MTPA Control of Induction Motor Drive using Fuzzy-Neural Networks Controller

Jung-Chul Lee, Hong-Gyun Lee, Su-Myeong Nam, Jung-Sik Choi, Jae-Sub Ko, Dong-Hwa Chung

Department of Electrical Control Engineering, Sunchon National University, Jeonnam, Korea
(Tel : +82-61-750-3543; E-mail: hwa777@sunchon.ac.kr)

Abstract: This paper is proposed maximum torque per ampere of induction motor using fuzzy-neural networks controller. Operation of maximum torque per ampere is achieved when, at a given torque and speed, the slip frequency is adjusted to that so that the stator current amplitude is minimized. This paper introduces a induction motor drive system with fuzzy-neural networks controller. A neural network-based architecture is described for fuzzy logic control. The characteristic rule and their membership function of fuzzy system are represented as the processing nodes in the neural network structure. This paper is proposed the analysis as well as the simulation results to verify the effectiveness of the new method.

Keywords: Induction Motor, Maximum Torque per Ampere, Fuzzy-Neural Networks, Fuzzy

1. INTRODUCTION

The profit of the induction motor for drive applications are well established [1-2]. As a result, the induction motor has become growingly popular for use in high performance drive applications such as spindle, traction and electric vehicle drives.

The maximum output torque and power developed by the machine is ultimately depended on the allowable inverter current rating and maximum voltage which the inverter can supply to the machine. Therefore, considering the limited voltage and current capacities, it is desirable to consider a control method which yields the best possible torque per ampere.

Recently, there has been observed an increasing interest in combining artificial intelligent control tools with adaptive control techniques. The principal motivations for such a hybrid implementation is that with fuzzy logic and neural networks issues such as uncertainty or unknown variations in plant parameters and structure can be dealt with more effectively, hence improving the robustness of the control system. Several works contributed to the design of such hybrid control scheme.[3]

In this paper, we propose fuzzy-neural networks(FNN) controller that combines a fuzzy control and the Neural Networks for high performance control of induction motor drive. FNN controller composes antecedence of the fuzzy rules and consequence by a clustering method and a multi-layer neural networks. This controller is compounding of advantages that robust control of a fuzzy control and high-adaptive control of the neural networks. Also, this paper is proposed control of maximum torque per ampere(MTPA) of induction motor. MTPA strategy is proposed which is simple in structure and has the honest goal of minimizing the stator current magnitude for given load torque[4]. The performance of the proposed induction motor drive with MTPA using FNN controller is verified by simulation at dynamic operation conditions. MTPA is found to be robust for applications in induction motor drive.

2. MODELING OF INDUCTION MOTOR

The dynamic equations of the induction machine can be expressed in the synchronous reference frame as [5]

$$v_{ds} = R_s i_{ds} + \frac{d\phi_{ds}}{dt} - \omega_e \phi_{qs} \tag{1}$$

$$v_{qs} = R_s i_{qs} + \frac{d\phi_{qs}}{dt} + \omega_e \phi_{ds} \tag{2}$$

$$v_{dr} = R_r i_{dr} + \frac{d\phi_{dr}}{dt} - \omega_s \phi_{qr} \tag{3}$$

$$v_{qr} = R_r i_{qr} + \frac{d\phi_{qr}}{dt} + \omega_s \phi_{dr} \tag{4}$$

where $\omega_s = \omega_e - \omega_r$ is the slip frequency

The stator flux may be expressed in terms of the current as

$$\phi_{ds} = L_s i_{ds} + L_m i_{dr} ; \phi_{qs} = L_s i_{qs} + L_m i_{qr} \tag{5}$$

$$\phi_{dr} = L_r i_{dr} + L_m i_{ds} ; \phi_{qr} = L_r i_{qr} + L_m i_{qs} \tag{6}$$

$$L_s = L_{ls} + L_m, \quad L_r = L_{lr} + L_m \tag{7}$$

It is assumed that all rotor variables are referred to the stator by the appropriate turns ratio. With stator currents as inputs and rotor windings short circuited, the state equations may be expressed

$$0 = \frac{R_r}{L_r}(\phi_{qr} - L_m i_{qs}) + p\phi_{qr} + \omega_s \phi_{dr} \tag{8}$$

$$0 = \frac{R_r}{L_r}(\phi_{dr} - L_m i_{ds}) + p\phi_{dr} - \omega_s \phi_{qr} \tag{9}$$

The electromagnetic torque can be expressed,

$$T_e = K(\phi_{dr} i_{qs} - \phi_{qr} i_{ds}) \tag{10}$$

where $K = \frac{3}{2}\frac{P}{2}$

In the indirect method of control , $\theta_e(0)$ is selected such that ϕ_{qr} is identically zero. Thus, (8) and (9) become

$$0=-\frac{R_r L_m}{L_r} i_{qs} + \omega_s \phi_{dr} \qquad (11)$$

$$0=\frac{R_r}{L_r}(\phi_{dr} - L_m i_{ds}) + p\phi_{dr} \qquad (12)$$

If i_{ds} is controlled so that it remains constant, (12) implies that $p\phi_{dr}=0$ and

$$\phi_{dr} = L_m i_{ds} \qquad (13)$$

Substituting into (11) and solving for ω_s

$$\omega_s = \frac{R_r i_{qs}}{L_r i_{ds}} \qquad (14)$$

The electromagnetic torque (10) can be expressed

$$T_e = K\frac{L^2{}_m}{L_r} i_{qs} i_{ds} \qquad (15)$$

A block diagram of the indirect vector control is shown in Fig.1. Therein, i_{ds}^* is the commanded magnetization current which is normally constant and i_{qs}^* is used to control the torque. The current command signals i_{as}^*, i_{bs}^* and i_{cs}^* are supplied to the inverter control system.

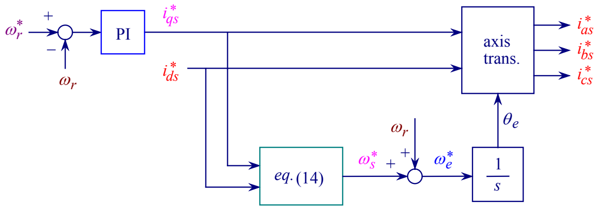

Fig. 1 Block diagram of indirect vector control

The stator current amplitude is defined as the peak ac current.

$$|i_s| = \sqrt{i_{qs}^2 + i_{ds}^2} \qquad (16)$$

The stator flux amplitude is similarly defined as

$$|\phi_s| = \sqrt{\phi_{qs}^2 + \phi_{ds}^2} \qquad (17)$$

3. MTPA CONTROL

Operation at MTPA is achieved when, at a given torque and speed, the slip frequency is adjusted so that the stator current amplitude is minimized. This mode of operation is subsequently referred to as the MTPA strategy. An expression for the slip frequency which minimizes the stator current amplitude is easily established by nothing that to maximize the product of i_{qs} and i_{ds} subject to the constraint that (15) is constant, i_{qs} should be set equal to i_{ds}. Therefore, the slip frequency for MTPA can be expressed.

$$\omega_{s,\,\mathrm{MTPA}} = \frac{R_r}{L_r} = \frac{1}{\tau_r} \qquad (18)$$

where τ_r is the rotor time constant. This suggests that to maintain minimum stator current, the induction motor should operate at a constant slip equal to the inverse rotor time constant.

Operation at maximum efficiency or minimum stator current may not be achievable for the entire speed and torque range due to operation constraints. Herein, it is assumed that three constraints exit: (1) the amplitude of the stator current cannot exceed a specified maximum, (2) the amplitude of the stator flux cannot exceed a specified maximum, and (3) the stator voltage cannot exceed rated. If condition (2) is satisfied, then condition (3) is automatically satisfied for rotor speed less than rated. To establish these limits, it is useful to express the stator current and flux in terms of the selected independent variables.

$$|\phi_s| = \sqrt{T_e\left(\frac{a}{\omega_s} + b\omega_s\right)} < |\phi_s|_{\max} \qquad (19)$$

where

$$a = \frac{R_r\left[L_m^4 + L^2 L_r^2 + 2L_m^2 L L_r\right]}{L_r^2 L_m^2} \qquad (20)$$

$$b = \frac{L^2 L_r^2}{R_r L_m^2} \qquad (21)$$

$$|i_s| = \sqrt{T_e \frac{L_r}{L_m}\left(\frac{1}{\tau_r\omega_s} + \tau_r\omega_s\right)} < |i_s|_{\max} \qquad (22)$$

As long as the flux amplitude is less than rated, the optimum slip frequency is equal to equation (18). For larger values of torque, the slip frequency must be set to the smallest value possible which does not violate the flux constraint. An expression for the slip frequency in the flux-limited mode of operation may be established by setting $|\phi_s|=1$ to 1 in (19) and solving for ω_s. This gives

$$\omega_s = \frac{1-\sqrt{1-4T_e^2 c}}{2T_e b} \qquad (23)$$

where

$$c = \frac{L^2\left[L_m^4 + L^2 L_r^2 + 2L_m^2 L L_r\right]}{L_m^4} \qquad (24)$$

The breakpoint between the constant slip and flux-limited regions of operation may be established by setting ω_s in (23) to the optimal slip defined by (18) and solving for T_e

$$T_{e,\,\mathrm{bp}} = \frac{R_r L_r}{bL_r^2 + (cR_r)^2} \qquad (25)$$

For $T_e < T_{e,\mathrm{bp}}$, the desired slip is given by (18) whereupon $\tau_r\omega_s = 1$, $T_e > T_{e,\mathrm{bp}}$, the desired slip is given by (23) whereupon

$$\tau_r\omega_s = \frac{\left(1-\sqrt{1-4T_e^2 b}\right)L_m^2}{2T_e L^2 L_r} \tag{26}$$

The equation (10) can be transformed into i_{qs}

$$i_{qs} = \frac{K_1 T_e}{i_{ds}} \tag{27}$$

where $K_1 = L_r / KL_m^2$

By substituting(27) into (16) the following can be obtained.

$$|i_s| = \sqrt{(K_1 T_e)^2 i_{ds}^{-2} + i_{ds}^2} \tag{28}$$

To solve i_{ds} that $|i_s|$ amounts to minimum calculate condition of $di_s / di_{ds} = 0$.

$$i_{ds} = \sqrt{K_1 T_e} \tag{29}$$

A overall block diagram of MTPA using FNN controller is shown in Fig.2.

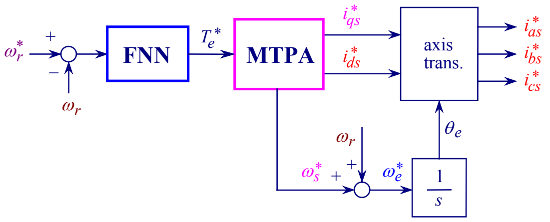

Fig. 2 Overall block diagram of MTPA using FNN controller

4. DESIGN OF FNN CONTROLLER

Fig.3 shows structure of FNN controller for induction motor drive.

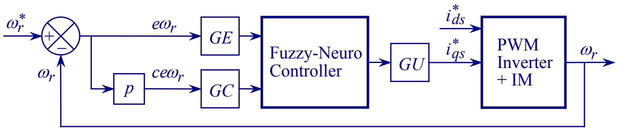

Fig. 3 Structure of FNN controller

The fuzzy controller can be embodied by a computational neural network structure. Also the antecedent and consequent parts of the "if-then" rule are constructed by a multi-layer neural network with nonlinearity and learning function. Fig. 4 shows the proposed configuration of FNN controller, where two input variables are the speed error e and the change in the speed error ce respectively, and one output is control variable u^*. The construction of the FNN controller be explained reference in detail.[6]

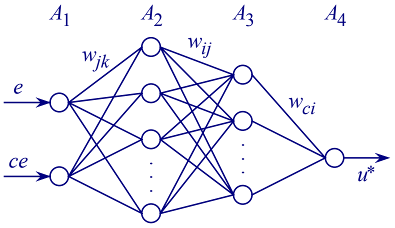

Fig. 4 construction of FNN controller

5. PERFORMANCE RESULT OF SYSTEM

Fig.5 shows drive system of induction motor with FNN and MTPA controller . The command d axis current is controlled to MTPA controller and speed is controlled to FNN controller.

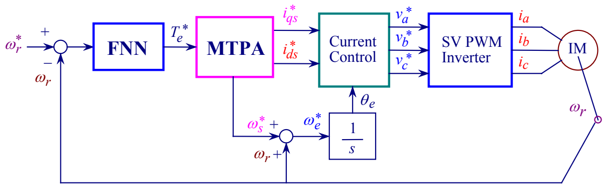

Fig. 5. Drive system of induction motor with FNN and MTPA controller

The parameters of the induction motor are listed in Table 1.

Table 1 Parameters of induction motor

Induction motor : 220V 2.2[kW] 4-Pole	
$R_s = 0.59$ [Ω]	$L_s = 64.72$ [mH]
$R_r = 0.18$ [Ω]	$L_r = 64.72$ [mH]
$f_{\text{req.}} = 60$ [Hz]	$L_m = 61.91$ [mH]

Fig. 6 shows the response comparison with conventional PI and MTPA control when the reference speed is set to 1800[rpm] at 0.5[sec]. Fig.6(a) shows the command speed and real speed. Fig.6(b) shows torque and Fig.6(c) is d-axis current. Fig.6(d) shows magnitude of current.

Fig. 7 shows the response comparison with conventional PI and MTPA control when the reference speed is set to 1800[rpm] and change to reference speed which is 1000[rpm] at 1[sec]. The proposed scheme which is MTPA revealed rapidly estimation in speed and increase torque and decrease magnitude of current. Therefore, Fig.(6) and (7) shows favorable performance of MTPA

Fig. 8 shows the response comparison with load change which is no load to 3[N.m] between 0.6[sec] to 0.9[sec] in 1000[rpm]. In case of load torque impression, MTPA controller is revealed rarely speed alteration more than conventional PI.

Fig.9 shows the response comparison at forward and reverse drive. The reference speed repeat 1000[rpm] and –1000[rpm]. In case of forward and reverse drive, MTPA controller is reached rapidly steady state and increase torque. Therefore, MTPA control presents very excellent performance at speed and load change.

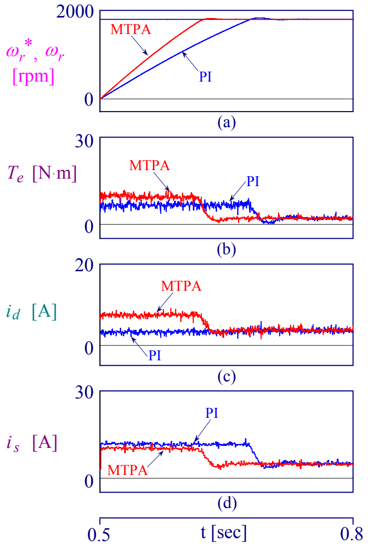

Fig. 6 Response comparison with command speed

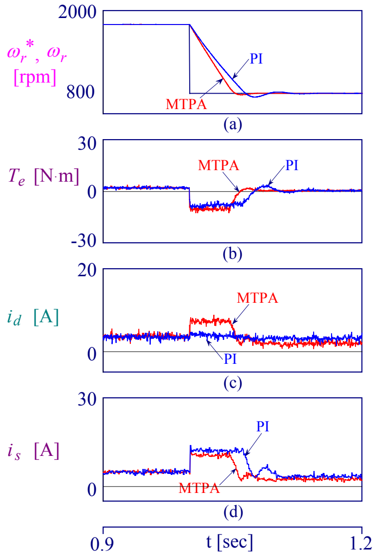

Fig. 7 Response comparison with command speed change

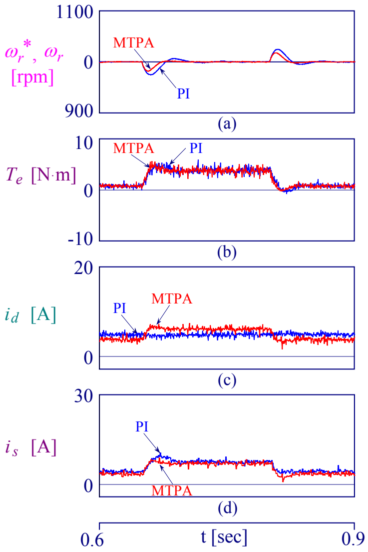

Fig. 8 The response comparison with load change

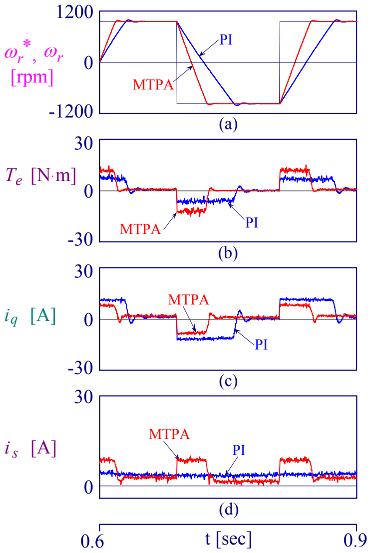

Fig. 9 The comparison of response at forward and reverse drive

6. CONCLUSION

This is proposed MTPA control of induction motor drive using FNN controller. A new control strategy for induction motor is proposed which has the straightforward goal of minimizing the state current amplitude for a given torque and speed. The controller is simple in structure and is relatively insensitive to parameter variations.

FNN controller composes an antecedence of fuzzy rules and consequent by clustering methods and multi-layer neural networks. FNN controller has merit such as a high control with the neural networks and a robust control of a fuzzy control. To improve the performance, we applied the FNN and MTPA controller to an induction motor drive and analyzed response characteristic of steady state, transient state and torque etc. Therefore, the validity of the proposed controller, which is FNN and MTPA controller, is confirmed by performance result.

REFERENCES

[1] R. Krishnan, “Selection Criteria for Servo Motor Drives”, *IEEE Transactions on Industry Applications*, Vol. IA-23, March/April, 1987, pp. 270-275

[2] M. A. Rahman and Ping Zhou, “Field Circuit Analysis of Brushless Permanent Magnet Synchronous Motors”, *IEEE Transactions on Industrial Electronics*, Vol. 43, No. 2, April 1996, pp. 256-267

[3] D. H. Chung, "Fuzzy control for high performance vector control of PMSM drive system," The Trans. of KIEE, vol. 47, no. 12, pp. 2171-2180, 1998

[4] P. C Krause, O. Wasynczuk, and S. D. Sudhoff, Analysis of Electric Machinery, IEEE press, 1994

[5] D. H. Chung, "Power electronics and motor control," Intervision Press, 2004.

[6] D. H. Chung, J. C. Lee, H. G. Lee and S. M. Nam," Speed control of induction motor drive using adaptive FNN controller," International Conference ICEMS'04, Conference no. PI-5(430-M09-052), 2004. [CD no. 2]