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Adaptive Fuzzy Neuro Controller for Speed Control of Induction Motor

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Abstract

This paper is proposed the adaptive fuzzy neuro controller(AFNC) for high performance of induction motor drive. The design of this algorithm based on the AFNC that is implemented using fuzzy controller(FC) and neural network(NN). This controller uses fuzzy rule as training patterns of a NN. Also, this controller adjusts the weights between the neurons of NN to minimize the error between the command output and the actual output using the back-propagation method. The control performance of the AFNC is evaluated by analysis in various operating conditions. The results of analysis prove that the proposed control system has high performance and robustness to parameter variation, and steady-state accuracy and transient response.

Key Words : Induction Motor Drive, Fuzzy Controller, Neural Network, AFNC, High Performance

1. Introduction

Recently, the artificial intelligent control(AIC) using fuzzy control(FC), neural network(NN) and genetic algorithm(GA) is recognized to important technique that can be improved performance of power electronic system. And a technique that is compounded these methods will be widely used in induction motor drive which is requested adaptability and robustness[1-3].

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The conventional PI controller is many used in industry because it has satisfactory performance in steady-state. However, it can't expect a satisfactory performance in transient-state due to non-linear of induction motor. Especially, it is difficult to control of high performance and robustness in conditions of disturbances and parameters variation such as changing of speed and load. To obtain satisfactory performance of drive, adaptive control is researched. It has excellent performance more than PI controller[4]. However, the adaptive control is very complex, because it is based on mathematic modeling and it has plenty of algorithms. To solve these problems, direct fuzzy control is researched. However, it can't expect an adaptability and satisfactory performance in various load and inertia changing[5]. The NN is evaluated very powerful method to control and parameter estimation[6-7]. It is excellent ability of adaptive control but it is weak high performance and robustness control that is advantage of fuzzy control.

To high performance control of induction motor considering these problems, this paper proposes AFNC that is consisted of FNN and adaptive control. The FNN is consisted of FC and NN and it can be obtained high performance and robust control that is advantage of FC and ability of adaptive control that is advantage of NN. The adaptive control uses adaptive mechanism based on reference model. The output of AFNC is sum of fuzzy neuro controller(FNC) and adaptive fuzzy controller(AFC) output. This controller is applied to induction drive system and validity of this controller proves through analyzing response characteristics of steady-state and transient-state about parameter variation such as speed and load changing.

2. Modeling Of Induction Motor

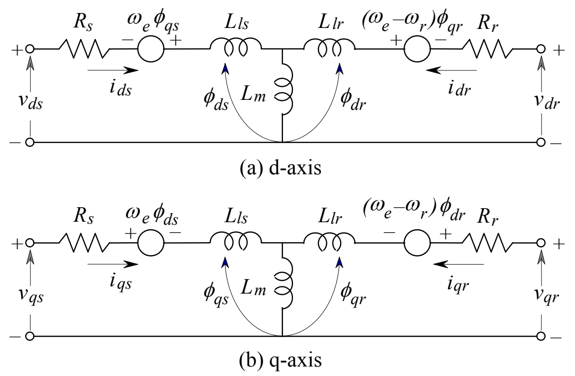

Fig. 1. equivalent circuit at synchronously rotating reference frame

Fig. 1 shows $d-q$ axis equivalent circuit of induction motor in a synchronously rotating reference frame.

In equivalent circuit of Fig. 1, the voltage equation can be expressed as follows.

$$\begin{bmatrix} v_{ds} \\ v_{qs} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + L_s p & -\omega_e L_s & L_m p & -\omega_e L_m \\ \omega_e L_s & R_s + L_s p & \omega_e L_m & L_m p \\ L_m p & -\omega_{sl} L_m & R_r + L_r p & -\omega_{sl} L_r \\ \omega_{sl} L_m & L_m p & \omega_{sl} L_r & R_r + L_r p \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} \tag{1}$$

$\omega_{sl} = \omega_e - \omega_r$: slip angular speed

$i_{ds}, i_{qs} : d, q$ axis stator current

v_{ds}, v_{qs} : d, q axis stator voltage

i_{dr}, i_{qr} : d, q axis rotor current

R_s, L_s : Resistance of stator, self inductance

R_r, L_r: Resistance of rotor, self inductance

L_m: Mutual inductance

The mechanical equation of induction motor can be expressed as follows.

$$T_e = J\frac{d\omega_m}{dt} + B\omega_m + T_l \tag{2}$$

$$\omega_r = \frac{P}{2}\omega_m \tag{3}$$

T_e: the electromagnetic generating torque,

T_l : the load torque, J: the inertia coefficient,

B: the friction coefficient

The electromagnetic generating torque can be expressed as follows.

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)L_m\left(i_{qs}i_{dr} - i_{ds}i_{qr}\right) \tag{4}$$

3. Hybrid Artificial Intelligent Controller

The PI, PID control methods is many uses to speed control of induction motor. However, these methods is complex calculation of $d-q$ axis parameter and very sensitive to parameter and load changing.

To speed control of induction motor, artificial intelligent control such as FC, NN and GA is researched. This method shows robust characteristic for parameter and load changing, system disturbance, but FC has problem of adaptability, NN has problem of robustness, GA has problem of depend on expert knowledge. Therefore, a hybrid control method which shares advantage of each control methods and supplements weakness of each control methods is needed. Fig. 2 shows the research of HAIC. The compound control can be made by sharing each control methods.

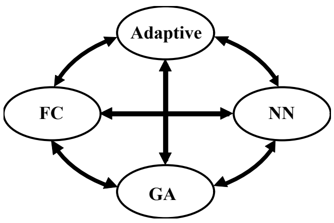

Fig. 2. The research of HAIC

4. Implementation of the FNC

The FNC is compounded from FC and NN. It has an advantage that is the robustness of fuzzy control and the ability to adapt of neural network.

Fig. 6 shows the FNC, where two input variables are the speed error e, and the change in the speed error ce respectively, and one output is control value u.

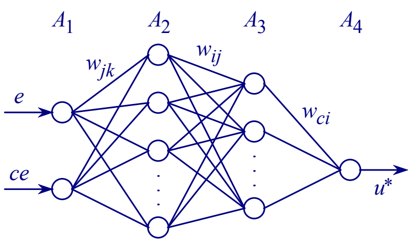

Fig. 3. The construction of FNC

4.1 Implementation of the Antecedent Parts of FNC Controller

The neural networks between the layer A_1 and A_3 in the Fig. 6 show the implementation of the antecedent parts of the fuzzy rule.

The error function is expressed as follows.

$$E=\frac{1}{2}\sum_{i=0}^{r}(T_i-O_i)^2 \tag{5}$$

Where, r is the number of cluster, T_i is a function to determine whether the certain input data belongs to the desired cluster or not, O_i is the output of the neuron at layer A_3

After defining the error function, to minimize the error, the weights W_{jk} and W_{ij} between the layers A_1 and A_3 adjusts by the error backpropagation algorithm. Through the weight adjustment, the neural network can completely implement the antecedent parts of the clustered fuzzy rules.

$$\Delta W_{ij}=-\eta\frac{\partial E}{\partial W_{ij}}=-\eta\delta_i O_j \tag{6}$$

$$\Delta W_{jk}=-\eta\frac{\partial E}{\partial W_{jk}}=-\eta\delta_j X_k \tag{7}$$

Where $\delta_i=(T_i-O_i)f'(U_i)$ (8)

$$\delta_j=f'(U_j)\sum\delta_i W_{ij} \tag{9}$$

O_i is the output of the neuron at layer A_2, η is a learning rate, $f'(\cdot)$ is the derivative of the sigmoid function, U_i and U_j are the total input to each neuron at the layers A_2 and A_3 respectively.

Finally to avoid vibrating during the process of learning and improve the convergence speed, a new adjustment with a momentum term as follows will be assumed.

$$W_{ij}(t+1) = W_{ij}(t) + \Delta W_{ij} + \alpha[W_{ij}(t) - W_{ij}(t-1)] \quad (10)$$
$$W_{jk}(t+1) = W_{jk}(t) + \Delta W_{jk} + \alpha[W_{jk}(t) - W_{jk}(t-1)] \quad (11)$$

Where $\alpha(0 < \alpha < 1)$ is the momentum term.

4.2 Implementation of the Consequent Parts of FNC Controller

In the Fig. 3, the neural network between the layer A_3 and A_4 shows the implementation of the consequent parts of the fuzzy rule. During the learning, the weight W_{ci} will be adjusted to minimize the following error function.

$$E^* = \frac{1}{2}\sum(U^* - U)^2 \quad (12)$$

Where U^* and U represents the value of the desired and actual outputs of the FNC controller.

Using the generalized delta rule, the variation ΔW_{ci} of the weight W_{ci}, which can minimize the error function (12) and refine the consequent parts of the fuzzy rules, can be determined as follows.

$$\Delta W_{ci} = -\eta \frac{\partial E^*}{\partial W_{ci}} = -\eta \delta_c O_i \quad (13)$$
$$W_{ci}(t+1) = W_{ci}(t) + \Delta W_{ci} + \alpha[W_{ci}(t) - W_{ci}(t-1)] \quad (14)$$

Where δ_c is the error signal at the output of the FNC controller.

5. Design of the AFNC

The IM drive is required high performance and robustness for parameter changing such as load and inertia in transient-state. Fig. 4 shows AFNC block diagram. The AFNC is connected FNC and AFC in parallel. The AFC uses to compensate error of FNN. The output of FNC is $\Delta i_{qs1}(k)$ and output of AFC is $\Delta i_{qs2}(k)$. These two outputs are summed and then it is obtained command q-axis current through integrator. The input of AFC is error($e\omega_m$) and error changing($ce\omega_m$) between real speed($\omega_r(k)$) and output of reference model($\omega_m(k)$). The reference model uses 1st-delay system to satisfy design standard such as settling time and overshoot. Fig. 5 shows AFC by reference model.

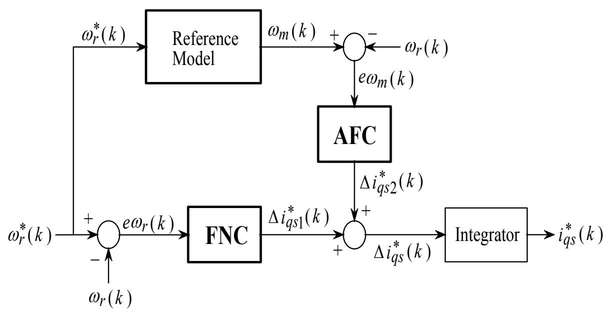

Fig. 4. Block diagram of AFNC

$$e\omega_m(k) = \omega_m(k) - \omega_r(k) \quad (15)$$
$$ce\omega_m(k) = e\omega_m(k) - e\omega_m(k-1) \quad (16)$$

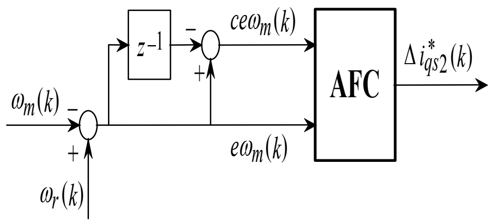

Fig. 5. AFC with reference model

The q-axis current by AFNC can be expressed as follow.

$$i^*_{qs}(k) = i^*_{qs}(k-1) + [\Delta i^*_{qs1}(k) + \Delta i^*_{qs2}(k)] \quad (17)$$

Fig. 6 shows IM drive system controlled by AFNC.

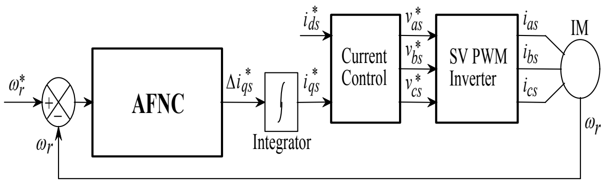

Fig. 6. The configuration diagram of induction motor drive

6. Performance Result of System

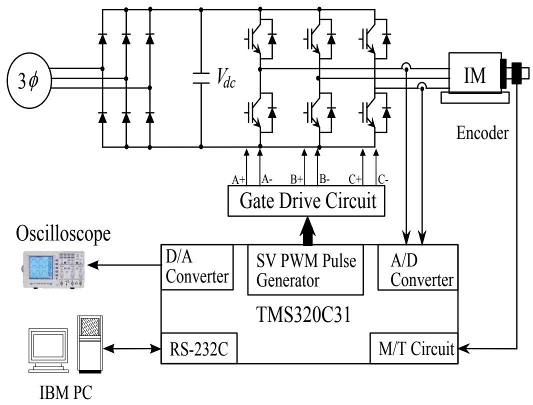

Fig. 7. The block diagram of induction motor system

Fig. 7 shows hardware system configuration manufactured for experimental. The microprocessor of hardware system uses TMS320C31, the main power circuit is consisted SKM50GB123D (1200V, 50A). Table 1 shows parameter of IM. This paper is compared with experimental results of the FNC and the AFNC in various operating conditions of IM.

Fig. 8 and 9 shows the responses of the FNC and the AFNC, respectively, where command speed is 1720[rpm] in no load. Fig. 8(a) and 9(a) shows command speeds and actual speeds, Fig. 8(b) and 9(b) shows q axis currents, Fig. 8(c) and 9(c) shows the generating torques, respectively. As shown in these figures, the responses of the proposed AFNC are obtained small overshoot, fast rising time and fast settling time more than the conventional FNC.

Table 1. parameter of induction motor

Pole	4
Stator Resistance(R_s)	0.345[Ω]
Rotor Resistance(R_r)	0.240[Ω]
Rated Frequency	60[Hz]
Stator Inductance(L_s)	114.14[mH]
Rotor Inductance(L_r)	115.81[mH]
Mutual Inductance(L_m)	109.81[mH]
Rated Speed	1720[rpm]
Rated Inertia(J_n)	0.02745[kg · m^2]

Fig. 10 and 11 shows the responses of the FNC and the AFNC, respectively, where load torque is 10[N · m] in operating speed 1000[rpm]. As shown in these figures, the responses of the proposed AFNC are obtained small overshoot, fast rising time and fast settling time more than the conventional FNC.

Fig. 12 and 13 shows the responses of the FNC and the AFNC, respectively, where step command speed is forward-reverse operation (-1200[rpm] ~ 1200[rpm]). As shown in these figures, the responses of the proposed AFNC are obtained good performances more than the conventional FNC.

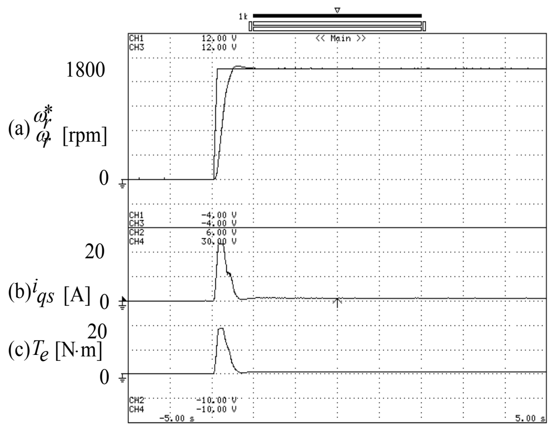

Fig. 8. Responses of the FNC with a step command speed

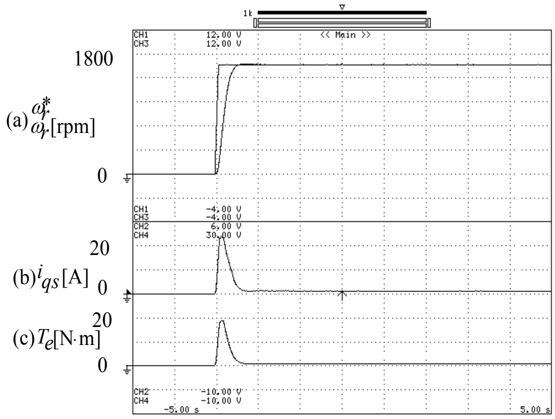

Fig. 9. Responses of the AFNC with a step command speed

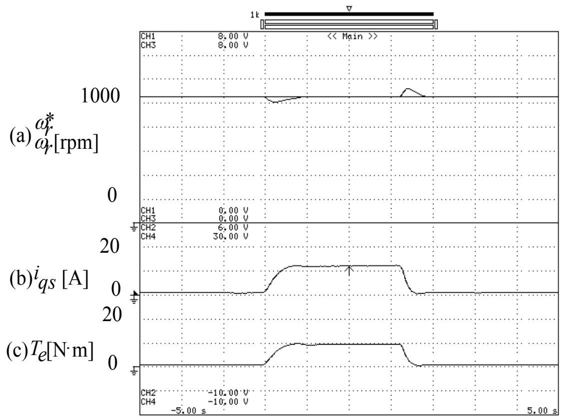

Fig. 10. Responses of the FNC with a change of load torque

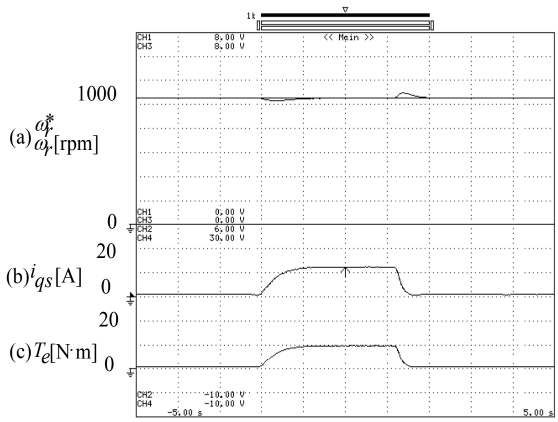

Fig. 11. Responses of the AFNC with a change of load torque

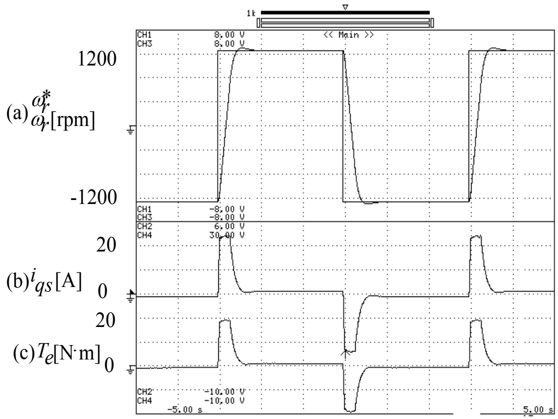

Fig. 12. Responses of the FNC with a change of a step command speed

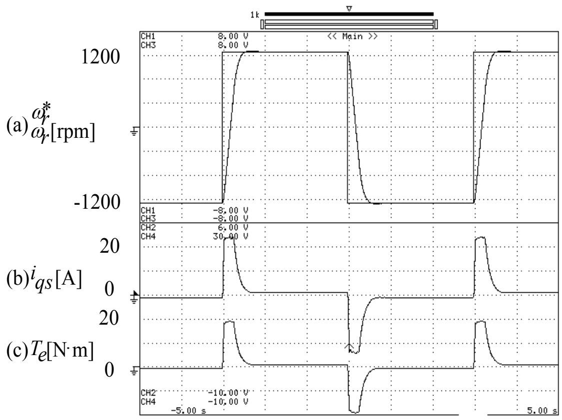

Fig. 13. Responses of AFNC with a change of a step command speed

7. Conclusion

This paper proposes the AFNC for high performance speed control of induction motor drive. The AFNC is consisted fuzzy, neural network and adaptive control. The AFNC is consisted FNC and AFC. The FNC is consisted fuzzy control and neural network and the AFC is consisted adaptive control and fuzzy control. The AFC uses to compensate error of FNC and output of FNC and AFC is sum and then it is obtained command q-axis current by integrator.

The response characteristics AFNC proposed in this paper is compared response characteristics of conventional FNC about various operating conditions such as command speed and load torque in transient-state and steady-state. The AFNC shows low overshoot and fast rising time in all operating conditions. Therefore, the validity of AFNC proposed in this paper is proved.

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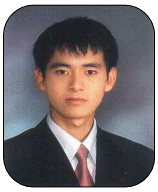

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