The Third AFSS(1998), 449−452

Implementation of Self-Tuning Fuzzy Control System for Speed Control of an Induction Motor

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Abstract

In this paper, we implemented the variable fuzzy speed controller of an IM(induction motor) using the fuzzy control algorithms. Specially, we proposed a self-tuning technique of scale factors which could make easily the fuzzy speed controller optimize. Comparing with the conventional PI speed controller, the dyanmic performances of a proposed fuzzy controller such as the reaching time, the maximum overshoot and the robustness against load disturbance were substantially improved.

Key Word : Fuzzy control, self-tuning, scale factors, PI control, speed controller, IM

1. Introduction

IM have strong, maintenance free and inexpensive structures. But they have defects which are difficult to control such as a servo system because of the weakness of control performance. In order to use them as servo motors, the vector controlled IM system which can be separated the stator currents into the flux and the torque component such as a separately excited DC machine was introduced. The torque component current for its speed control is obtained from PI (Proportional-integral) Controller, while the flux component current is kept constantly. However, the PI controller is not adequate for high performance control system, because it is a linear controller of which the control signal is decided by its gains.[1~2]

Recently, there has been developed the design methods with fuzzy algorithm to drive IM. Then, the design of optimal fuzzy controller must needs much time and effort, since it is obtained through trial and errors based on expert's knowledge.

In this paper, we propose a self-tuning technique of scale factors to design it easily. The fuzzy speed control system for IM was implemented on the 80586 microcomputer. Its experimental results were introduced. The results were more satisfactory in the performances such as the reaching time, the speed overshoot and the robustness than its performances of conventional PI speed controller.

2. VSI-Fed Vector-Control system for Induction Motor Driving

In the vector-controlled IM, the flux component current, $i^*_{1\alpha}$ and the torque component current, $i^*_{1\beta}$ in the $\alpha-\beta$ reference frame, rotating with the rotor flux can be written as follows:[1]

$$i^*_{1\alpha} = \text{constant} \tag{1}$$

$$\omega^*_0 = \omega_r + \frac{Mr_2}{L_2 \lambda_{2\alpha}} \tag{2}$$

Also, the voltage equations are expressed as follows:

$$e^*_{1\alpha} = r_1 i^*_{1\alpha} - L_\sigma \omega_0 i^*_{1\beta} \tag{3}$$

$$e^*_{1\beta} = r_1 i^*_{1\beta} + L_1 \omega_0 1^*_{1\alpha} \tag{4}$$

where,

r_1, r_2: resistances of stator and rotor

L_1, L_2 : self-inductance of stator and rotor

M : mutual inductance

ω_r : angular velocity of rotor

$e_{1\alpha}, i_{1\alpha}$: stator voltage and current of α-axis

$e_{1\beta}, i_{1\beta}$: stator voltage and current of β-axis

$\lambda_{2\alpha}, \lambda_{2\beta}$: rotor fluxes of $\alpha-\beta$ frame

$L_\sigma = (L_1 L_2 - M^2)/L_2$

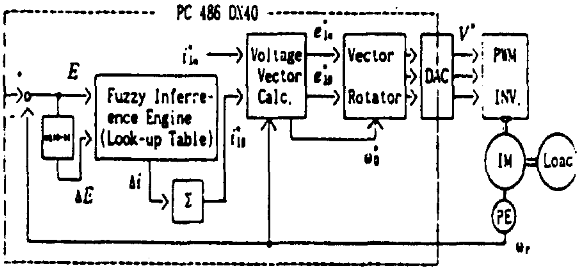


Fig.1 Block Diagram of Fuzzy Speed Control System for IM

Fig.1 shows the VSI-fed vector control system with the fuzzy speed controller.
The torque command current is decided by the fuzzy controller, which input parameters are the speed error and its error change.

3. The Design of Fuzzy Controller

The typical i-th linguistic fuzzy rule is as follows: A_{2i}

If x_1 is A_{1i} and x_2 is ,then y is B_i (5)

where, A_{1i}, A_{2i}, B_i are the fuzzy variables.

Fuzzy controller constructs with the sets of this rules, and its output is calculated by the fuzzy inference for the input values.

We have adopted that the input parameters of Fuzzy controller are the speed error of IM, E and its error change, △E ,and the output parameter is a change of torque component current △i.
At t-th instant, their parameters can be written as follows:

$$E = \omega_r^* - \omega_r(t) \quad (6\text{-a})$$

$$\Delta E = E(t) - E(t-1) \quad (6\text{-b})$$

$$\Delta i = i_{1\beta}^*(t) - i_{1\beta}^*(t-1) \quad (6\text{-c})$$

Also, we have used the membership functions of triangular type such as Fig 2 for each parameters, which had been used by Mizumoto.[3~4]

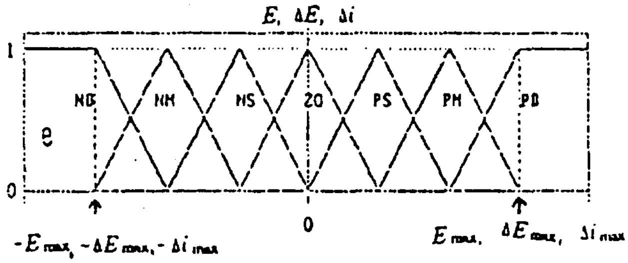


Fig.2 Membership Functions for $E, \Delta E$ and Δi

where,
NB: Negative Big, NM: Negative Medium
NS: Negative Small, ZO: Zero
PS: Positive Small, PM: Positive Medium
PB: Positive Big

Table 1 Fuzzy rule table

ΔE \ E	NB	NM	NS	ZO	PS	PM	PB
PB	NB	NB	NB	NB	NM	NS	ZO
PM	NB	NB	NB	NM	NS	ZO	PS
PS	NB	NM	NM	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
NS	NM	NS	ZO	PS	PM	PM	PB
NM	NS	ZO	PS	PM	PB	PB	PB
NB	ZO	PS	PM	PB	PB	PB	PB

The performances of fuzzy controller depend on the rules and the membership functions which is selected by a designer. Therefore, it is difficult to acquire the optimal control performance from the fuzzy controller.[5] In order to these problems, we found the initial fuzzy rules from the results of a conventional PI speed controller such as table 1, and improved the performances of the fuzzy controller by adjusting optimally the scale factors of fuzzy in-output parameter.
The in-output parameters with the scale factors can be written as follows:

$$E_{MAX} = (set\ value\ of\ E) \times SF_E \quad (7)$$

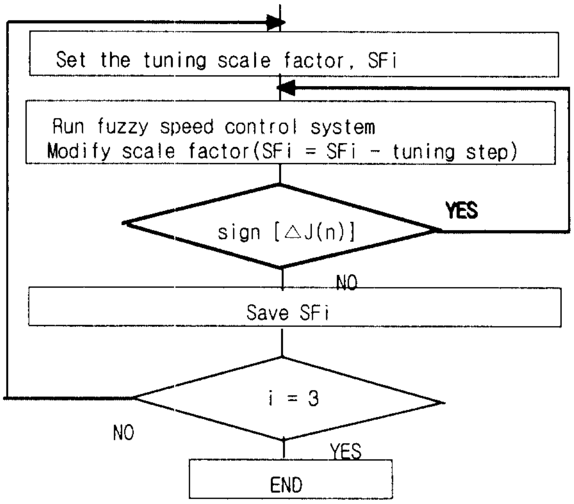
$$\Delta E_{MAX} = (set\ value\ of\ \Delta E) \times SF_{\Delta E}$$

$$\Delta i_{MAX} = (set\ value\ of\ \Delta i) \times SF_{\Delta i}$$

where, $0 < SF_E,\ SF_{\Delta E},\ SF_{\Delta i} \le 1$ and the set values are based on the dynamic characteristics of the experimental IM. Their fundamental values are as follows.

set value of E = 1800[rpm]
set value of ΔE = 20[rpm]
set value of Δi = 3[A]

Fig.3 shows the proposed self-tuning algorithm of the scale factors, which can make substantially the tuning times reduce in comparison to an sequential tuning method, because the tuning of the scale factors are



decided by the signs of the estimated function J.

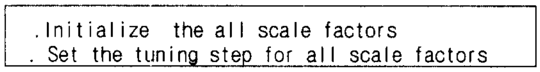


Fig.3 Flow chart of self-tuning algorithm

The evaluation function J for the reaching time, overshoot and undershoot of the motor was defined as follows:

$$J=\int_0^{t_s} \left| \frac{\omega_r^* - \omega_r(t)}{\omega_r^*} \right| dt \qquad (8)$$

$$\Delta J = J(n) - J(n-1) \qquad (9)$$

where, the tuning steps of SF_E, $SF_{\Delta E}$, $SF_{\Delta i}$ are 0.1, 0.05 and 0.05 respectively. Also, the integral period of J is 2 [sec] which is more than the settling time of IM.

The optimal scale factors determined by the proposed algorithm are as follows:

SF_E = 0.5, $SF_{\Delta E}$ = 0.45, $SF_{\Delta i}$ = 0.85

4. Experimental Results

The hardware implementations of experimental system are constructed of the 80586 micro-computer, I/O interface board, voltage-controlled PWM inverter, 1/2HP IM and DC generator, etc.

In order to achieve the real-time control of IM, we adopted the look-up tables of the fuzzy inference results for the expected input values of E and △E.

When the speed error is given, the torque command current I*1 can be calculated by this inference table. Also, the flux command current $i_{1\alpha}^*$ is 1.2[A] as the rated value.

The results of the fuzzy inference, the voltage vectors $e_{1\alpha}^*$, $e_{1\beta}^*$ and the three phase command voltage V^* are calculated on the PC.

The three phase voltages are outputed from the three 12bit DACs. Each signals are applied to the triangular waveform comparators which has 1KHz frequency, and offers the switching signals of PWM inverter. Also, the angle speed of rotor is obtained from the pulse encoder attached to the shaft of motor.

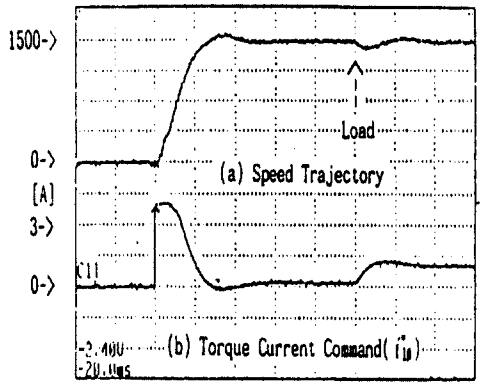


Fig. 4 Experimental Results for PI Control (200[ms/div)(1/2 load applied at 1[sec])

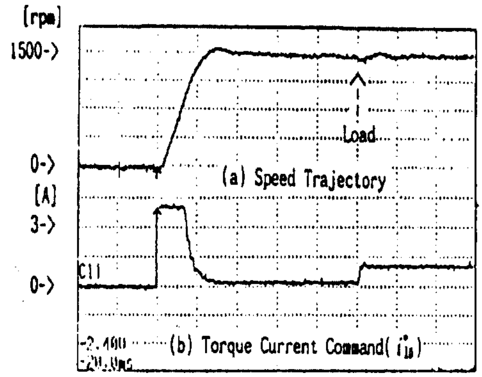


Fig. 5 Experimental Results for Fuzzy Control (200[ms/div)(1/2 load applied at 1[sec])

The Fig.4 and 5 show the experimental results for the evaluations of the robustness at load disturbance. Initially, IM was driven at no-load and after 1[sec], the electrical 1/2 load was added.

In the starting characteristic, the reaching time of a proposed fuzzy controller at constant speed command was reduced by 40[msec] than the conventional PI controller. Also, in case of connecting 1/2 load, the fuzzy controller has good performances for a external load disturbance.

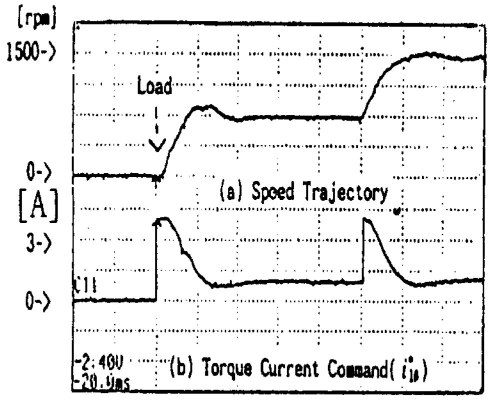


Fig. 6 Experimental Results for PI Control at 1/2 load (200[ms/div)

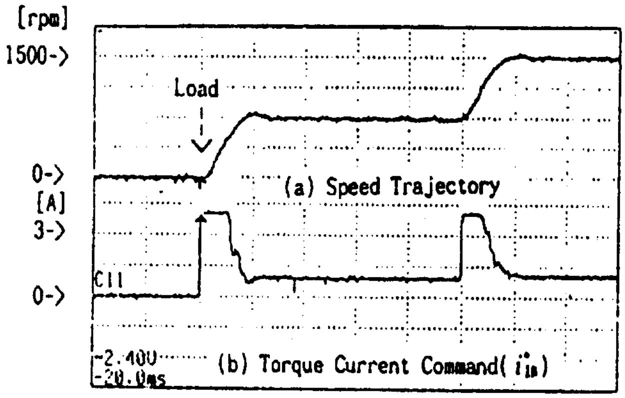


Fig. 7 Experimental Results for Fuzzy Control at 1/2 load (200[ms/div)

The Fig.6 and 7 show the dynamic results at stepwise speed command with 1/2 load respectively.

In the case of PI controller, the reaching time was 400[msec] and the excessive overshoot was occurred. But the fuzzy controller has rarely overshoot, and futhermore the reaching time was reduced by 1/2 than one of the PI controller.

The proposed fuzzy speed controller showed good transient and robust characteristics for the stepwise speed command and for the load disturbance.

5. Conclusion

In this paper, we designed the fuzzy speed controller to achieve a robust variable-speed drive of IM. The proposed self-turning technique of scale factors made the design of optimal fuzzy controller easy.

The hardware implementations were executed by the 80586 microcomputer, I/O interface board, voltage-controlled PWM inverter, 1/2HP IM and DC generator, etc. The experimental system was evaluated for the stepwise speed change and for the half load. The dynamic responses of the proposed self-tuning fuzzy controller such as dynamic response and load disturbance were substantially improved than the one of a conventional PI controller.

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