Simulation of Z-Source Inverter Fed Induction Motor

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Abstract: ***Traditionally Voltage Source Inverter (VSI) and Current Source Inverter (CSI) fed induction motor drives have a limited output voltage range. Conventional VSI and CSI support only current buck DC-AC power conversion and need a relatively complex modulator. The limitations of VSI and CSI are overcome by Z-source inverter.The Z-source inverter system employs a unique LC network in the DC link and a small capacitor on the AC side of the diode front end. By controlling the shoot-through duty cycle, the Z-source can produce any desired output AC voltage, even greater than the line voltage regardless of the input voltage. The proposed Z-source inverter system provides ride-through capability during voltage sags, reduces line harmonics, improves power factor and reliability, and extends the output voltage range. Analysis, simulation results were presented to demonstrate these features. This system reduces harmonics, electromagnetic interference noise and it has low common mode noise.***

Keywords: current source inverter (CSI), voltage source inverter (VSI), Z-sourceInverter (ZSI), electro-magnetic interference (EMI)

1. Introduction

The traditional general-purpose motor drive or adjustable speed drive (ASD) system is based on the VSI, which consists of a diode rectifier in the front end with the DC link capacitor, and Inverter Bridge. The VSI is a buck (or step-down) converter that can only produce an AC voltage limited by the DC link voltage which is equal to 1.35 times the line voltage. Because of this nature, the VSI based ASD system suffers the following common limitations and problems [2]:

1) The voltage obtained at output is limited which is less than the input line voltage.
2) The ASD systems are limited by the voltage sags and results in shut down of the system at critical loads. Also, the DC capacitor in an ASD system cannot hold DC voltage above the operational level due to its relatively low energy storage capacity under such voltage sags.
3) The ride-through capacity is lagging in VSI which lead to serious problem for sensitive loads driven by ASDs.
4) The ASD system can be accompanied with fly back converter or boost converter having energy storage capacity or diode rectifier to achieve ride-through; but, these combined circuits suffer with disadvantages of cost, size/weight, and complexity.
5) Diode rectifier produces inrush and harmonic current which can further pollute the line. The traditional ASD system also suffers from low power factor.
6) EMI's majorly responsible for miss-gating which can cause shoot- through that lowers the performance of the inverter.
7) The dead time needed to avoid shoot-through creates distortion and unstable operation at low speeds.

2. Z-Source Inverter

The Impedance Source Inverter is used to overcome the problems in the traditional source inverters. This impedance source inverter shown in Fig.1 employs a unique impedance network coupled with the inverter main circuit to the power source. This inverter has unique features compared with the traditional sources.

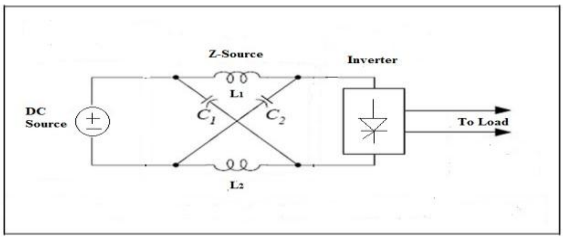

Figure 1: Z-Source Inverter

It consists of voltage source from the rectifier supply, Impedance network, and three phase inverter with A.C. motor load. AC voltage is rectified to DC voltage by the rectifier. The rectifier unit consist of six diodes, which are connected in bridge way. This rectified output DC voltage fed to the Impedance network. Which consist of two equal inductors (L_1, L_2) and two equal capacitors (C_1, C_2).The network inductors are connected in series arms and capacitors are connected in diagonal arms [9].

The impedance network used to buck or boost the input voltage depends upon the boosting factor .This network also act as a second order filter. This network should require less inductance and smaller in size. Similarly capacitors required less capacitance and smaller in size. The output voltage from impedance network is fed to the three phase inverter main circuit [9]. The inverter main circuit consists of six switches .Gating signals are generated from the driving circuit. Depends upon the Gating signal inverter operates and the output of inverter is fed to the AC load or motor.

3. Z-Source Network

Impedance network is a two port network. Usually one pair represents the input and other represents the output. This network also called as lattice network [10]. Lattice network is the one of the common four terminal two port network. The lattice network is used in filter sections and is also used as attenuators. Lattice networks are sometimes used in preference to ladder structure in some special applications. Thislattice network that consists of split inductors L_1 and L_2 and capacitors C_1 and C_2connected in X-shape [12].

The three phase impedance source inverter bridge has nine switching states unlike the traditional VSI that has eight switching states. Because of this special structure, the ZSI has an additional switching state, when the load terminals are shorted through both the upper and lower switching devices of any phase leg, which called the shoot-through (ST) state besides the eight traditional non-shoots through(NST) states. The ZSI has two operating modes: non-shoot-through mode and shoot-through mode, as shown in Fig. 3& 4. During the ST switching state, the input diode is reverse biased; the input dc source is isolated from the load, and the two capacitors discharge energy to the inductors and to the load. During the NST switching states, the input diode turns ON, and the dc input voltage source as well as the inductors transfer energy to the load and charge the capacitors, as a result the dc-link voltage of bridge is boosted.The impedance source inverter bridge has one extra zero state, when the load terminals are shorted through both upper and lower devices of any one phase leg or all three phase legs. This shoot through zero state is forbidden in the VSI, because it would cause a shoot- through [10]. This network makes the shoot through zero state possible. This state provides the unique buck-boost feature to the inverter [14]. The equivalent switching frequency from the impedance source network is six times the switching frequency of the main inverter, which greatly reduces the required inductance of the Impedance source network. The equivalent circuit of the Impedance source inverter is shown in Fig.2

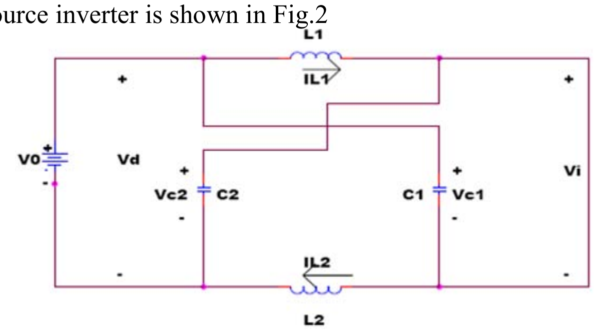

Figure 2: Equivalent circuit of the Impedance Source Inverter

4. Mathematical Analysis of Z-Source Network

The impact of the phase leg shoot through on the inverter performance can be analyzed using the equivalent circuit shown in Fig.3 and Fig.4. Assume the inductors (L_1 and L_2) and capacitors (C_1 and C_2) have the same inductance and capacitance values respectively; the Z-source network becomes symmetrical.

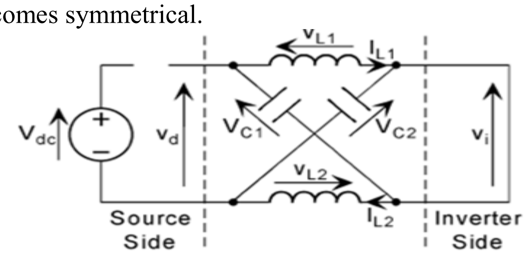

Figure 3: Equivalent circuit when ZSI in shoot through state

In shoot through state the inverter side of Z-Source network is shorted during time interval T_0 as in Fig.3.Therefore $L_1=L_2=L$ and $C_1=C_2=C$.

$V_{c1} = V_{c2} = V_c = V_{L1} = V_{L2} = V_L$

$V_d = V_L + V_c = V_c + V_c = 2\,V_c$ ....(1)

$V_i = 0$

Alternatively, when in non-shoot through active or null state current flows from Z-Source network through the inverter topology to connect ac load during time interval T_1.The inverter side of the Z-source network can now be represented by an equivalent circuit [10] as shown in Fig.4

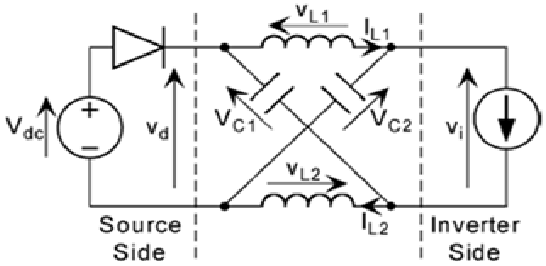

Figure 4: Equivalent circuit when ZSI in non-shoot through state

The following equations can be written:

$V_L = V_{dc} - V_C$

$V_d = V_{dc}$

$V_i = V_C - V_L$

Putting $V_L = V_{dc} - V_C$in above equation

$V_i = V_C - (V_{dc} - V_C) = V_C - V_{dc} + V_C = 2\,V_C - V_{dc}$....... (2)

Averaging the voltage across a Z-source inductor over a switching period (0 to T),

$V_C = T_1 / (T_1 - T_o)\, V_{dc}$......(3)

Using equations (2) and (3)

The peak DC-link voltage across the inverter bridge is

$V_i = 2\,V_C - V_{dc}$

$= 2[T_1 / (T_1 - T_o)\, V_{dc}] - V_{dc}$

$= (2T_1 - T_1 + T_0) / (T_1 - T_0)\, V_{dc}$

$= (T_1 + T_0) / (T_1 - T_0)\, V_{dc} = (T_1 + T_0) / (T_1 + T_0 - 2T_0) V_{dc}$

$= (T) / (T - 2T_0)\, V_{dc}$

$= 1 / (1 - 2T_o/T)\, V_{dc}$..... (4)

$V_i = B.\,V_{dc}$......(5)

Where, $B = T / (T_1 - T_o)$ i.e. ≥ 1 and B is a boost factor, T- Switching period.

The peak ac output phase voltage, For Z- source

$V_{ac} = M.V_i/2 = B.M\, V_{dc}/2$

In the traditional sources, $V_{ac} = M.\, V_{dc}/2$, where M is modulation index. The output voltage can be stepped up and down by choosing an appropriate buck – Boost factor BB = B.M (it varies from 0 to α), where α=firing angle.

The Buck - Boost factor BB is determined by the modulation index M and the Boost factor B. The boost factor B can be controlled by duty cycle of the shoot through zero state over the non-shoot through states [14] of the PWM inverter. The shoot through zero state does not affect PWM control of the inverter, because it equivalently produce the same zero voltage to the load terminal. The available shoot through period is limited by the zero state periods that are determined by the modulation index.

5. MATLAB Simulation

The MATLAB simulation is performed for comparing the results of Z-Source Inverter at no load condition & loaded condition. The specifications of three phase induction motor used in simulation as a load are as follows: 0.5HP, 3-Ø, 8-pole, 240V, 50 Hz, 750 rpm.

a) For No Load Condition

Simulations have been performed to confirm the above analysis. Fig. 5.1 shows the circuit configuration of Z-Source fed Induction motor drive. The simulation parameters are as follows:

1) AC input voltage: 230 V AC
2) Rectifier output voltage: 314V DC
3) Z-source network: $L_1 = L_2 = 1$ mH, $C_1 = C_2 = 900$ µF
4) Switching frequency: 10 KHz

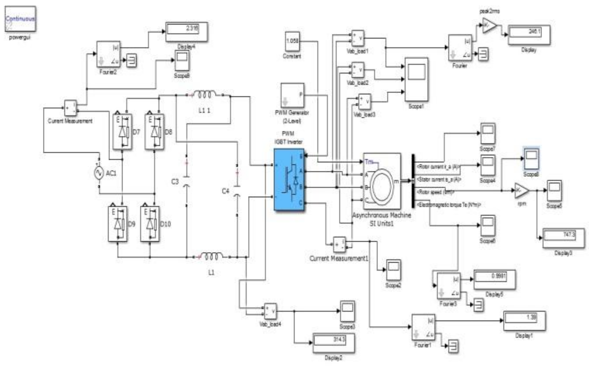

Figure 5.1: Simulation circuit for Z-Source Inverter fed Induction Motor

b) For Loaded Condition:

The following MATLAB simulation is done for loaded condition i.e. the three phase induction motor used in the simulation circuit is loaded mechanically by providing an input torque of 6.26 N-m.

5.1 a) Simulation Results for No Load Condition:

i) Rectified Output Voltage (V_R):

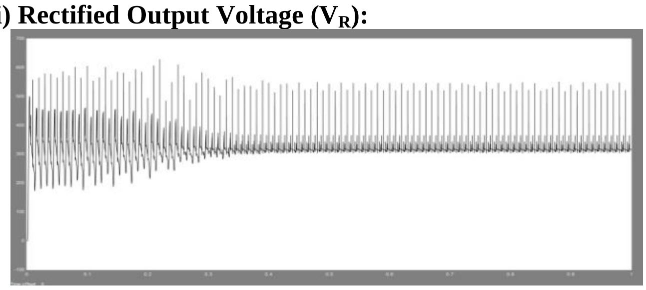

Figure 5.2: Rectified output voltage

ii) Inverter Output Line to Line Voltages (V_L):

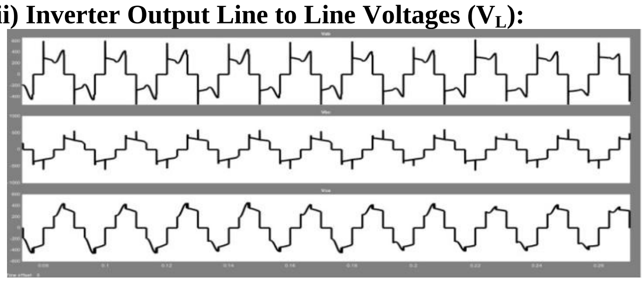

Figure 5.3: Inverter output line to line voltages

iii) Rotor Speed (N):

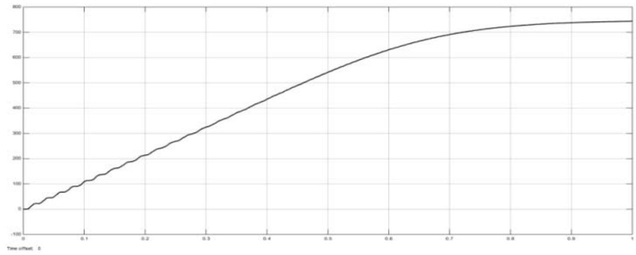

Figure 5.4: Rotor Speed

b) Simulation Results for Loaded Condition:

i) Rectified Output Voltage (V_R):

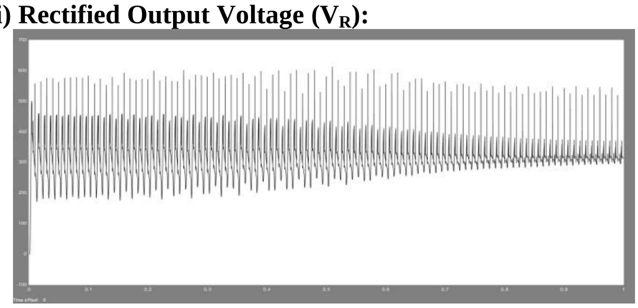

Figure 5.5: Rectified output voltage

ii) Inverter Output Line to Line Voltages (V_L):

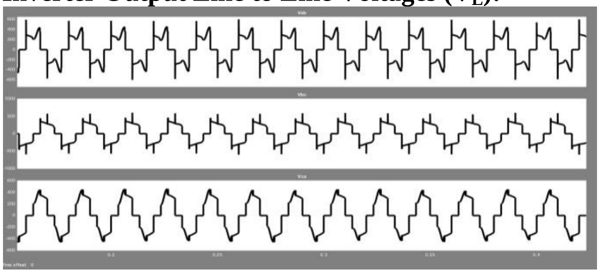

Figure 5.6: Inverter output line to line voltages

vi) Rotor Speed (N):

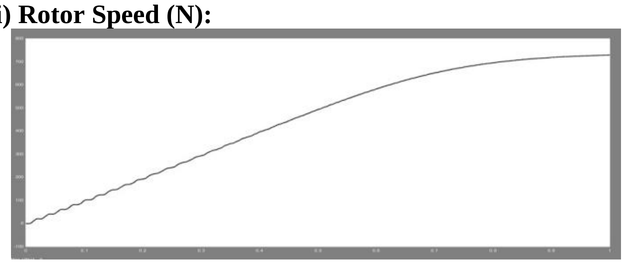

Figure 5.7: Rotor Speed

Table 1: Comparison of Simulation Results

Parameters	DC Output Voltage	Inverter line voltage	Motor Speed
No Load Condition	313.7	245.1	743.8
Loaded Condition	312.3	242.2	729.2

Table 2: VSI performance

Voltage Source Inverter					
Sr. No.	AC Input Voltage	Input Current	DC Output Voltage	Inverter line voltage	(THD) %
1	125	138.64	123.55	120.23	105.96
2	150	168.28	148.56	144.55	104.00
3	175	197.25	173.55	168.87	104.20
4	200	224.7	198.5	193.2	102.39
5	230	257.7	228.5	222.35	103.56

Table 3: ZSI performance

Z-Source Inverter					
Sr. No.	AC Input Voltage	Input Current	DC Output Voltage	Inverter line voltage	(THD) %
1	125	1.255	172.18	139.2	7.51
2	150	1.506	207.05	167.18	7.27
3	175	1.757	229.7	195.18	7.08
4	200	2.008	276.6	223.2	6.89
5	230	2.310	314.3	246.1	6.51

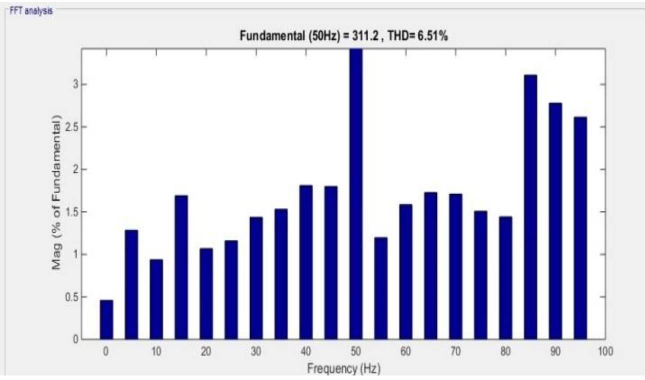

Figure 5.8: THD analysis of ZSI

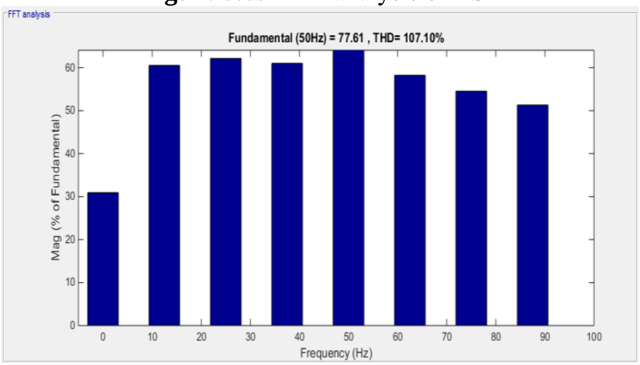

Figure 5.9: THD analysis of VSI

6. Conclusion

From the analysis, we have verified that the output voltage can be boosted to any value irrespective of input voltage by using Z- Source inverter. This circuit also provides reduced line current harmonics.

Therefore Impedance Source Inverter ASD system has several unique advantages that are very desirable for many ASD applications:
1) The Impedance Source Inverter concept can be applied to all AC-AC, DC-DC, AC-DC, DC-AC power conversion.
2) The output voltage range is not limited.
3) The Impedance Source Inverter is used as a buck-boost inverter.
4) The Impedance Source Inverter does not affect the Electromagnetic Interference noise.
5) The Impedance Source Inverter cost is low.
6) The Impedance Source Inverter has low current compared with the traditional source inverter.

References

[1] Fang Zheng Peng and Yi Huang Michigan, "Z-Source Inverter for Power Conditioning and Utility Interface of Renewable Energy Sources," IEEE Trans, Vol. 23, no. 4, 2004.
[2] F. Z. Peng, "Z-source inverter," IEEE Trans. Ind. Applicant., Vol. 39,no.2, pp.504–510, Mar./Apr. 2003.
[3] B. Justus Rabi and R. Arumugam, "Harmonics Study and Comparison of Z-source Inverter with Traditional Inverters", in American Journal of Applied Sciences 2 (10):1418-1426, 2005, ISSN 1546-9239 2005 Science Publications.
[4] M. Shen, J.Wang, A. Joseph, F Z. Peng, L. M. Tolbert, and D. J. Adams, "Maximum constant boost control of the Z-source inverter," presented at the IEEE Industry Applications Soc. Annual Meeting, 2004.
[5] Poh Chiang Loh, Sok Wei Lim Feng Gao, and Frede Blaabjerg, "Three- Level Z-Source Inverters Using a Single LC Impedance Network," IEEE Transactions on Vol. 22, NO. 2 March 2007.
[6] P. C. Loh, D. M. Vilathgamuwa, Y. S. Lai, G. T. Chua, and Y. W.Li,"Pulse-width modulation of Z-source inverters," in Proc. IEEE-IAS Annual Meeting, 2005, pp. 148–155.
[7] P. C. Loh1, F. Blaabjerg2, S. Y. Feng1 and K. N.Soon, "Pulse-Width modulated Z-source neutral-point-clamped inverter," in proc. IEEE APEC 06, 2006, pp.431-437.
[8] P.C Loh, D.M. Vilathgamuwa, C.J.Gajanayake, L.T. Wong, and C.P.Ang, "Z-Source current-type inverters: Digital modulation and logic implementation," in Proc. IEEE Annual Meeting, 2007, pp. 940-947.
[9] Fang Zheng Peng, Alan Joseph, Jin Wang, Miaosen Shen, Lihua Chen, Zhiguo Pan, Eduardo Ortiz-Rivera, and Yi Huang, "Z-Source Inverter for Motor Drives" , IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 20, NO. 4, JULY 2005.
[10] Poh Chiang Loh, Chandana Jayampathi Gajanayake, D. Mahinda Vilathgamuwa, and Frede Blaabjerg, "Evaluation of Resonant Damping Techniques for Z-Source Current-Type Inverter," IEEE Transactions, Vol. 23, no. 4, July 2008.
[11] Xu-Peng Fang', Zhaoming Qian', Qi-Gao', Bin-Gut, Fang-Zheng Pengl.', Xiao-ming Yuan', "Current Mode Z-Source Inverter-Fed ASD System,"2004 35lh Annual 1EEE Power Electronics Specialists Conference2004.
[12] Yam P.Siwakoti, Fang Zheng Peng, Frede Blaabjerg, Poh Chiang Loh, and Graham E. Town, "Impedance-Source Networks for Electric Power Conversion Part I: A Topological Review", IEEE 2015.
[13] Shen, Miaosen; Peng, F.Z., "Operation Modes and Characteristics of Z- Source Inverter with Small Inductance or Low Power Factor", IEEE Transaction on Industrial Electronics, vol. 55, issue: 1, January 2008, pp. 89-96.
[14] Gao, Zhiqiang; Wang, Jianze; Chen, Qichao, "An Improved Control Method for Inductive Load of Z-Source Inverter", School of Electrical Engineering and Automation Harbin Institute of Technology, Harbin, China.
[15] Ding, Xinping; Qian, Zhaoming; Yang, Shuitao; Cui, Bin; Peng, F.Z., "A Direct DC-link Boost Voltage PID-like Fuzzy Control Strategy in Z-Source Inverter", IEEE Power Electronic Specialist Conference, 2008.
[16] Huang, Yi; Shen, Miaosen; Peng, F.Z., "Z- Source Inverter for Residential Photovoltaic Systems", IEEE

Transactions on Power Electronics, vol. 21, issue: November 2006, pp. 1776-1782.

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