International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 3, No. 1, March 2013, pp. 41~52
ISSN: 2088-8694

Induction Motor Speed Control using Indirect Z-source Matrix Converter with PSO-PI Controller under Various Break Conditions

Majid salim *, Mohammad sarvi **
* Islamic Azad University Saveh Branch, Ma.salim1986@gmail.com
** Imam Khomeini International University, Sarvi@ikiu.ac.ir

Article Info

Article history:

Received Nov 11, 2012
Revised Jan 2, 2013
Accepted Jan 20, 2013

Keyword:

Indirect Z-source Matrix Converter
Induction motor
Particle swarm optimization (PSO) algorithm

ABSTRACT

Since induction motors are preferred over direct current machines in the view of cost and simplicity, they have widely been used in industry. In this paper, the speed of the three-phase induction motor has been controlled using an indirect z-source matrix converter. The method used for this purpose is flux control keeping the V/f ratio and regulating slippage. The effect of flux changes and reference velocity in this method has been taken into consideration and various electric break methods on the motor have been studied accordingly. Coefficients of PI controllers have been obtained in the proposed system for desirable response by PSO Algorithm. The proposed system with the respective converter has been simulated in SIMULINK environment using the information of an induction machine by MATLAB Software. The results show to using the proposed system and indirect z-source matrix converter, appropriate velocity and desirable torque are obtained in a short time.

Corresponding Author:

Majid Salim
Islamic Azad University Saveh Branch
Email: ma.salim1986@gmail.com

1. INTRODUCTION

Among the families of power converters, because of its ability of direct power conversion (AC/AC), Matrix Converter has been of great interest. This kind of converter was presented by Venturini in 1980 [1] and subsequently, in 1989, it was analyzed in detail by Venturini and Alesina [2] accordingly. Due to such advantages as sinusoidal input-output current, no need of bulky reactive power conserving elements, its ability of regulating input power factor per each load, its monolithic and simplicity design and great ability of recovery, Matrix Converter has been of great interest in the recent years as a desirable replacement of traditional converters of indirect power converter [3-6]. Complicated switching strategy and a huge number of switches used in the converter have caused that the same has found no trading utilization yet [2-8]. One of the methods for overcoming the inherent disadvantage of the matrix converter, i.e. low voltage transfer ratio is to use a z-source converter in the matrix converter. The idea of z-source matrix converter was first put forward in 2008 by Zhong and Song introducing two direct and indirect z-source matrix converters [10]. When the matrix converter is used for feeding induction motor, there is a possibility for passage of bidirectional current, using bi-directional switches. Thus, changes of velocity-torque may be done in four quadrants [11]. From among control methods for speed control of the induction motor using the matrix converter, one can point out field oriented control with Venturini pulses and modulation with a voltage transfer ratio less than 0.866, in harmonic with the signals of the converter [12], direct vector control and vector space control using modulation technique [13] creating errors in calculations at low velocities due to slow changes in parameters [14].

In this paper, control of the velocity of induction motor is conducted using the z-source indirect matrix converter and the proposed method by which voltage transfer ratio in required states shall be larger than 1. This work cause decrease voltage stress on switches and power losses in the converter. On the other hand, there is a possibility to control the velocity of the motor with a less voltage less than nominal quantity of the motor. In part 2, the z-source indirect matrix converter is presented. In part 3, the proposed system for control of the speed of the induction motor and in part 4, the simulated results is studied.

2. Z-source Indirect Matrix Converter (ZIMC)

Figure 1 shows the z-source indirect matrix converter. This converter can be used for removal of innate defect of the converter, i.e. low voltage transfer ratio.

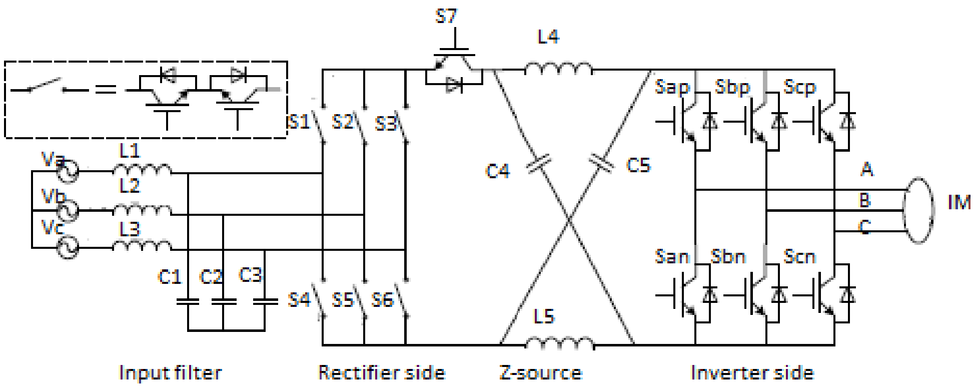


Figure 1. Z-source Indirect Matrix Converter

2.1. Configuration and operational principles

Z-source Indirect Matrix Converter, described in Figure 1 consists of a rectifier, an inverter, z-source converter and a filter. The rectifier part comprises six bi-directional switches. The part of impedance network (Z-source), connecting the rectifier part to the inverter, increases voltage transfer ratio. The inverter part also consists of 6 unidirectional switches and it connecting converter to the load. In order to control the switches in the rectifier part, PWM technique has been used so that the difference between the most positive and the most negative input three-phase voltage is put in the rectifier output at every moment. Working and switching stages have been indicated in Figure 2.

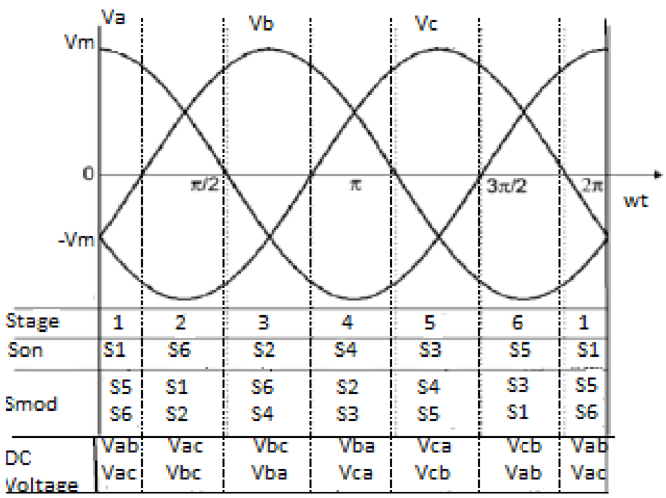


Figure 2. Working stages of the rectifier part in the converter

According to Figure 2, a time cycle consists of six parts. During each part, one of the input phases enjoys the largest quantity of voltage. For example, at part 1, V_a has the largest quantity and at part 2, V_b has the largest quantity. Impedance-network (Z-source) works at two states of Active and Shoot-through. All of these states are created using inverter switches. In order to control work states of the z-source converter with the inverter, Simple Boost Control method [15], indicated in Figure 3, has been used. In this method, two director lines, which larger than or equivalent to the maximum three-phase reference voltage quantity has been used for control of Shoot-through ratio. When the shape of the triangular wave is larger than upper line (V_p) or smaller than lower line (V_n), the inverter stands at Shoot-through state. Other switching states are similar to Sinusoidal Pulse Wide Modulation method.

2.2. Calculation of voltage transfer ratio

If we consider the three-phase input voltage in form of the following formula:

$$V_i = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = V_m \begin{bmatrix} Cos\ \omega t \\ Cos\ (\omega t - 120) \\ Cos\ (\omega t + 120) \end{bmatrix} \tag{1}$$

Because of use of PWM method for control of the rectifier, calculating the voltage average at each stage of Figure (2) (for example, stage 1) consists of two parts of V_{ab} and V_{ac}. The ratio of each at stage 1 is written according to the following formula:

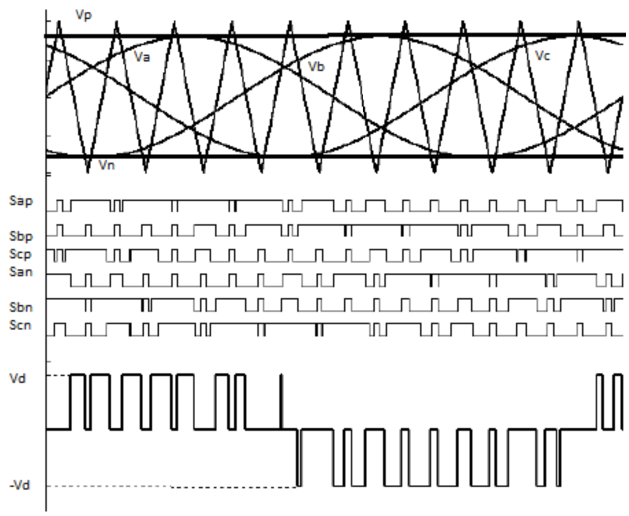


Figure 3. Simple Boost Control Method

$$d_{ab} = \frac{-V_b}{V_a} \quad , \quad d_{ac} = \frac{-V_c}{V_a} \tag{2}$$

Where d_{ab} and d_{ac} are duty cycles are associated with V_{ab} and V_{ac}. Considering Figure (2), voltage average at stage 1 is calculated as follows:

$$\overline{V_{rec}} = d_{ab} V_{ab} + d_{ac} V_{ac} = \frac{3.V_m}{2|Cos\ \omega_t|} \tag{3}$$

While W_t is angular frequency of input voltage.

With respect to the z-source converter and in consideration of equivalent circuit 2 of Shoot-Through Working State of Figure (4_a) and Active figure (4_b), voltage transfer ratio is calculated as follows:

In Shoot-through State:

$$V_l = V_c \quad , \quad V_d = 0 \tag{4}$$

In Active state:

$$\begin{cases} V_l = V_{rec} - V_c \\ V_d = V_c - V_l \end{cases} \tag{5}$$

Figure 4. Operational states of z-source converter: a) Shoot-through b) Active state

Regarding the period of Shoot-Through state as T_1 and the period of Active State as T_2 and concerning the average of inductor voltage is zero during a period, we shall have:

$$\langle V_l \rangle = \left((T_1 . V_c) + T_2 (V_{rec} - V_c) \right) \frac{1}{T} = 0 \tag{6}$$

$$\frac{V_c}{V_{rec}} = \frac{T_2}{T_2 - T_1} \tag{7}$$

$$V_d = V_c - V_l = 2V_c - V_{rec} = \frac{T_2}{T_2 - T_1} V_{rec} = B . V_{rec} \tag{8}$$

$$\mathrm{B} = \frac{1}{1 - 2\mathrm{D}_0} \tag{9}$$

Where:

$$D_0 = \frac{T_1}{T}$$

$$V_o = \frac{m . V_d}{2} = m \times B \times V_{rec} \tag{10}$$

Where m is modulation index.

On the other hand, since Simple Boost Control method is used in the inverter part, the relation between D_0 and m is written as follows:

$$D_0 = 1 - m \tag{11}$$

When equation (11) is replaced in equations (8) and (10):

$$V_{ac} = \frac{3m\ V_i}{2(2m-1)Cos(\theta_a)} \tag{12}$$

3. The proposed system

Figure (5) shows the proposed system for speed control of induction motor. In a closed loop system, the signal of the velocity taken from the motor is compared to the reference velocity and the signal of velocity error is applied to the proportional-integral controller. The controller's output will be applied to the regulator of slippage velocity so that slippage velocity ($(w)_{sl}$) will be obtained. Synchronous velocity (W_{ms}), the first harmonic frequency and the output voltage converter and working frequency of the motor are determined. Moreover, using (W_{ms}), required voltage of the motor is determined by flux control block. In this state, if V is less than maximum output voltage of the matrix converter in without z-source impedance converter state, Modulation index is used at Block 1 in order to regulate desirable voltage in converter output. In fact, Block 1 is taken from Equation (9) irrespective of B coefficient. Otherwise, since the required voltage range exceeds maximum output voltage of the converter, generated by Block 1.from Block 2, which is associated with application of the z-source converter, is issued in order to obtain the required voltage range. These conditions are provided using a Selector. The structure of Block 1 has been obtained from Equation 13, and Block 2, from Equation (14). Considering Equation 14, due to dependency of D_0 on the quantity of m, the equation has been written based on m. Use of the proposed system leads into decrease of voltage stress and losses in converter switchers since it doesn't use the z-source converter and Shoot-through state at low frequencies.

$$\frac{V_{ac}}{\frac{V_d}{2}} = \frac{\mathrm{V_{con}}}{\mathrm{V_{tri}}} \Longrightarrow \mathrm{V_{tri}} = \frac{\mathrm{V_{con}}}{\mathrm{V_{ac}}} \times \frac{\mathrm{V_d}}{2} \tag{13}$$

As:

$$M = \frac{V_{con}}{V_{tri}}$$

Where V_{con} is control voltage and V_{tri} is triangular voltage in Sinusoidal Pulse Wide Modulation, V_d is output voltage of the rectifier part and V_{ac} is the first harmonic range and output voltage of the converter.

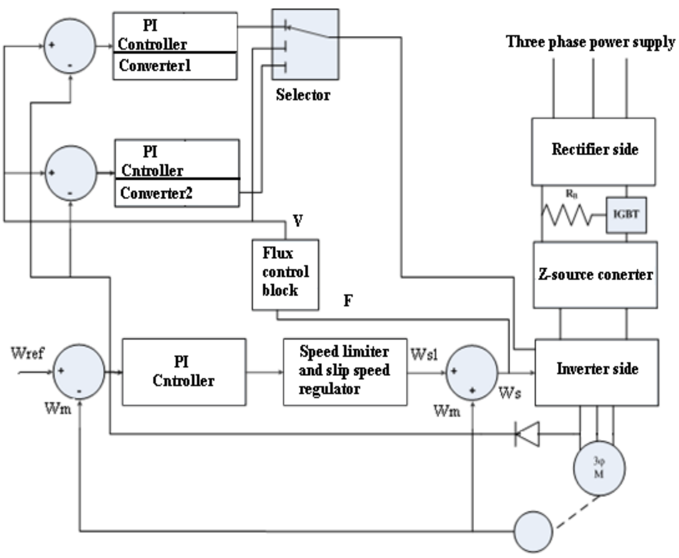


Figure 5. The proposed system

$$\frac{V_{con}}{V_{tri}} = \frac{V_{ac}}{20V_{ac} - \frac{V_d}{2}} \tag{14}$$

Consequently, output voltage changes at flux control block are converted to modulation coefficient and then to V_{tri}.

3.1. PSO-PI controller

Pso is a novel population based optimization method that was introduced by Kennedy and Eberhart in 1995 for stimulating bird flock and fish school [13]. It uses a number of particles that constitute a swarm. That swarm continuously updates the knowledge of given searching space. Each particle in the swarm involves a position array and a velocity array. The position array is a possible solution to the problem. Let x and v denote a particle coordinates and its corresponding flight velocity in a search space, respectively. The particle updates their velocities and positions as:

$$V^{k+1} = W^k V^k + c_1 r_1 (P_{best} - x^k) + c_2 r_2 (G_{best} - x^k) \quad (15)$$

$$x^{k+1} = x^k + xV^{k+1} \quad (16)$$

Where k is current iteration. c_1 and c_2 are two positive factors called acceleration coefficients. r_1 and r_2 are two random number in range of [0,1] with uniform distribution. P_{best} is the best previous position of particle and G_{best} is the best particle among all the particles. W^k is inertia weight suitable selection of W provides a balance between global and local explorations.

X is constriction factor to ensure convergence is a function of c_1, c_2 as below:

$$x = \frac{2}{2 - c - \sqrt{c - 4c}} \quad (18)$$

Where $c = c_1 + c_2$ and $c \rangle 4$

In the proposed system (Fig.5), three PI controllers have been used. Each has two variables of P and I and six variables are defined for the system totally. In order to achieve improved quantities for the system, a primary population consisting of 10 particles was defined. Each comprises all six variables. Consequently, a matrix of 10 × 6 is defined. After repetition for three times and according to the target function, which is minimization of the velocity and torque error, the improved quantity of controllers has been obtained.

3.2. Attainment of break state

When a step change in velocity command signal occurs in a system for less than that of a working motor speed, due to negative slippage, the motor will be in generator's state, current direction in the induction motor is reversed, blocking its direction through reverse parallel diodes of the inverter part of the matrix converter toward z-source converter and causes the capacitors of the converter to be charged. If the generated energy is not employed properly, the voltage of the capacitors will be increased and it may damage semi-conducting components. During dynamic break state, considering figure 6, one of the methods is to discharge the energy of the capacitor in a resistance and to lose the said energy in form of heat.

Another method is to use bi-directional switches in the rectifier part. For this purpose, it is possible to return the power back to the network by maintaining the switches that make transmission of power of the source impedance toward the feeding source of the network in "on" state. Moreover, this point must be taken into consideration that during generator's state, the power delivered by the motor to the source may exceed its power for absorption of the same and causes explosion of the capacitors of the z-source converter. Thus, attainment of break state is desirable using a combination of both methods described earlier. If we consider the said converter considering another aspect, dynamic break method is cost-effective for the system considering other aspects. Because of the capacitors of the z-source converter have been used as dynamic break capacitors and the switches of the rectifier part for return the power back to the network and eventually, there is no need to use extra circuits, which noticeably decreases costs and losses of energy in the circuit.

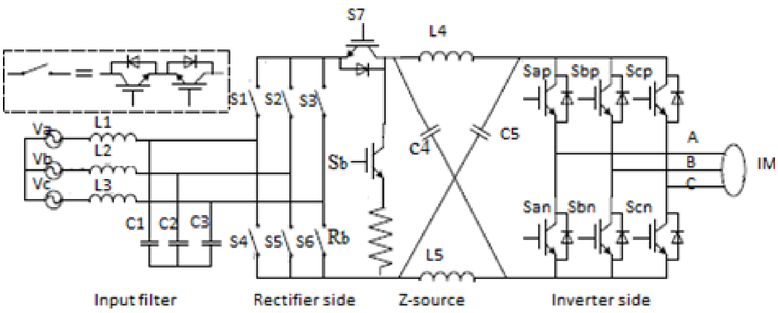


Figure 6. Attainment of break state

4. Simulation Results

In order to study the performance of the proposed system, it has been simulated in MATLAB-SIMULINK environment. Such simulation has been conducted in the following states:

A. Startup state.
B. Break operational state.
C. Operational state with a step up and step down at reference speed.
D. Operational state with a step up and step down at load torque.

Respective results of simulation for indirect z-source matrix converter for speed control of the induction motor in various operational conditions have been shown as per figures 7-13. For this purpose, primary parameters for simulation have been shown in the 1, 2 tables:

TABLE 1. PARAMETERS OF THE MOTOR USED IN SIMULATION

Parameters	Values[unit]
Rating Power	5[KW]
Frequency	60[HZ]
Rating Speed	1750[r.p.m]
Poles	4
Line Voltage	460[V]

TABLE 2. PARAMETERS OF THE CONVERTER USED IN SIMULATION

Parameters	Values[unit]
Input voltage	5[KW]
InputFrequency	60[HZ]
Z-source Inductors	5.3[mH]
Z-source Capacitors	470[µF]
Rectifier Side Frequency Switch	20[KHZ]
Inverter Side Frequency Switch	10[KHZ]

Figure 7 shows motor startup state with PI controllers. In this condition, speed response and dynamic is slowest than figure (8-a). Figure 8 shows velocity, electric torque, and current in induction motor and inductor current of the z-source converter part and load torque in startup condition with PSO-PI controller. In this state, at 3.2 seconds, a load of 3N.m is devised on the shaft of the motor.

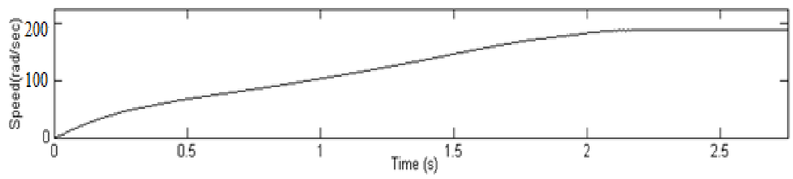
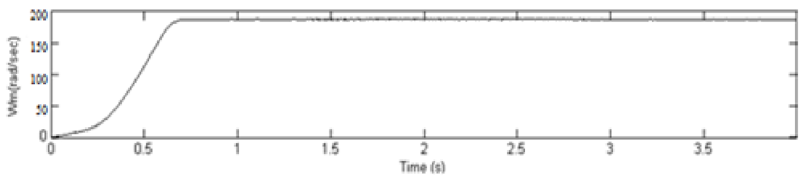
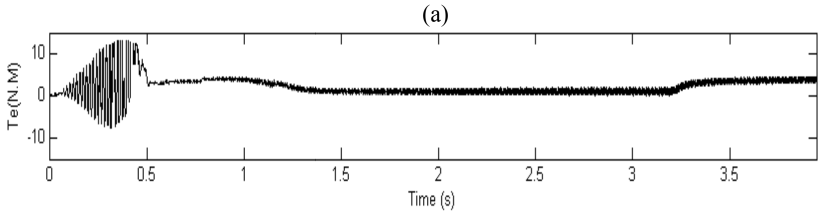


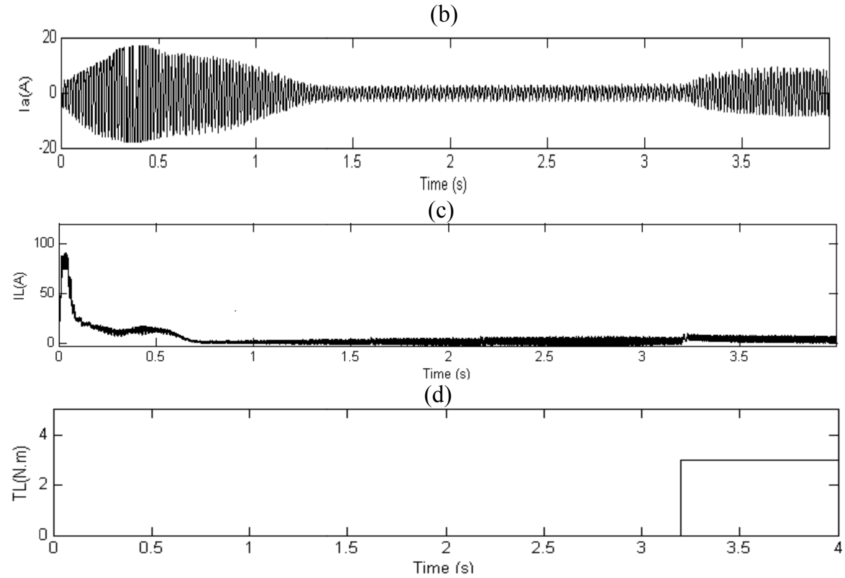
Figure 7. motor startup state with PI controllers



(a)



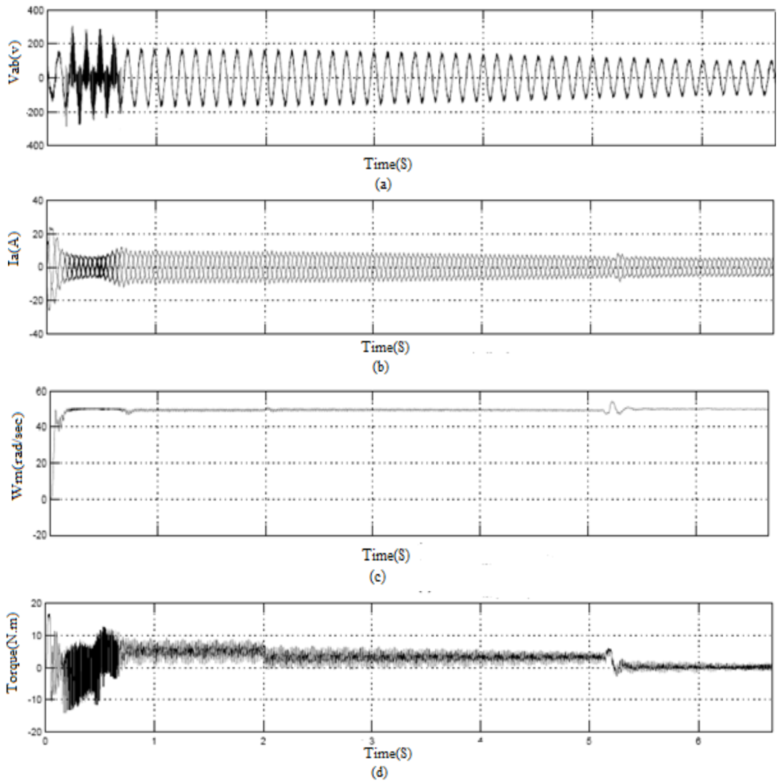
(b)

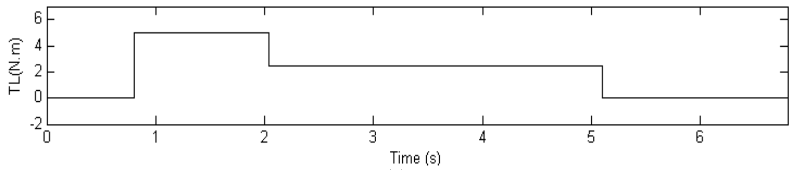


(e)

Figure 8. Startup condition a) velocity curve b) torque curve c) motor current d) Z-source inductor current e) load torque

Figure (9) indicates line voltage, three-phase current, velocity and electric torque of the motor for change in load torque respectively. In this state, first, load torque is 5 [N.m] to the motor and at t=2 [sec], torque is decreased to 2.5 [N.m] and at t=5.1 [Sec], the torque equals to zero and the only load on the shaft of the motor are friction and inertia. During this process, it is found that motor velocity enjoys minor fluctuations and finally, it remains constant at 50 [rad/sec].





(e)

Figure 9. System parameter response to load torque changes a) line voltage b) three-phase motor current c) motor velocity d) electromagnetic torque e) load torque.

Figure (10) shows Command signal indicates the velocity, induced to the system. Respective results of changes of motor parameters and converter are shown in figures (10-12).

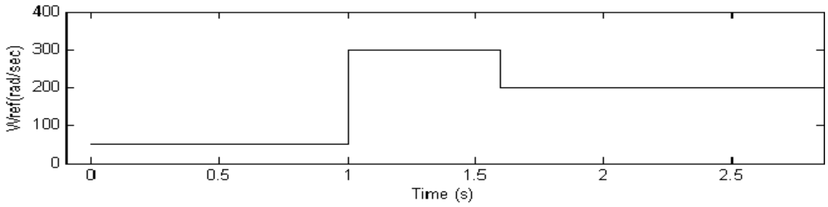
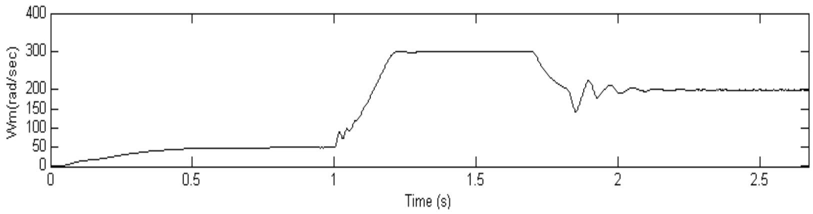
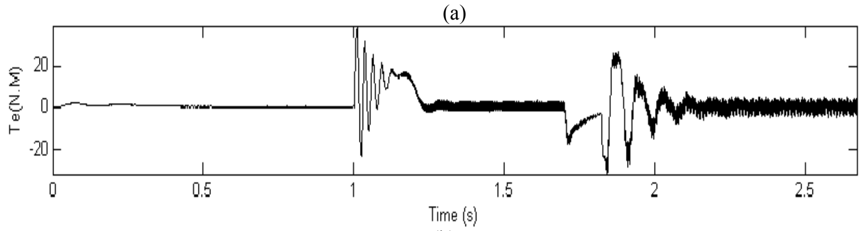


Figure10. Command signal induced to the system

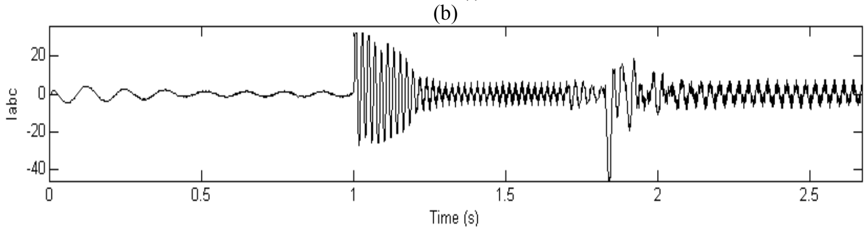
Figure (11) shows velocity changes, torque, single-phase current of the motor, output voltage of matrix converter and output voltage of z-source for changes of command signal of velocity (as per figure 9) through resistive break method.



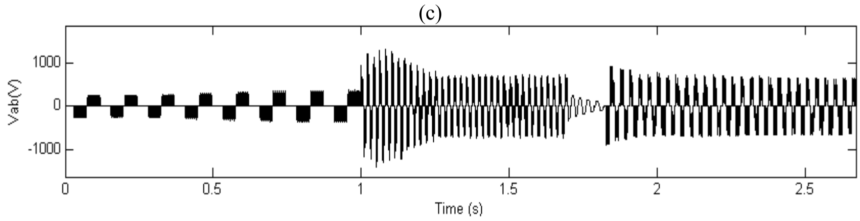
(a)



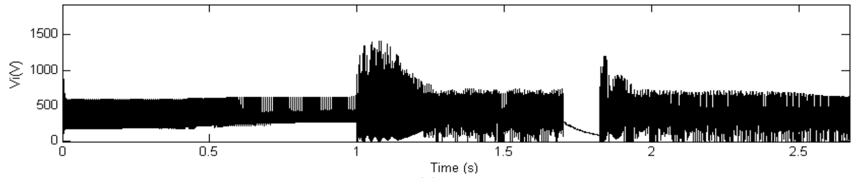
(b)



(c)

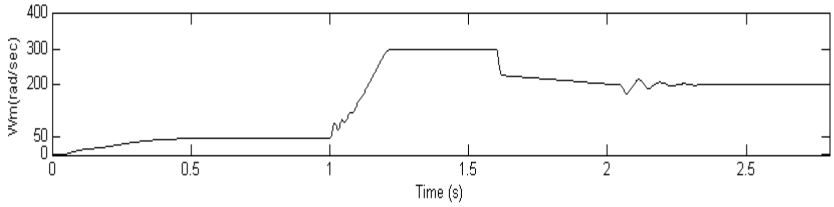


(d)

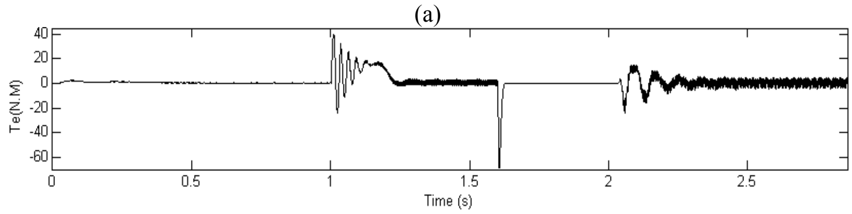


(e)

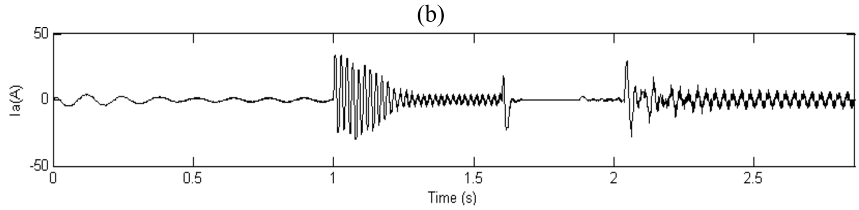
Figure11. Parameter changes compared to command signal changes at resistive break state a) velocity b) torque c) single-phase current of the motor d) output voltage of matrix converter e) output voltage of Z-source converter.



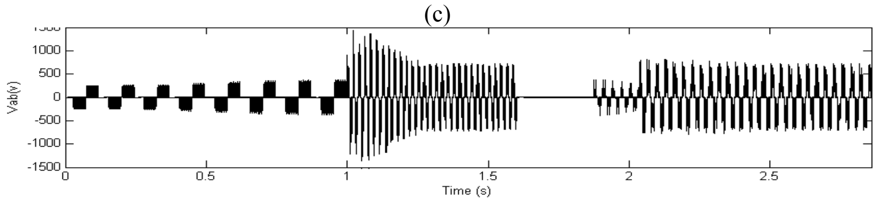
(a)



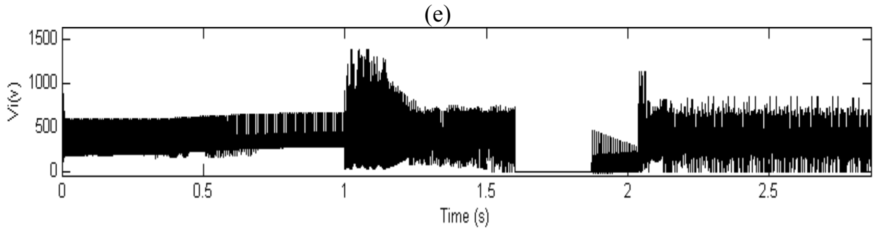
(b)



(c)



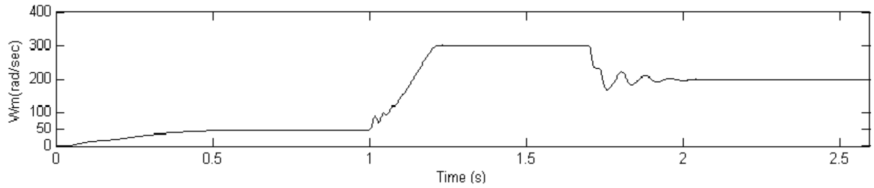
(e)



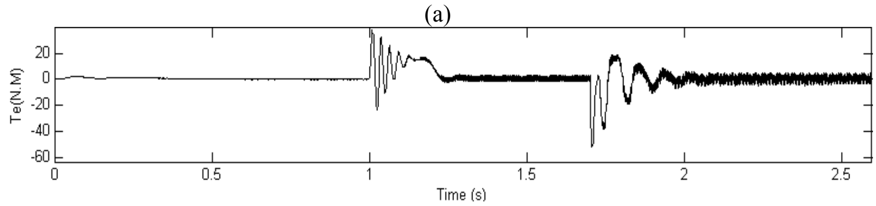
(f)

Figure 12. Parameter changes compared to command signal changes at generator's break state a) velocity b) torque c) single-phase current of the motor d) output voltage of matrix converter e) output voltage of Z-source converter.

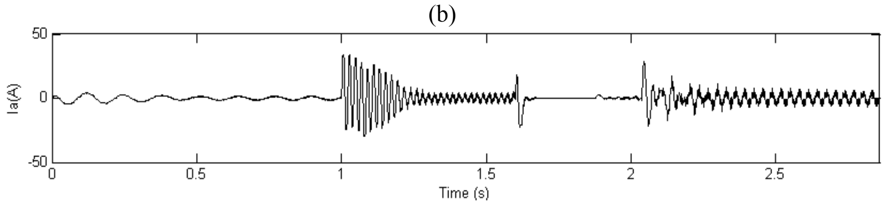
Figure 13 shows variation in motor parameter such as 11, 12 figures, compared to command signal changes. In this condition, method breaking is resistive- generator. In this state damping time of velocity and torque fluctuations are better than two mentioned methods. Also fluctuations amplitude in velocity is less than breaking resistive state and fluctuations amplitude in torque is less than generation breaking method.



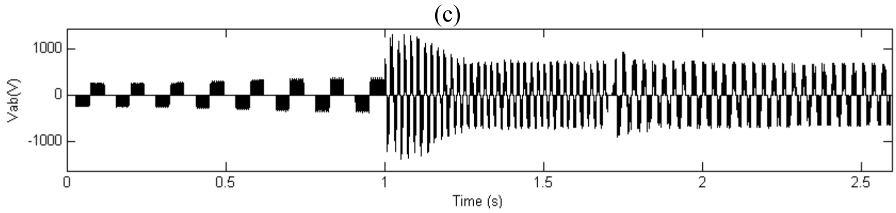
(a)



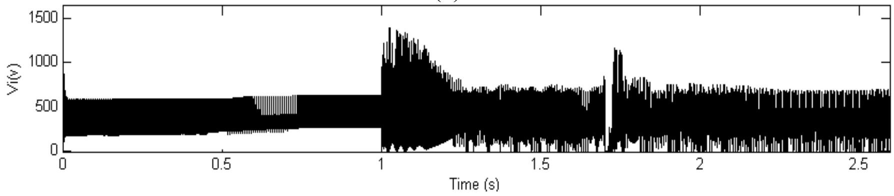
(b)



(c)



(d)



(e)

Figure 13.Changes in motor parameters and converter, compared to command signal changes in resistive-generator breaking state a) velocity b) torque c) three-phase current of the motor d) output voltage of the converter e) output voltage of Z-source converter.

5. CONCLUSION

In this paper, simulation of z-source indirect matrix converter for speed control of the induction motor has been studied. In order to study the improvement of characteristics, corresponding results have been compared to PI results. Respective characteristics of z-source converter have been used for increase voltage transfer ratio in the matrix converter. With respect to study of various break methods and in consideration of the results obtained in this regard, it has been revealed that innate characteristic of the converter can be used in order to establish various break states and extra circuits can be discarded accordingly. Moreover, use of the offered system has led to increase and decrease of voltage in the converter by Shoot-through coefficient and that of modulation index for various frequencies of management resulting in decrease of voltage stress and losses in the switches of the converter. Considering number of PI controllers in the system, PSO Algorithm has been used for improvement. Corresponding results have shown that this method enjoys more desirable reactions compared to common PI.

REFERENCES

[1] M. Venturini, "A new sine wave in sine wave out, conversion technique which eliminates reactive elements", *proceedings of powercon 7,* pp.E3 │1-E3 │15, 1980.
[2] A. Alesina, M. Venturini, "Analysis and design of optimum amplitude nine switch direction AC-AC converters", *IEEE Trans. on Power Electron.,* vol.4, no.1, pp.101-112, 1989.
[3] P. W. Wheeler, J. Rodriguez, J. C. Clare, "Matrix converters a technology review", *IEEE Trans. on Ind. Electron*, vol. 49, no. 2, pp. 276-288, 2002.

[4] J. W. Kolar, M. Baumann, F. Schafmeister, H. ertl, “Novel three ac-dc-ac spurse matrix converter”, *IEEE APEG,* vol. 2, pp. 287-292, 2002.

[5] S. K. Wak, H. A. Toliyat, “Development of modulation strategy for two-phase ac-ac matrix converter”, *IEEE Trans. on Energy converter*, vol. 20, pp. 493-493, 2004.

[6] H. Kara ca, R. Akkaya, “A matrix converter controlled whit the optimum amplitude – direct transfer function approach”, *6th International Conference on Electrical Engineering,* ICEENG 2008, May 2008.

[7] J. W. Kolar, F. Schafmeister, S. D. Round and H. ertl, “Novel three-hase AC-AC spurse matrix converters”*, IEEE Trans. on Power Electronics,* vol.22, pp.1649-1661, 2007.

[8] P. D. Ziogas, S.I khan, and M. H. Rashid, “Analysis and design of forced commutated cycloconverter structures with improved transfer characteristics”, *IEEE Trans. on Ind. Electron,* vol. 33, pp. 271-280, Aug 1986.

[9] F. Z. Peng, “Z-Source inverter”, *IEEE Trans. On Ind. Appli,* vol. 39, no. 2, pp. 504-510, March/April 2003.

[10] W. Song and y. Zhong, “A study of Z-Source matrix converter with high voltage transfer ration”, *in conf. Rec. of IEEE VPPC,* September 2008.

[11] S. Sunter, and J. C. Clare, “A true four quadrant matrix converter induction motor drive with servo performance”, *27th Annual IEEE, Power electronic specialists conference,* volume 1: 146-151, 1996 .

[12] S. Sunter, and H. Altun, “A method for calculating semiconductor losses in the matrix converter”, *Mediterranean electro technical conference, Melecon 98, vol*. 2, pp. 1260-1264, 1998.

[13] D. Casadei, G. Sevra, A. Tani, “The use of matrix converters indirect control of indirect torque control of induction machines”, *industrial electronics of the IEEE,* volume 2., 744-449 (1998) .

[14] B. K Bose, “modern power electronics and AC drives”, (*prentice hold*. New Jersey, 153-183, 2002).

[15] F. Z. Peng, M. Shen, and Z. Qian, “Maximum boost control of the Z-Source inverter”, *IEEE Trans. on Power Electron., vol. 20, no. 4, pp. 833-838, 2005.*

BIOGRAPHIES OF AUTHORS

Majid Salim was born in Saveh, Iran, in 1986. He received his B.Sc. from Tafresh University, Tafresh, Iran in 2008 in Electronic Engineering, M.Sc. degree from Saveh University, Saveh, Iran in 2012 in Electrical Engineering. His research areas include the power electronic, robotic and industrial control.

Mohammad Sarvi received his Bachelor in Electrical Engineering in 1998 from the Amirkabir Polytechnic University, and Master and PhD degrees in 2000 and 2004, respectively, from the Iran University of Science and Technology, Tehran, Iran. His research interest includes power electronics and Renewable Energy, Facts and HVDC. Presently, Dr. Sarvi is an Assistant Professor at the International Imam Khomeini University, Qazvin, Iran.