SWITCHED INDUCTOR QUASI Z-SOURCE INVERTER FED INDUCTION MOTOR DRIVE WITH REDUCED THD

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Abstract: This paper proposes a reduction of harmonics in source current and load current of Switched Inductor Quasi Z Source Inverter fed Induction Motor Drive. An Electro Magnetic Interference filter is suggested at the input to reduce the harmonics in the source current and a three phase LC filter is proposed at the output to reduce the load harmonics. The simulation results of the existing system and proposed system are presented to study the reduction in the harmonics.

Key words: *Switched inductor quasi z source inverter, Boost inversion ability, Shoot through duty ratio, Induction motor drives.*

1. Introduction

High performance voltage and current source inverters (VSI and CSI) [1]-[3] are extensively used in various industrial applications such as AC Motor Drives, Uninterruptible Power Supplies, Hybrid Electric Vehicles and Distributed Power Systems. However, the conventional VSI and CSI have key drawbacks. AC output voltage of conventional voltage source inverter is not more than the input DC source voltage and can only do buck dc-ac power conversion. In voltage source inverter, the shoot through developed by both power switches in a leg, is outlawed.

AC output voltage of current source inverter cannot lower than the input DC source voltage, consequently it supply only voltage boost dc-ac power conversion and it cannot abide an open circuit. An additional dc-dc converter is applied where both buck and boost voltage are required. The dc-dc converter acts as both a voltage and current source inverter, completes two-stage power conversion with high cost and low efficiency [3].

In ZSI, reported the ability of buck-boost in the single stage power conversion to defeat the restrictions in conventional inverters [4]. A leg consists of upper and lower power switches; it will be turned on equally due to that increased reliability, eliminated dead time and reduces the distortion in the output waveform. Dynamic modeling and boost control methods [5]-[7], pulse width modulation methods [8]-[12] and other z-source network topologies [13]-[20] are analyzed. QZSI is developed to overcome the drawbacks in conventional ZSI is analyzed in [13]-[15]. Compared with conventional ZSI, QZSI have the ability to provide improved input profiles, reducing passive component ratings and but there is no improvement on voltage boost ability. The focal point here is improved the boost factor of the ZSI [21]-[23]. A high dc-link voltage is produced in the main power circuit of ZSI with a low input dc voltage, added inductors, capacitors and diodes to the network [21, 23]. The transformer (2:1) is connected in the impedance network in place of two inductors to create voltage gain [23]. Transformer less structure with high boost, high power density, high efficiency can be getting by providing switched inductor and capacitor, voltage lift techniques and voltage multiplier cells [24]-[26] to dc-dc conversion Switched inductor impedance source inverter (SLQZSI) is the combination of ZSI and switched inductor structure gives high step-up inversion to defeat the boost limitation of the classical ZSI [4].

The switched inductor structure is applied to quasi impedance source inverter topology; therefore it is proposed and called as a switched inductor quasi z source inverter (SLQZSI). The proposed SL-QZSI is capable of obtaining a higher boost ratio compared to that of conventional ZSI in adding the topologies introduced in [14] and [15]. The high voltage boost can be produced by a short shoot through duty ratio. Moreover the voltage stress on z source capacitors, shoot-through current, current stress on inductor and diodes and Inverters Bridge is greatly reduced for the same input and output voltage. At startup, inrush current destroying the devices is avoided in the proposed SLQZSI. The operating principles of proposed and conventional ZSI, simulation waveforms are investigated by those of conventional ZSI.

2. Introduction to ZSI Topologies

ZSI topology [4] consists of a two port impedance network, which couples the inverter main circuit to dc voltage source. The two port impedance network has inductor L1 and L2 and capacitor C1 and C2 are connected in X shape. An extra shoot-through, zero state is added to provide unique feature with switching states, i.e., voltage boost. The shoot through the zero state is not used, when the dc input voltage is enough to produce the required ac voltage with good performance. Hence the ZSI acts as a buck inverter just like a VSI. Fig.1. shows the conventional ZSI.

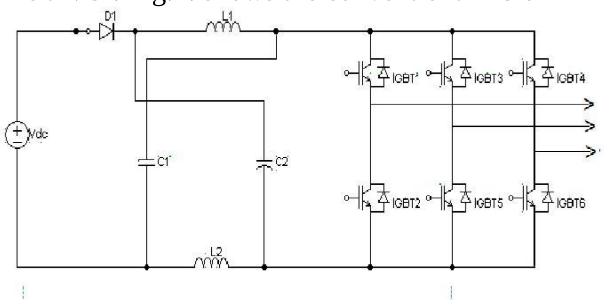

Fig. 1. Conventional ZSI

The classical ZSI has following limitation

1. In some applications, the current taken from the dc input source is intermittent.
2. DC source and converter do not share the common ground.
3. It needs a dc link coupling capacitor is connected across the energy source to protect unwanted discontinuity of current. Boost factor B can be expressed as a conversion relation between dc-link voltage across the inverter bridge V_{dc} and input source voltage V_{in}.

$$B = \frac{V_{PN}}{V_{dc}} = \frac{1}{1-2(T_o/T)} = \frac{1}{1-2D} \tag{1}$$

Where To is the interval of the shoot through the zero state during a switching cycle T and D is the duty ratio of each cycle. D=To/T

From equation (1), it is observed that D should be limited to a minimum value of zero to the maximum value of 0.5. In this range, the impedance network can achieve the step up dc-dc conversion from V_{dc} to V_{PN}. But the large value of D needs to be taken from a low voltage DC energy source to provide a very high boost factor. Hence z source converter should be operated for a long interval of the shoot through zero state.

This problem in the classical ZSI is conquered by QZSI [13] -[15]. Fig. 2 shows the QZSI topology for continuous input current. It shares a common ground with the dc source and lowers voltage stress on capacitors.

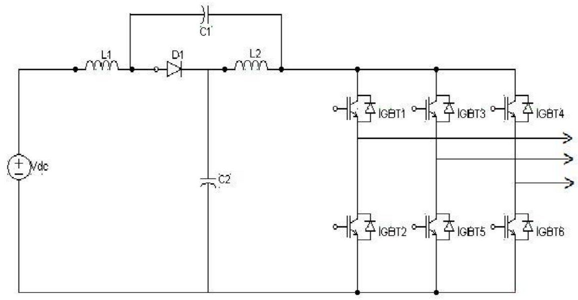

Fig. 2. Q-ZSI Topology

Fig. 3 shows the SL-ZSI with a high voltage conversion ratio [21] was obtained with a very short shoot through state improving the power quality of the output ac waveform.

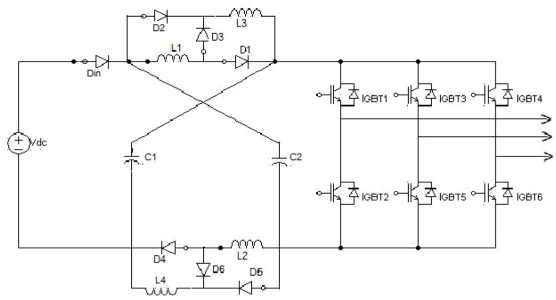

Fig. 3. SL-ZSI

The Boost factor of this inverter is improved to:

$$B = \frac{1+(T_o/T)}{1-3(T_o/T)} = \frac{1+D}{1-3D} \tag{2}$$

The SL-ZSI consists of four inductors (L_1, L_2, L_3, and L4), two capacitors (C_1 and C_2) and six diodes (D_1, D_2, D_3, D_4, D_5 and D_6). The combination of L_1-L_3-D_1-D_3-D_5 forms the top SL cell and the combination of L_2-L_4-D_2-D_4-D_6 forms bottom SL cell respectively. Both top and bottom cells perform the function of the energy storage and transfers energy from the capacitors to dc bus under the switching action of the main circuit.

Even though SL-ZSI has increased in boost inversion and it has the following drawbacks.

1. The inrush current cannot be suppressed. At the startup, resonance is introduced by providing the

source impedance inductors and capacitors.
2. The devices are destroyed by voltage and current spike.
3. The input current is discontinuous and needs a DC link capacitor at the front end of energy source.

3. SL-QZSI Topology

The proposed SL-QZSI topology is show n in Fig. 4, it has three inductors (L_1, L_2, and L_3), two capacitors (C_1 and C_2), and four diodes (D_{1n}, D_1, D_2, and D_3). The combination of L_2– L_3– D_1–D_2–D_3 acts as a SL cell.

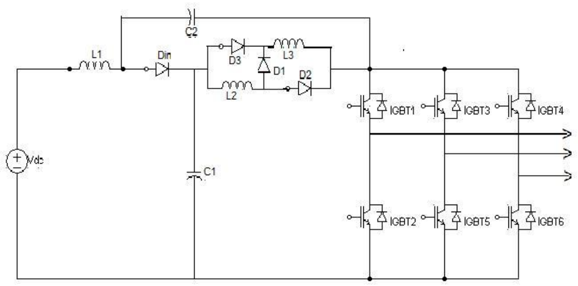

Fig. 4. SL-QZSI topology

However, at start up resonance is provided by the source impedance of inductor and capacitors and there are no current flows to the main power circuit. Hence, the proposed topology is suppressing the inrush current. The proposed inverter increases factor of boost from 1/(1−2D) to (1+D)/(1−2D−D2) by adding three diodes and one inductor to the topology.

A. Circuit Analysis

The proposed SL-QZSI has traditional six active, two zero states and extra shoot-through zero states like conventional ZSI. Thus, the operating principles of both proposed inverter and the classical ZSIs are similar. The operating states of proposed SL-QZSI are classified into a shoot-through and non shoot-through states. Fig. 5 and Fig. 6 shows the non shoot-through operating state and shoot-through operating state respectively.

Non shoot-through state:

During the non shoot-through state the proposed inverter has six active states and two zero states. In this state, D_{in} and D_1 are on, while diodes D_2 and D_3 are off. Inductors L_2 and L_3 are connected in series. The capacitors C_1 and C_2 are charged, while the inductors L_1, L_2, and L_3 transfer energy from the dc input source to the main power circuit. V_{L2}_non and V $_{L3}$_non are the corresponding voltages across L_2 and L_3 respectively. Fig. 6 shows the reduced equivalent circuit of SL-QZSI under non shoot-through state.

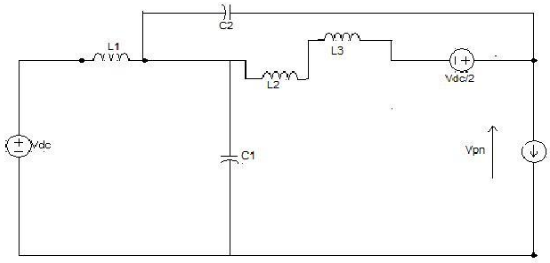

Fig. 5. Non shoot-through operating state

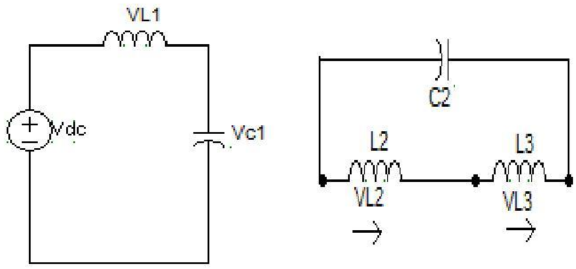

Fig. 6. Reduced Equivalent circuit of SL-QZSI under non shoot-through state

$$V_{L1} = V_{C1} = V_{dc} \tag{3}$$

$$V_{L2} = V_{L2\_non} = V_{C2} - V_{L3\_non} \tag{4}$$

$$V_{L3} = V_{L3\_non} = V_{C2} - V_{L2\_non} \tag{5}$$

$$V_{PN} = V_{C1} + V_{C2} \tag{6}$$

Shoot through state:

This state occurs when both the upper and lower switching references. The shoot through state repeats periodically every device of any phase leg of the inverter is shorted. Fig. 7 shows the shoot through operating state. The reduced equivalent circuit of SL-QZSI under shoot-through state is shown in Fig. 8. During the shoot through state, D_{in} and D_1 are off, while D_2 and D_3 are on. The inductors L_2 and L_3 are connected in parallel and the capacitors C1 and C2 is discharged, while inductors L_1, L_2, and L_3 store the energy.

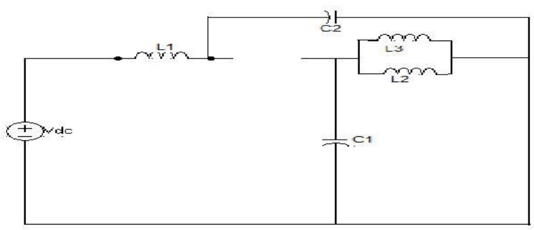

Fig. 7. Shoot-through operating state

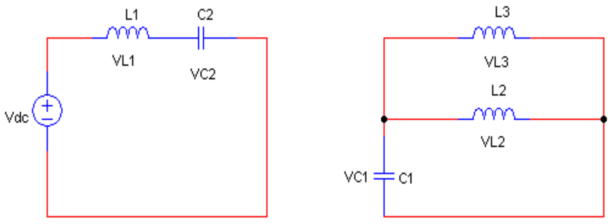

Fig. 8. Reduced Equivalent circuit of SL-QZSI under shoot-through state

$$V_{L1} = -V_{C2} - V_{dc} \tag{7}$$

$$V_{L2} = V_{L3} = -V_{C1} \tag{8}$$

4. Induction Motor

Three phase induction motors are most widely used in various industrial applications because of its self-starting property, elimination of a starting device, robust construction, higher power factor and good speed regulation. But it is a constant speed machine which makes its applications pretty much limited. Its speed is controlled by varying the supply frequency and thereby it can save the energy spent by the machine. The base speed of an induction motor is directly proportional to the supply frequency and the number of poles. The poles are fixed and the speed of the motor is controlled by varying the supply frequency. The torque developed by the motor is directly proportional to the ratio of the applied voltage and the supply frequency. The torque is kept constant by varying the applied voltage and the supply frequency and by keeping their ratio to a constant value. The torque speed characteristics also denote that:

1. The starting current requirement is lower.
2. The stable operating point of the motor is increased. The motor can be run at 5% of the synchronous speed up to base speed instead of running the motor from the base speed itself.
3. The acceleration and deceleration of the motor can be controlled by controlling the change of the supply frequency of the motor with respect to time. Fig. 9 shows the SLQZSI fed induction motor drive.

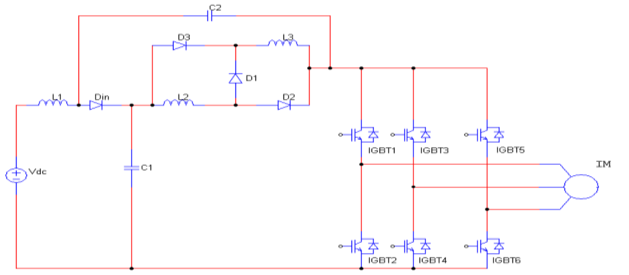

Fig. 9. SLQZSI Fed Induction Motor

5. Simulation Results

A. SLQZSI without filter:

The AC-AC Z Source based Induction Motor Drive System without filter is modeled and simulated using Matlab and the results are discussed. The simulink diagram of SLQZSI fed induction motor without filter is shown in Fig. 10. The AC input voltage of 110V (peak amplitude), 50Hz are applied to SLQZSI fed induction motor without filter is shown in Fig. 11. The circuit parameters are chosen as follows.

1. SLQZ-source impedance network: $L1=L2=1x10^{-3}H$, $L3=L4=1.5x10^{-3}H$, $C1=9000x10^{-6}F$.
2. The switching frequency fs=1/T=10KHz.
3. All components are assumed ideal.
4. Three phase induction motor load: 5.4HP (4KW), 400V, 50Hz, 1430RPM.
5. Diode D1, D2, D3, D4, D5, D6: R=0.001Ω, forward voltage=0.8V, snubber resistance=500 Ω, snubber capacitance=$250x10^{-9}F$.

The source current is shown in Fig. 12. Fig. 13 and Fig. 19 shows the total harmonic disturbance (THD) spectra with FFT analysis of source current and line current of SLQZSI without LC filter. The THD is 7.75%. The DC output voltage for the rectifier is shown in Fig. 14. The DC voltage is 240V.The driving pulses applied to the gate of first leg at various time periods are shown in the Fig. 15. Shoot through condition is added to produce the boosting of the output voltage. The phase to phase output voltage of three phases is shown in Fig. 16. The line currents waveforms of induction motor are shown in Fig. 17. The speed of the induction motor is increased up to 0.65 seconds and settles at 1450 rpm as shown in the Fig. 18. The FFT Analysis is done for the line current and the spectrum is shown in Fig. 19. The THD is 5.18%.

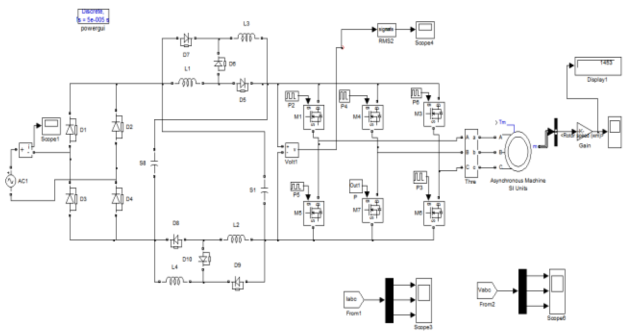

Fig. 10. SLQZSI fed induction motor drive without fileter

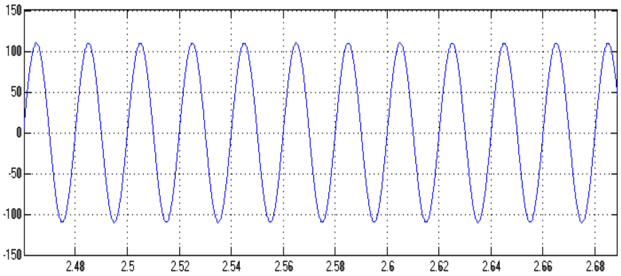

Fig. 11. AC input voltage

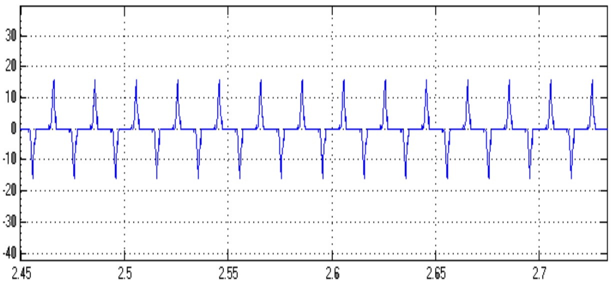

Fig. 12. AC source current

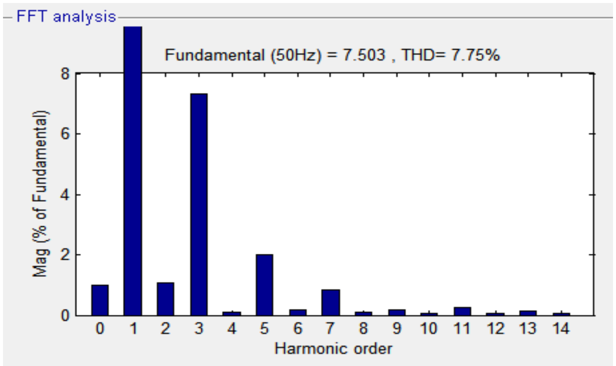

Fig. 13. FFT Analysis for source current

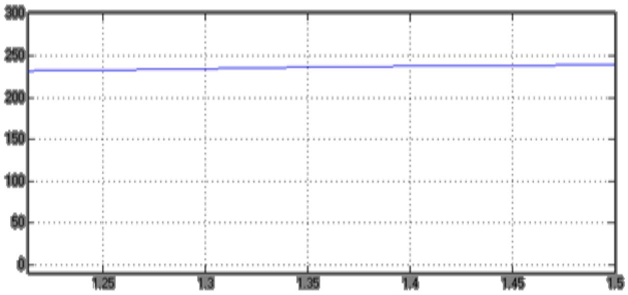

Fig. 14. Rectifier output voltage

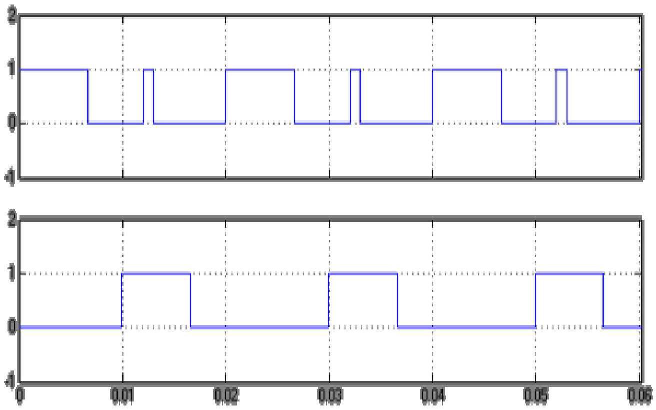

Fig. 15. Driving pulses for first leg.

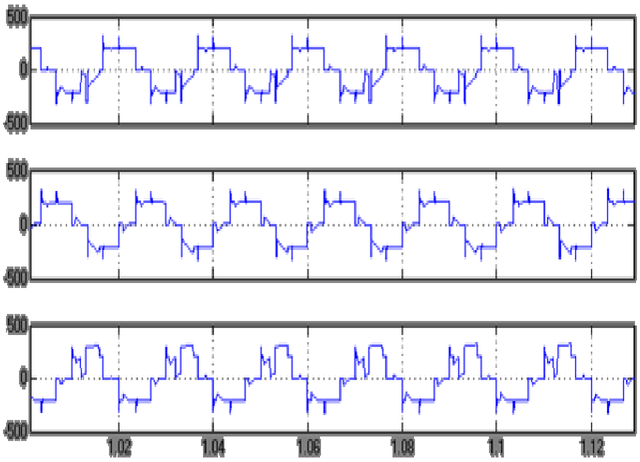

Fig. 16. Phase to Phase output voltage.

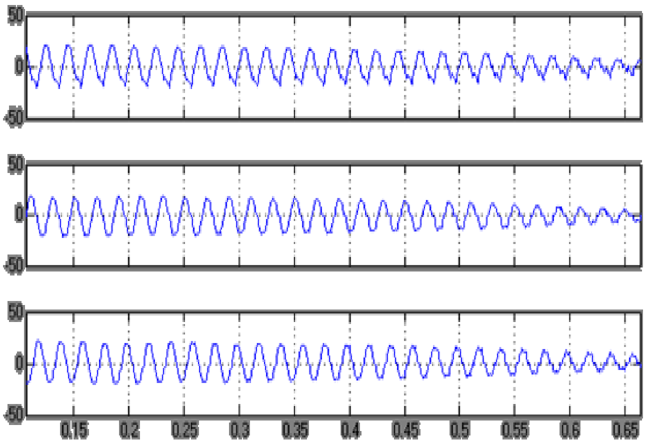

Fig. 17. Line current waveforms of Induction Motor

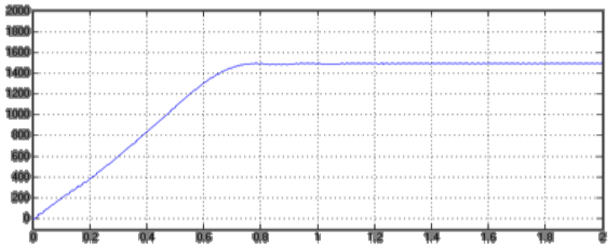

Fig. 18. Rotor speed

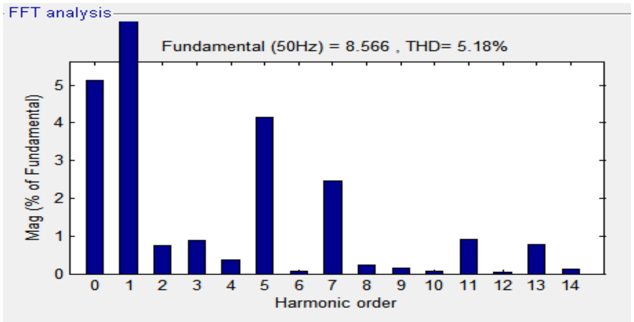

Fig. 19. FFT Analysis for Line current

B. SLQZSI with filter:

The Circuit diagram of SLQZSI fed induction motor drive with EMI filter at the input and LC filter at the output is shown in Fig. 20. The Ac input voltage of 110V (peak amplitude) and 50Hz are to be applied is shown in Fig. 21. Fig. 22 shows the input current of 11A is applied to SLQZSI fed induction motor drive with EMI and LC filter. The current is nearby sinusoidal due to the addition of EMI filter. FFT Analysis for the source current is done and the spectrum is shown in Fig. 23 and its THD is 4.38%. The DC output voltage of the rectifier is shown in Fig. 24. The voltage is 240V. The circuit parameters are chosen as follows.

1. SLQZ-source impedance network: $L1=L2=1x10^{-3}H$, $L3=L4=1.5x10^{-3}H$, $C1=9000x10^{-6}F$.
2. The switching frequency fs=1/T=10KHz.
3. All components are assumed ideal.
4. Three phase induction motor load: 5.4HP (4KW), 400V, 50Hz, 1430RPM.
5. Diode D1, D2, D3, D4, D5, D6: R=0.001Ω, forward voltage=0.8V, snubber resistance=500 Ω, snubber capacitance=$250x10^{-9}F$.
6. EMI filter has 10V (peak amplitude) AC voltage source and 50Hz frequency.
7. EMI filter components are chosen as r1=1 Ω, $L=20x10^{-3}=L1$, $C1=5x10^{-9}=C$, $C2=100x10^{-6}=C3$.

The driving pulses applied to the first leg at various time periods are shown in Fig. 25. The line voltage waveforms and line current waveforms are shown in Fig. 26 and Fig. 27 respectively. The speed of the induction motor is increased upto 0.65 seconds and settles at 1450 rpm as shown in the Fig. 28. FFT analysis is done for the motor current and the spectrum is shown in Fig 29. The THD is 4.16%. The summary of input and output current THD is with and without filter is given in Table 1. The input current THD reduces by 3.37% and the output current THD reduces by 1.02% by introducing the filters.

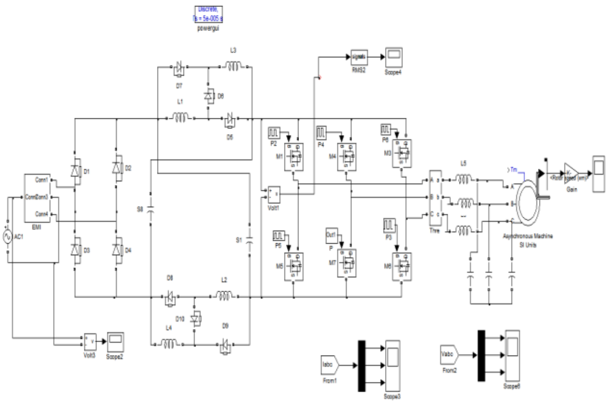

Fig. 20. SLQZSI fed Induction motor drive with EMI and LC filter

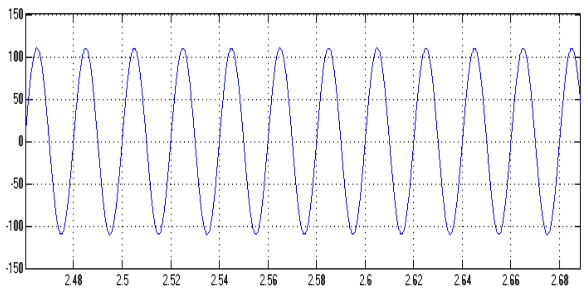

Fig. 21. AC Input Voltage

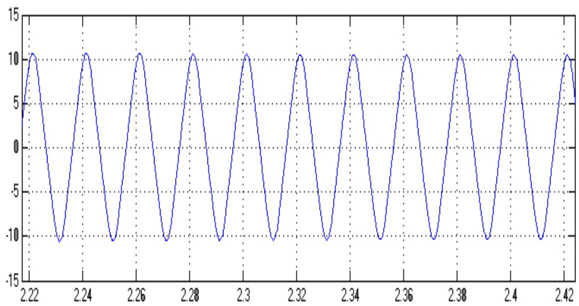

Fig. 22. AC Input Current

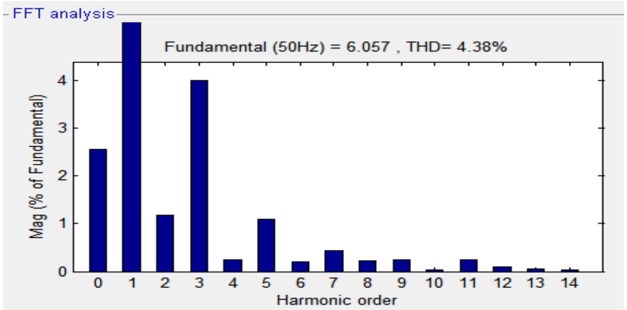

Fig. 23. FFT Analysis for Source Current without Filter

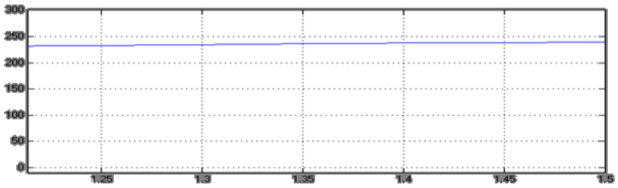

Fig. 24. Rectifier output voltage

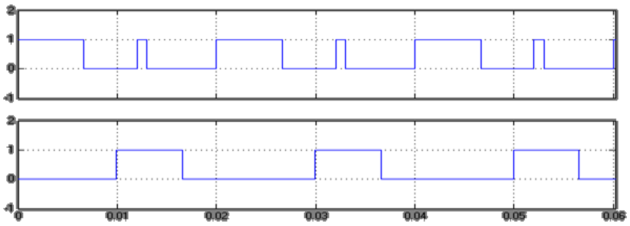

Fig. 25. Driving pulses for first leg

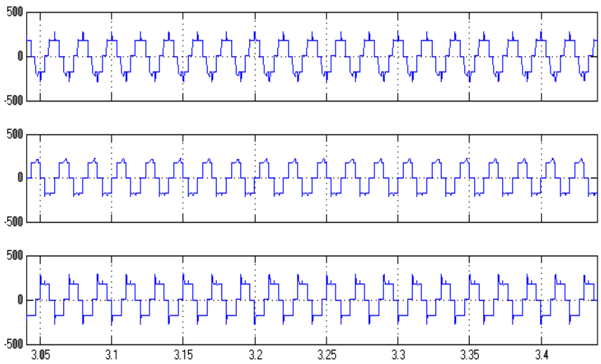

Fig. 26. Phase to phase output voltage

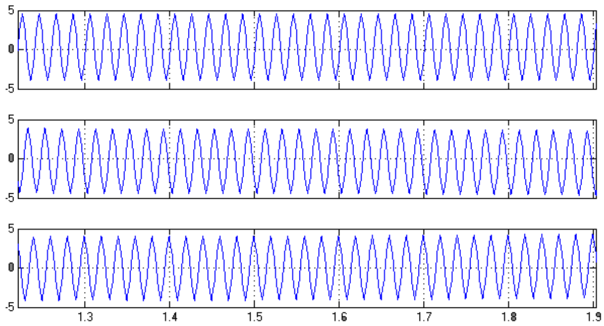

Fig. 27. Inverter output phase current

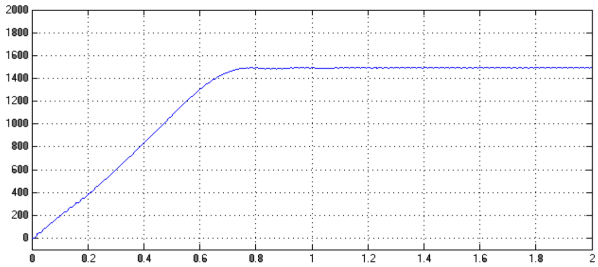

Fig. 28. Rotor speed

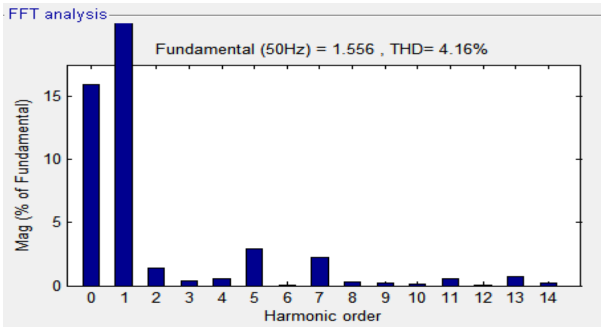

Fig. 29. FFT Analysis for source current with filter

Table. 1.Comparison of Input and output current harmonics THD of SL-QZSI with and without EMI & LC filter

Switched Inductor Quasi-Z-Source	Input Current Harmonics THD	Output Current Harmonics THD
Without EMI & LC Filter	7.75%	5.18%
With EMI & LC Filter	4.38%	4.16%

6. Conclusions

A Switched inductor Quasi Z Source inverter fed induction motor drive with and without input/output filters is modeled and simulated successfully using MATLAB Simulink. The simulation results indicate that THD in the input current and output current are reduced by introducing EMI filter at the input and the LC filter at the output. The advantages of the proposed system are reduced heating and improved efficiency of the induction motor drive. The disadvantages of the present system are increased number of diodes and passive elements.

The present work deals with reduction of EMI and reduction of load harmonics in open loop system.

References

[1] T. Kerekes, R. Teodorescu, M. Liserre, C. Klumpner, and M. Sumner, “Evaluation of three-phase transformer less photovoltaic inverter topologies,” IEEE Trans. Power Electron., vol. 24, no. 9, pp. 2202–2211, Sep. 2009.

[2] F. Gao, P. C. Loh, R. Teodorescu, and F. Blaabjerg, “Diode-assisted buck- boost voltage-source inverters,” IEEE Trans. Power Electron., vol. 24, no. 9, pp. 2057–2064, Sep. 2009.

[3] M. Shen, A. Joseph, J. Wang, F. Z. Peng, and D. J. Adams, “Comparison of traditional inverters and Z-source inverter for fuel cell vehicles,” IEEE Trans. Power Electron., vol. 22, no. 4, pp. 1453–1463, Jul. 2007.

[4] K.Nguyen,Y.-G.Jung,andY.-C.Lim,“Single-Phase AC-AC converter based on quasi-Z-source topology,” IEEE Trans. Power Elec- tron., vol. 25, no. 8, pp. 2200–2210, Aug. 2010.

[5] F. Z. Peng, “Z-source inverter,” IEEE Trans. Ind. Appl., vol. 39, no. 2, pp. 504–510, Mar./Apr. 2003.

[6] D. Grahame Holmes, Thomas A. Lipo, “Pulse width modulation for power converters : principles and practice, Wiley-IEEE press, October 2003.

[7] P. C. Loh, D. M. Vilathgamuwa, G. J. Gajanayake, Y. R. Lim, and C.W. Teo, “Transient modeling and analysis of modulated Z-source inverter,” IEEE Trans. Power Electron., vol.22, no.2, pp.498–507, Mar. 2007.

[8] J. B. Liu, J. G. Hu, and L. Y. Xu, “Dynamic modeling and analysis of Z- source converter-derivation of AC small signal model and design-oriented analysis,” IEEE Trans. Power Electron., vol. 22, no. 5, pp. 1786–1796, Sep. 2007.

[9] P. C. Loh, C. J. Gajanayake, D. M. Vilathgamuwa, and F. Blaabjerg, “Evaluation of resonant damping techniques for Z-source current-type inverter,” IEEE Trans. Power Electron., vol. 23, no. 4, pp. 2035–2043, Jul. 2008.

[10] F.Z.Peng, M.Shen, and Z.Qian,“Maximum boost control of theZ-source inverter,” IEEE Trans. Power Electron., vol. 20, no. 4, pp. 833–838, Jul. 2005.

[11] M. Shen, J. Wang, A. Joseph, F. Z. Peng, L. M. Tolbert, and D. J. Adams,“Constant boost control of the Z-source inverter to minimize current ripple and voltage stress,” IEEE Trans. Ind. Appl., vol. 42, no. 3, pp. 770–778, May/Jun. 2006.

[12] P. C. Loh, D. M. Vilathgamuwa, Y. S. Lai, G. T. Chua, and Y. Li, “Pulse- width modulation of Z-source inverters,” IEEE Trans. Power Electron., vol. 20, no. 6, pp. 1346–1355, Nov. 2005.

[13] P. C. Loh, F. Blaabjerg, and C. P. Wong, “Comparative evaluation of pulse width modulation strategies for Z-source neutral-point-clamped inverter,” IEEE Trans. Power Electron., vol. 22, no. 3, pp. 1005–1013, May 2007.

[14] J. Anderson and F. Z. Peng, “Four quasi-Z-source inverters,” in Proc. IEEE PESC’08, Jun. 2008, pp. 2743–2749.

[15] Y. Tang, S. Xie, C. Zhang, and Z. Xu, “Improved Z-source inverter with reduced Z-source capacitor voltage stress and soft-start capability,” IEEE Trans. Power Electron., vol. 24, no. 2, pp. 409–415, Feb. 2009.

[16] M. K. Nguyen, Y. G. Jung, and Y. C. Lim, “Single-phase ac-ac converter based on quasi-Z-source topology,” IEEE Trans. Power Electron., vol.25, no. 8, pp. 2200–2210, Aug. 2010.

[17] K. Youand M. F. Rahman,“Analytical model of conduction and switching losses of matrix-Z-source converter,” J. Power Electron., vol. 9, no. 2, pp. 275–287, Mar. 2009.

[18] P. C. Loh, F. Gao, P. C. Tan, and F. Blaabjerg, “Three-level ac–dc–ac Z- source converter using reduced passive component count,” IEEE Trans. Power Electron., vol. 24, no. 7, pp. 1671–1681, Jul. 2009.

[19] P. C. Loh, F. Gao, F. Blaabjerg, and S. W. Lim, “Operational analysis and modulation control of three-level Z-source inverters with enhanced output waveform quality,” IEEE Trans. Power Electron., vol. 24, no. 7, 1767–1775, Jul. 2009.

[20] M. K. Nguyen, Y. G. Jung, and Y. C. Lim, “Single-phase Z-source ac-ac converter with wide range output voltage operation,” J. Power Electron., vol. 9, no. 5, pp. 736–747, Sep. 2009.

[21] M. K. Nguyen, Y. G. Jung, Y. C. Lim, and Y. M. Kim, “A single-phase Z-source buck–boost matrix converter,” IEEE Trans. Power Electron., vol. 25, no. 2, pp. 453–462, Feb. 2010.

[22] Zhu, K. Yu, and F. L. Luo, “Switched-inductor Z-source inverter,” IEEE Trans. Power Electron., vol. 25, no. 8, pp. 2150–2158,Aug.2010.

[23] .J.Gajanayake,F.L.Luo,H.B.Gooi,P.L.So,andL.K.Siow,“Extended boost Z-source inverters,” IEEE Trans. Power Electron., vol. 25, no. 10, pp. 2642–2652, Oct. 2010.

[24] W. Qian, F. Z. Peng, and H. Cha, “Trans-Z-source inverters,” in Proc. IEEE IPEC-Sapporo 2010, pp. 1874–1881, Jun. 2010.

[25] B. Axelrod, Y. Berkovich, and A. Ioinovici, “Switched-capacitor/ switched-inductor structures for getting transformerless hybrid dc-dc PWM converters,” IEEE Trans. Circ. Syst. I: Fundamental Theory Appl., vol. 55, no. 2, pp. 687–696, Mar. 2008.

[26] M. Zhu, F. L. Luo, and Y. He, “Remaining inductor current phenomena of complex dc-dc converters in discontinuous conduction mode: General concepts and case study,” IEEE Trans. Power Electron., vol. 23, no. 2, pp. 1014–1019, Mar. 2008.