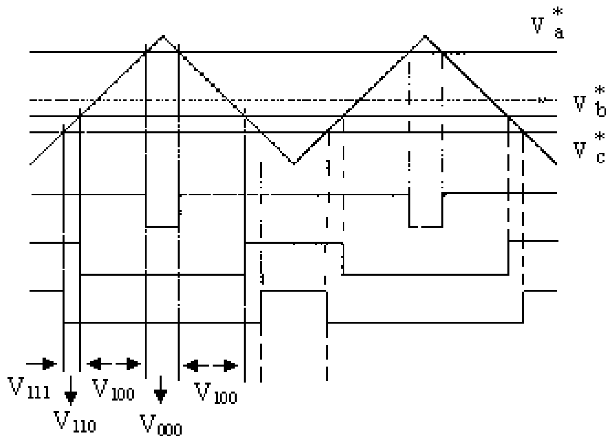
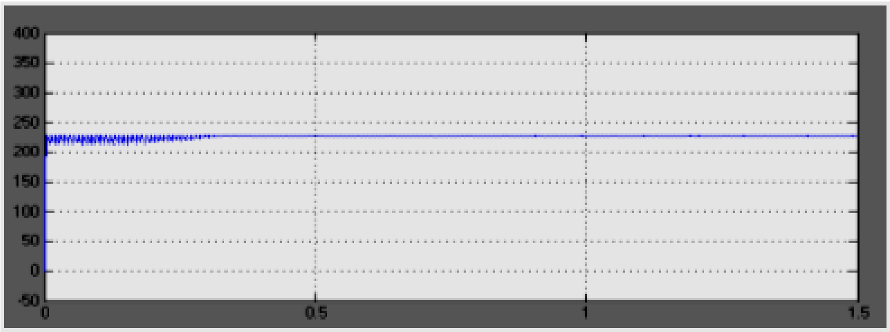


Fig. 4: PWM strategies of ZSI



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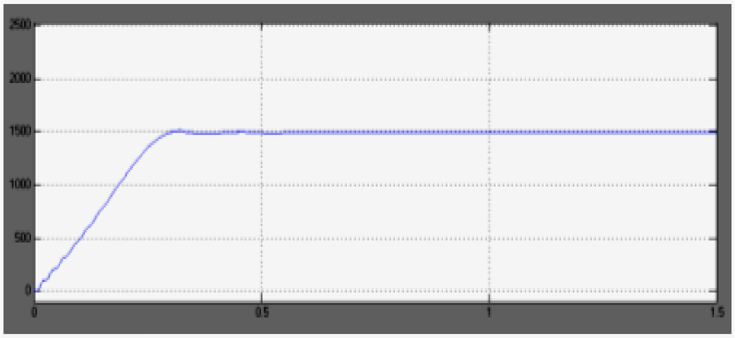

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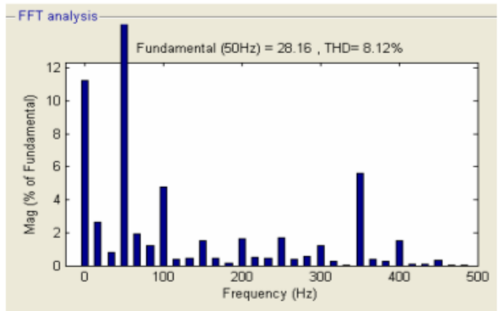
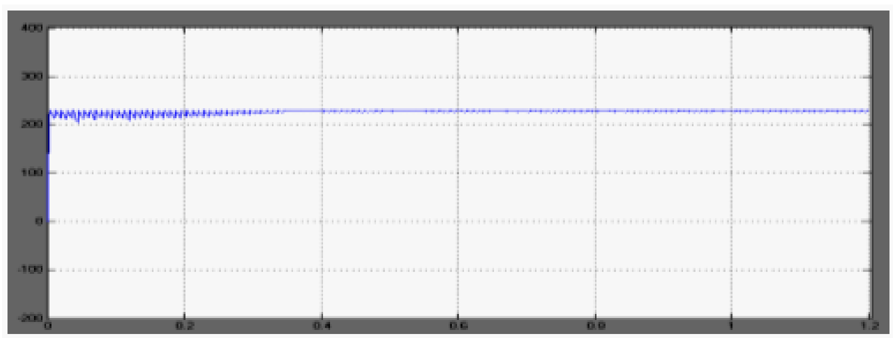


(c)

Fig. 5: (a) Rectified output voltage (b) Motor speed (c) FFT analysis



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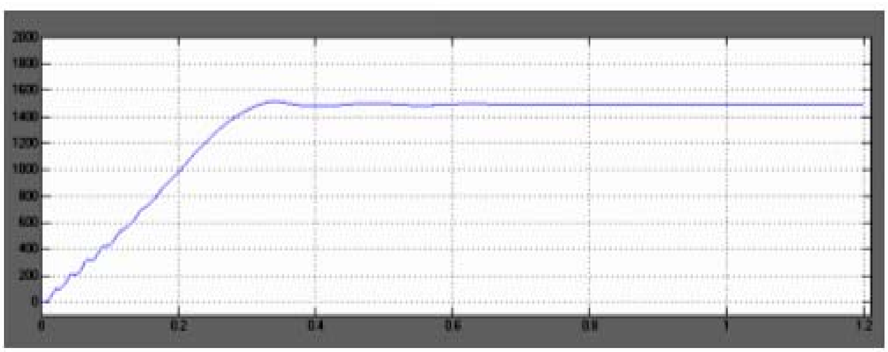

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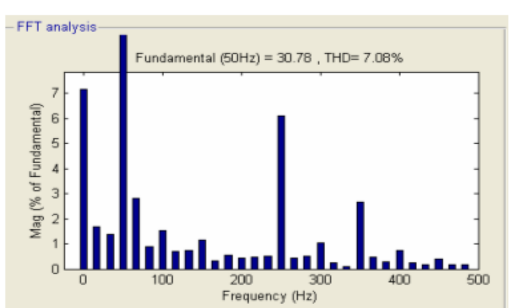


Fig. 6: (a) Rectified output voltage (b) Motor speed (c) FFT analysis

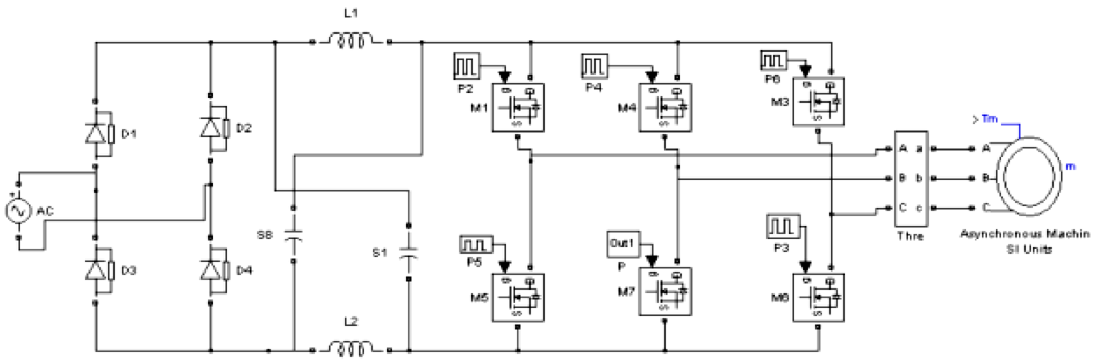


Fig.7: Proposed Z-source inverted fed Induction motor

somewhat considered to has higher efficiency over its counterpart of two-stage. Z-source inverter has a special impedance network between the bridge and the input voltage source (Fig. 3). This special circuit structure makes ZSI has an additional Shoot-Through (ST) switching state in which the upper DC rail and lower rail are shorted together. In ST state the two inductors are being charged by the capacitors and in Non-Shoot-Through (NST) states the inductors and input DC source transfer energy to the capacitors and load. This process is similar to the boost converter.

Seen from the AC side the ST states are the same with null states, so by replacing the null states with ST states, the boost function of ZSI is achieved. The DC link voltage of the bridge of ZSI can be expressed.

$$V_{I(ZSI)} = \frac{V_R}{1-2d_o} \quad (1)$$

Where d_O is the duty cycle of ST state. The output phase RMS voltage of ZSI is:

$$V_X = \frac{V_{I(ZSI)}}{2\sqrt{2}}.m_{ZSI} \qquad X \in \{a,b,c\} \quad (2)$$

where m_{ZSI} is the modulation index of ZSI. Note that d_O has a maximum limit of 1- m_{ZSI}, because the null state duty cycle depends on the modulation index. A third harmonic can be injected into the modulation signals to achieve the maximum constant d_O and boost voltage gain. In this case d_O have an expression shown, where m_{ZSI} has a variation range from 1/ to 2/ for the boost function:

$$d_O = 1 - \frac{\sqrt{3}}{2}.m_{ZSI} \quad (3)$$

There are typically two categories of PWM strategies for ZSI according to the different ST state insertion methods. The principle of this method is that the ST states are inserted at every transition by overlapping the upper and lower driver signals.

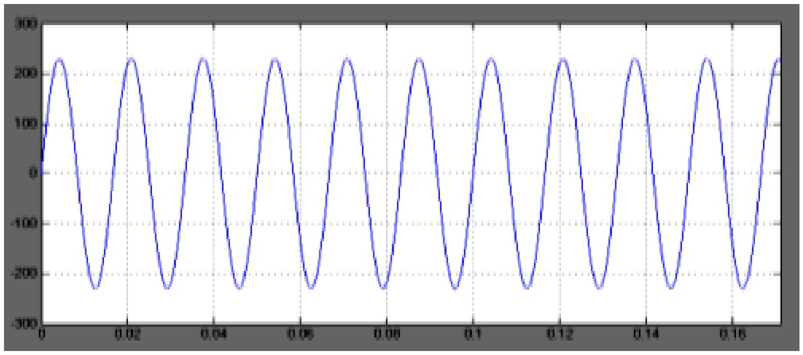
The upper and lower driver signals can be derived by properly level shifting the modulation signals of Voltage Source Inverter (VSI) as shown in Fig. 4. The shifting values are set properly so as to ensure the occupied duration of the two null states to be the same. The feature of this modulation strategy is that the transition times in one switching cycle is the same with VSI, the ST state is divided into six parts and the equivalent switching frequency of impedance network is six times of switching frequency. Therefore, the volume of inductors could be reduced dramatically.

SIMULATION RESULTS

The results of CSI fed drive are shown in Fig. 5. Figure 5a shows the output of rectifier. Figure 5b shows the speed. Figure 5c shows the FFT analysis. The THD is 8.1%. Results of VSI fed induction motor drive are shown in Fig. 6. Rectifier output is shown in Fig. 6a. Speed curve is shown in Fig. 6b. FFT analysis is shown in Fig. 6c. The THD is 5.73%. Results of Current source inverter fed Induction motor (CSI)

The results of CSI fed drive are shown in Fig. 7. The Fig. 7a shows the output of rectifier. Figure 7b shows the speed. Figure 7c shows the FFT analysis. The THD is 8.1%. Results of ZSI fed induction motor drive are shown in Fig. 8. Rectifier output is shown in Fig. 8b. Speed curve is shown in Fig. 8c. FFT analysis is shown in Fig. 8d. The THD is 5.73%. Table 1 gives comparison of Z-source inverter with traditional source inverters.

It can be seen that the THD is minimum by using ZSI fed IM drive system. The contribution o this work is the development of simulink model for ZSI fed drive system.



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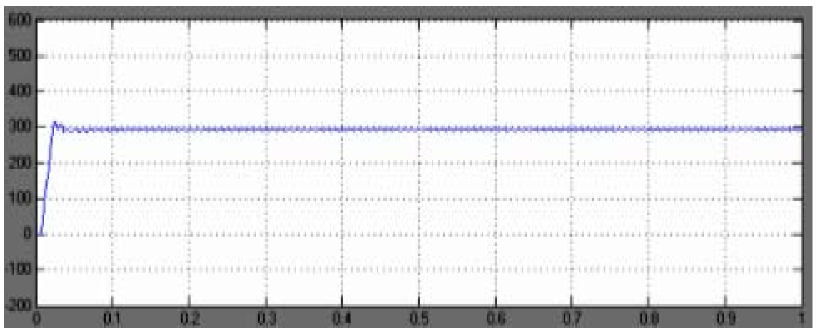

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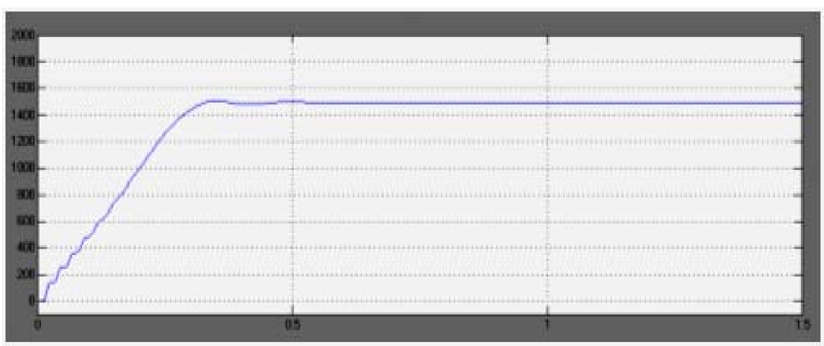

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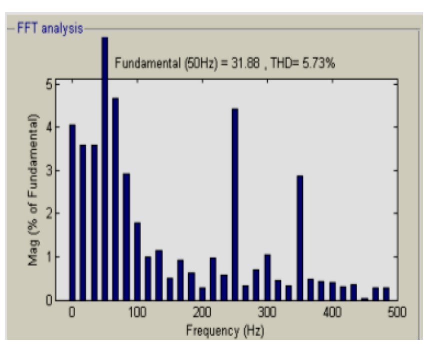

(d)

Fig. 8: (a) AC input voltage (b) Rectified output voltage (c) Motor speed (d) FFT analysis

Table 1: Comparison of Z-source with traditional inverters

	VSI	CSI	ZSI
AC input (Volts)	230	230	230
Rectified Output (Volts)	220	220	300
T.H.D. (%)	7.08	8.12	5.73

CONCLUSION

This paper examines and compares the rectified output voltage, motor speed and Total harmonic distortion of traditional inverter systems with Z-source inverter system. From the above results, it can be concluded that the rectified output voltage in Z-source inverter is higher than the other traditional inverters and harmonics are reduced here. The simulation results are in line with the predictions.

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