JPE 6-1-8

A New Study on Indirect Vector AC Current Control Method Using a Matrix Converter Fed Induction Motor

Hong-Hee Lee† and Hoang M. Nguyen*

†*Department of Electrical Engineering, University of Ulsan, Ulsan Korea

ABSTRACT

This paper introduces two different types of AC current control methods for an indirect vector controlled induction motor using a matrix converter. The proposed methods combine the advantages of matrix converters with the advantages of the indirect vector AC current control methods. The first proposed method explains the basic idea of the hysteresis current control method for matrix converters and shows its capability and stability in comparison to the conventional method usually used for VSI. With the aid of the special configuration of the matrix converter, we also propose another current method which is modified from the first one in order to reduce both current ripple and torque ripple. Simulation results have verified the feasibility and the effectiveness of the proposed methods.

Keywords: voltage source inverter (VSI), induction motor (IM), matrix converter (MC), indirect vector ac current control, hysteresis current control

1. Introduction

In past two decades, the progress of power device technology and the development of large power integrated circuits have reviewed direct AC-AC power conversion technologies. This fulfills all the requirements of the conventionally used rectifier/ dc link/ inverter structures [2,7,8] and provide an efficient way to convert electric power for motor drives, UPS, VF generators and reactive energy control.

In general, the desirable characteristics of AC to AC converters are

- Sinusoidal input and output wave forms with minimal higher order harmonics and no subharmonics,
- Bidirectional energy flow capability,
- Minimal energy storage requirements (minimal size reactive component),
- A controllable power factor.

Furthermore, according to [1], the matrix converter has more advanced potential as compared with conventional voltage source inverters. Advantages include:

- Compact design and long life due to the absence of a bulky electrolytic capacitor,
- Unity input power factor at the power supply side,
- Availability of the continuous zero speed operation because no current concentrates in any of the switches.

The matrix converter is shown in Fig. 1, where each of the nine switches represents a bidirectional configuration, so that any input line can be connected to any output line for any given length of time. The switches are then

Manuscript received February 1, 2005; revised Dec. 1, 2005
†Corresponding Author: hhlee@mail.ulsan.ac.kr
Tel: +82-52-259-2187, Fax: +82-52-259-1686, Univ. of Ulsan
*Dept. of Electrical Eng., Univ. of Ulsan

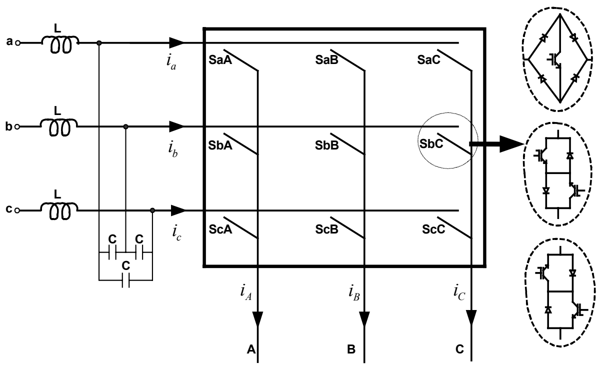

Fig. 1 The ideal matrix converter block diagram and the configurations of bidirectional switch

controlled to give the desired output waveforms.

In the past, current-controlled PWM voltage source inverters were widely employed in field-oriented induction motor drive systems because of its fast current response as compared to conventional CSIs, especially the torque response dependent on the current control performance. Due to the simple algorithm and implementation, instantaneous current control methods are generally used in these PWM inverters. Studies for obtaining better PWM patterns are under current study by many researchers [3-6].

In this paper, we first review the conventional indirect vector AC current control using a VSI fed induction motor. Then, two kinds of new current control methods using a matrix converter are consecutively presented. Some simulation results are displayed to show the effectiveness and the possibility of the previously proposed current control method compared to the conventional one using VSI. Furthermore, another current control method which is modified from the previous one is introduced to provide better performance compare to both the conventional method using VSI and the previously proposed one from the viewpoint of torque and current ripple performance.

2. Conventional and New Current Control Methods

2.1 Conventional indirect vector ac current control method

Fig. 2 shows a block diagram of the indirect vector AC current control method of the IM using a VSI. As shown

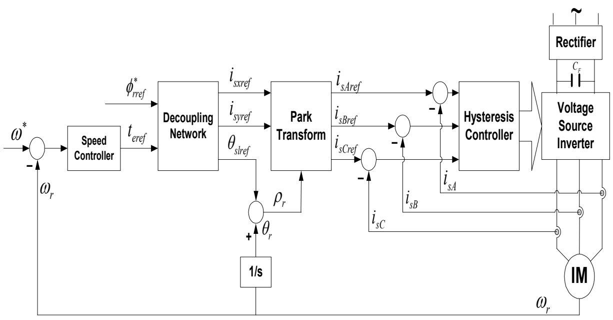

Fig. 2 The block diagram of conventional indirect vector control system for IM using VSI

in Fig. 2, it is needed to measure three phase currents and rotor speed.

The speed of the rotor magnetizing current space vector is

$$\omega_{mr} = \omega_r + \omega_{slref} \qquad (1)$$

where $\omega_{slref} = \dfrac{i_{syref}}{T_r i_{sxref}}$, $T_r = \dfrac{L_r}{R_r}$

And, i_{sxref}, i_{syref} are the stator currents in the rotor-flux-oriented reference frame.

The space angle of the rotor magnetizing current phasor (ρ_r) is obtained as the sum of the rotor angle (θ_r) and the reference value of the slip angle (θ_{sl}).

$$\rho_r = \int \omega_{mr} dt = \theta_r + \int \frac{i_{syref}}{T_r i_{sxref}} dt \qquad (2)$$

The Park transform which transposes the rotor-flux-oriented reference frame into the instantaneous reference frame is

$$\begin{bmatrix} i_{sAref} \\ i_{sBref} \\ i_{sCref} \end{bmatrix} = \begin{bmatrix} \cos\rho_r & -\sin\rho_r \\ \cos(\rho_r - 2\pi/3) & -\sin(\rho_r - 2\pi/3) \\ \cos(\rho_r - 4\pi/3) & -\sin(\rho_r - 4\pi/3) \end{bmatrix} \qquad (3)$$

The three-phase current reference values are compared with the three-phase instant current values, and then passed through the hysteresis controller to choose the opportune switching state. In the conventional indirect vector control method, the operation principle of the

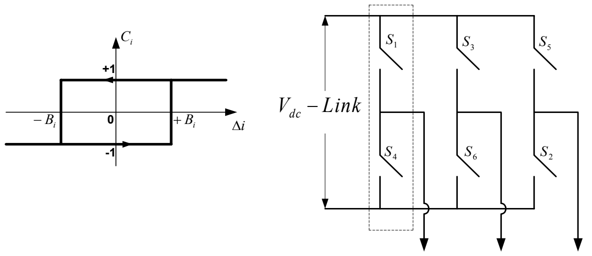

Fig. 3 The hysteresis current control using VSI

hysteresis current controller can be explained from Fig. 3: within each sampling period, the upper switch is selected if the hysteresis controller output(C_i) is +1 and the lower switch is selected if C_i is -1. Therefore, the currents can be controlled effectively within the limited boundary.

2.2 The proposed current control method I using MC

Fig. 4 shows a block diagram of the proposed current control method using a matrix converter fed induction motor. As can be easily seen, three input voltages of the matrix converter are measured. Due to the basic difference in the power supply at the input side between the voltage source inverter module, DC voltage, and the matrix converter module, AC voltage, there exist three selectable voltage values which can be readily used as an output voltage applied to the induction motor.

As shown in Fig. 5, in the proposed method I, if current error exceeds positive bandwidth during each sampling period, the hysteresis controller output (C_i) becomes +1 and the selected output voltage is the maximum voltage value, $V_{\max}$. If current error exceeds negative bandwidth, i.e., C_i is -1, then, the selected voltage is accordingly the minimum voltage value, $V_{\min}$. In this case, if the current error is within its boundary, the hysteresis controller output is kept consistent in the next sampling period.

Consequently, the middle measured voltage is obviously redundant and there are only both the maximum voltage and the minimum voltage values which are alternatively used in this proposed method.

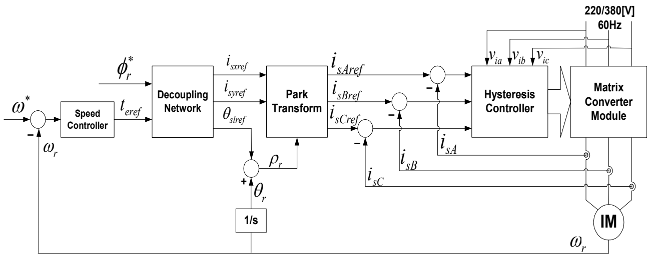

Fig. 4 The block diagram of the proposed current control method I using MC

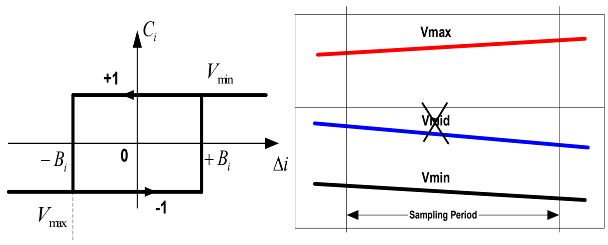

Fig. 5 The principle of proposed hysteresis current controller I

2.3 The proposed current control method II using MC

In the proposed method II, any three-phase input voltage can be selected as an input power source corresponding to the hysteresis controller output during each sampling period.

As shown in Fig. 6, if the current error exceeds the positive bandwidth, the hysteresis controller output (C_i) is +1 and the selected voltage is the maximum voltage value, $V_{\max}$. If the current error exceeds the negative bandwidth, i.e., C_i is -1, then, the selected voltage is the minimum voltage value, $V_{\min}$. Finally, if the current error is within its bandwidth, i.e., C_i is 0, then the middle voltage value, V_{mid}, is definitely selected.

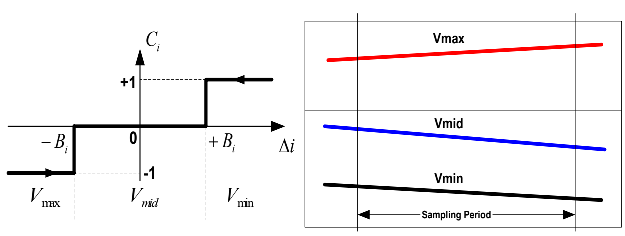

Fig. 6 The principle of proposed hysteresis current controller II

3. Simulated Results

Simulations are carried out by Matlab/Simulink for the conventional indirect vector AC current control method using VSI and the two proposed methods using an MC fed induction motor. The power supply of the MC is 220/380[V], 60Hz, the sampling frequency is 10KHz and the three-phase induction motor parameters are given in Table 1.

Table 1 Induction motor parameters

Parameter	Value
Rated Power	1[Hp]
Rated Voltage	220/380[V], 60[Hz]
Number of Poles	4
Stator Resistance	9.53 [Ω]
Rotor Resistance	5.619 [Ω]
Stator Inductance	0.5317 [H]
Rotor Inductance	0.505 [H]
Mutual Inductance	0.447 [H]
Inertia	0.0026 [kg.m^2]

Fig. 7 shows the three-phase input voltage waveforms corresponding to the two proposed methods. In the proposed method I, the output voltages of MC follow the boundary of the input voltages, but, in the proposed method II, both of the input voltages can be selected properly at any instant.

Fig. 8 shows the torque responses for each case which include the conventional method and the two proposed methods. The load torque changes from 1N-m to 4N-m at 0.8s at the constant speed 1146 rpm. As shown in Fig. 8, the torque responses for each case are almost the same in both the steady state and transient state. However, judging from Fig. 8(c), the torque ripple is diminished greatly compared to the two methods shown in Fig. 8(a) and Fig. 8(b).

Fig. 9 and Fig. 10 show the three-phase currents of induction motor at the two steady-state modes, 1146 rpm and load torque are 1N-m and 4N-m respectively. As can be seen, the current ripple of the proposed method II in Fig. 9(c) and Fig. 10(c) are visibly smaller than in Fig. 9(a), (b) and Fig. 10(a), (b) respectively.

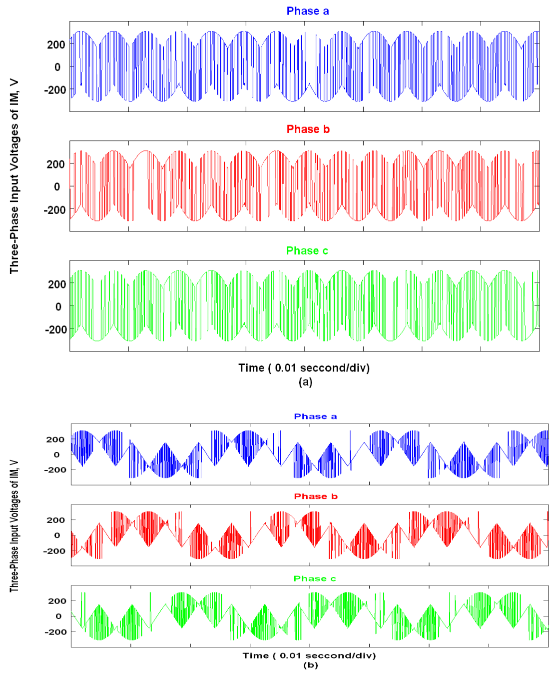

Fig. 7 Stator voltages of IM (a) the proposed method I and (b) the proposed method II using MC

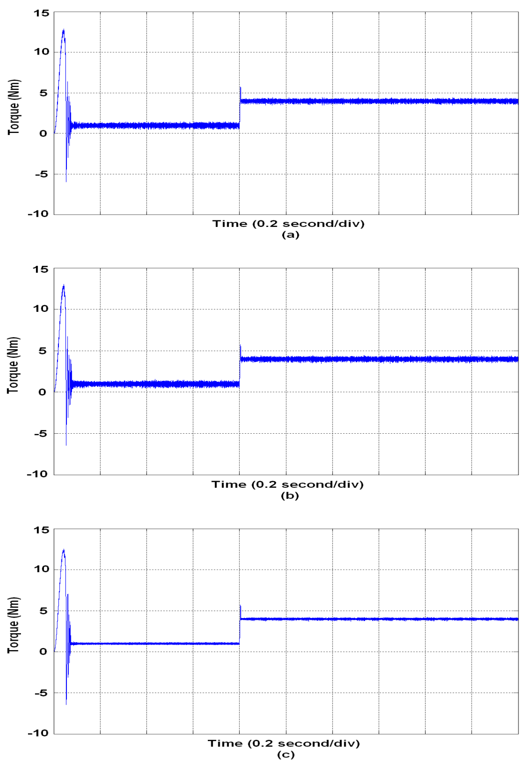

Fig. 8 Torque responses at 1146 rpm for load torque change (a) the conventional method using VSI (b) the proposed method I and (c) the proposed method II using MC

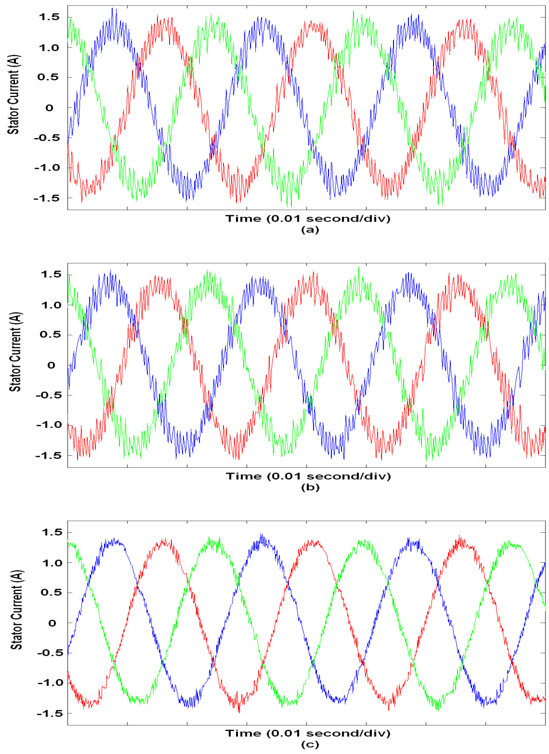

Fig. 9 Stator currents at 1146 rpm, 1N-m (a) the conventional method using VSI (b) the proposed method I and (c) the proposed method II using MC

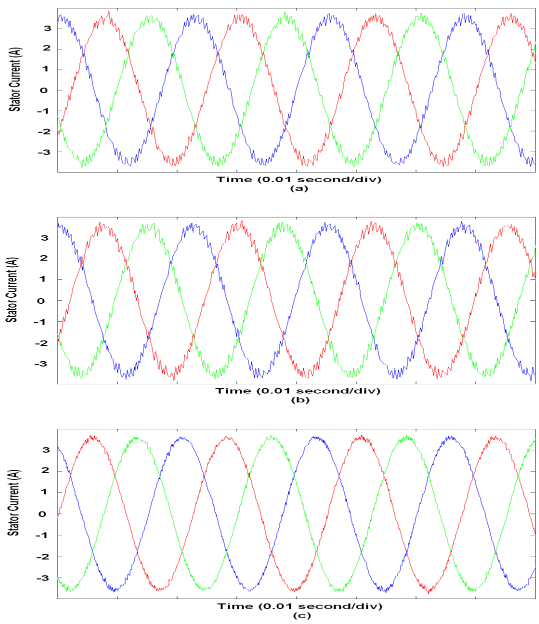

Fig. 10 Stator currents at 1146 rpm, 4N-m (a) the conventional method using VSI (b) the proposed method I and (c) the proposed method II using MC

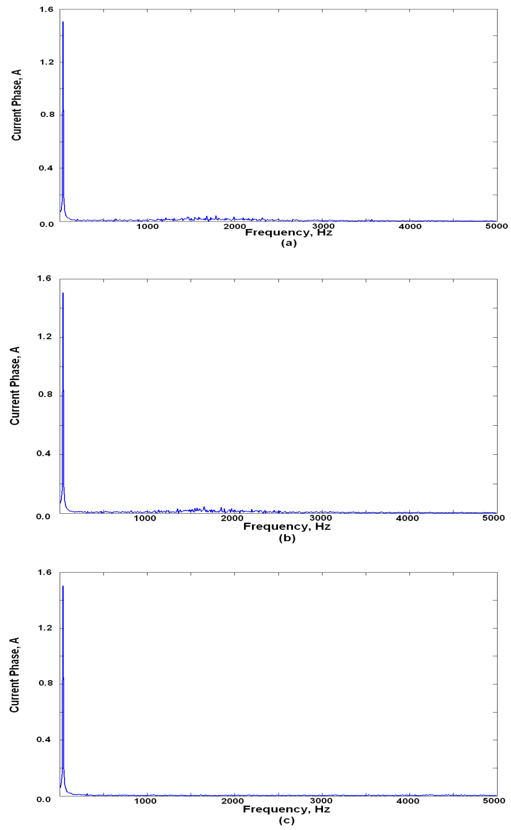

Fig. 11 Frequency spectrum of IM's phase current at 1146 rpm, 1N-m (a) the conventional method using VSI (b) the proposed method I and (c) the proposed method II using MC

Fig. 11 shows the frequency spectrum of the IM's phase current at 1146 rpm, 1N-m to verify the effectiveness of the two proposed methods. The main harmonic is located at 40 Hz and higher harmonic frequencies are eliminated considerably in the proposed method II.

4. Conclusion

This paper proposes an unprecedented operation principle for an indirect vector AC current control using a matrix converter fed induction motor. The proposed method I is comparable to the conventional current control using VSI in both steady state and transient state. Furthermore, the proposed current control method II, using MC shows a smaller current ripple and torque ripple in the steady state compared to both the conventional method using VSI and the proposed method I using MC.

Some simulation results were carried out to verify the proposed technologies.

To our knowledge, this is the first time that the matrix converter fed induction motor with indirect vector AC control method has been examined. The next step of this research will be to consider the experimental results more carefully.

Acknowledgement

The authors would like to thank the University of Ulsan and Korean Ministry of Commerce, Industry and Energy which partly supported this research through the Network-based Automation Research Center (NARC) at University of Ulsan.

References

[1] Watanabe, E.; Ishii, S.; Yamamoto, E.; Hara, H.; Jun-Koo Kang; Hava, A.M., "High performance motor drive using matrix converter", Advances in Induction Motor Control (Ref. No. 2000/072), IEE Seminar , 23rd , May 2000.

[2] Alesina, A; Venturini, M; " Instrinsic amplitude limits and optimum design of 9-switches direct PWM AC-AC converters", Power Electronics Specialists Conference, 1998. PESC'88 Record, 19th Annual IEEE, Pages: 1284 -1291, Vol. 2; 11-14, April 1998.

[3] Espinoza, J.R.; Joos, G, "A current-source inverter fed induction motor drive system with reduced losses", Industry Applications Conference, 1995. Thirtieth IAS Annual Meeting, IAS '95., Conference Record of the 1995 IEEE 1, Vol.1, Pages:45 - 52, October 1995.

[4] Bojoi, R.; Lazzari, M.; Profumo, F.; Tenconi, A, "Digital field oriented control for dual three-phase induction motor drives", Industry Applications Conference, 2002. 37th IAS Annual Meeting. Conference Record of the IEEE 2, Vol. 2, Pages:818 - 825, October 2003.

[5] Palanivel, S.; Srinivas, P.; Ranganathan, V.T, "A new rotor time constant adaptation method for a VSI fed indirect field oriented induction motor drive", Power Electronics, Drives and Energy Systems for Industrial Growth, 1996., Proceedings of the 1996 International Conference on P.E.,1, Vol.1 ,Pages: 222- 228, January 1996.

[6] Chang, S.-C.; Yeh, S.-N,"Current sensorless field-oriented control of induction motors", Electric Power Applications, IEEE Proceedings 143 ,Pages: 492 - 500, November 1996.

[7] Wheeler, P.W.; Clare, J.C.; Empringham, L.; Bland, M.; Kerris, K.G, ".Matrix converters", Industry Applications Magazine, IEEE , Volume: 10 , Issue: 1, Pages:59 - 65, Jan-Feb 2004.

[8] Zuckerberger, A.; Weinstock, D.; Alexandrovitz, A. "Simulation of three-phase loaded matrix onverter", Electric Power Applications, IEE Proceedings, Vol. 143, Issue: 4 , Pages:294 - 300, July 1996.

Hong Hee Lee is a professor in the School of Electrical Engineering, University of Ulsan, Ulsan, Korea. He is also director of the Network-based Research Center (NARC). He received his B.S., M.S., and Ph.D. degrees from Seoul National University, Seoul, Korea, in 1980, 1982, and 1990, respectively. His current research interests include power electronics, network-based motor control and control networks. He is also a member of the Institute of Electrical and Electronics Engineers (IEEE), Korean Institute of Power Electronics (KIPE), Korean Institute of Electrical Engineers (KIEE), and the Institute of Control, Automation, and Systems Engineers (ICASE).

Hoang M. Nguyen was born in Nha Trang, Vietnam, in 1979. He received his B.S. degree in Electrical Engineering from the University of Technology, HoChiMinh, Vietnam in 2002 and his M.S. degree from the University of Ulsan, Korea in 2005. He is currently a Ph.D. student at the University of Ulsan, Ulsan, Korea. He is engaged in research on motor control, especially matrix converters and industrial networks.