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비선형 외란 관측기를 이용한 모델 불확실성을 고려한 유도전동기의 회전자 저항 추종

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Rotor Resistance Estimation Of Induction Motor With Model uncertainty Using NonLinear Disturbance Observer

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Abstract - This paper presents a new method for estimating rotor resistance of induction motor. The rotor resistance changes dramatically with temperature and frequency. Speed is controlled by PID as it is simplest and most intuitive control method. The change in rotor resistance has a great influence on the performance of IM. In this paper rotor resistance is estimated using Non Linear Disturbance Observer. The model uncertainty and system non linearity are treated as disturbance in this method. Using NDO it does not require an accurate dynamic model to achieve high precision motor control. Controller with NDO has more superior tracking performance. Simulation results are presented to show the validity of the proposed controller.

1. INTRODUCTION

Induction motors are widely used for industrial application because of their reliability, low cost and ruggedness to environment as compared to other motors used in same area. They require practically low maintenance .Consequently much attention has been given to induction motor control.

The main objective of this paper is the speed control by using PID controller and rotor resistance estimation using Non-Linear Disturbance Observer. Speed is controlled by PID.

Two strategies have been proposed in [3]. (a) Improvement of rotor speed tracking performance by robust speed control using NDO, and (b) minimization of electric power loss of induction motor by Efficiency Flux Control EFC.

MRAS is a fast converging adaptive technique. Active power and MRAS based rotor resistance identification has been shown [4].

This paper has two objectives. Speed is controlled by using PID controllers. And rotor resistance is estimated using NDO.

2. PROBLEM STATEMENT

2.1 INDUCTION MOTOR MODEL

In case of linear magnetic circuits, the fifth-order dynamic model of induction motor is given as

$$\begin{aligned}
\frac{d\omega}{dt} &= \mu(\psi_a i_b - \psi_b i_b) - \frac{T_L}{J} - \frac{B}{J}\omega \\
\frac{di_a}{dt} &= \alpha\beta\psi_a + n_p\beta\omega\psi_b - \gamma i_a + \frac{1}{\sigma L_s}u_a \\
\frac{di_b}{dt} &= -n_p\beta\omega\psi_a + \alpha\beta\psi_b - \gamma i_b + \frac{1}{\sigma L_s}u_b \\
\frac{d\psi_b}{dt} &= -\alpha\psi_a - n_p\omega\psi_b + \alpha M i_a \\
\frac{d\psi_b}{dt} &= -\alpha\psi_b + n_p\omega\psi_a + \alpha M i_b
\end{aligned} \tag{1}$$

in which ω is rotor speed ψ_a and ψ_b are rotor fluxes, i_a and i_b are stator currents, u_a and u_b are stator voltages, T_L is load torque, J is the moment of inertia, B is the friction coefficient R_r and R_s are stator and winding resistances respectively, M is the mutual inductance, $1/\alpha = L_r/R_r$ is the rotor time constant. Let $\mu = n_p M/(JL_r)$, $\sigma = L_s(1 - M^2/(L_s L_r))$, $\beta = M/(\sigma L_r)$, $\gamma = (M^2 R_r/\sigma L_r^2) + (R_s/\sigma)$. T_L, R_r and J are uncertain parameters.

The two second order subsystems are given as

$$\begin{aligned}
\frac{d\omega}{dt} &= \mu\psi_d i_q - \frac{T_L}{J} - \frac{B}{J}\omega \\
\frac{di_q}{dt} &= \gamma i_q - n_p\beta\omega\psi_d - n_p\omega i_d - \alpha M\frac{i_d i_q}{\psi_d} + \frac{1}{\sigma L_s}u_q \\
\frac{di_d}{dt} &= -\gamma i_d - \alpha\beta\psi_d + n_p\omega i_q + \alpha M\frac{i_q^2}{\psi_d} + \frac{1}{\sigma L_s}u_d \\
\frac{d\psi_d}{dt} &= -\alpha\psi_d + \alpha M i_d
\end{aligned} \tag{2}$$

2.2 SPEED CONTROL

we used PID controller for speed control, as it is simplest and most immediate control method.

$$PID(s) = K_p\left(1 + \frac{1}{T_i s} + T_d s\right) \tag{3}$$

where $K_p = 0.6K_{cr}$, $T_i = 0.5P_{cr}$, $T_d = 0.125P_{cr}$ in the equation $(1 + 1/(T_i s) + T_d s)$ make the second and third component zero and increase the value of K_p from zero to a value where we get oscillation. this will be the value of K_{cr} and from that oscillated signal we can get its time period P_{cr} and

$$u = \left(K + \frac{1}{\gamma^2}I\right)\left(e_1^{\bullet} + K_p e_1 + K_I\int e_1 dt\right) \tag{4}$$

2.3 ADAPTIVE BACKSTEPPING CONTROL

Rotor flux amplitude ψ_d is controlled through a control input u_d.

$$\frac{d\omega}{dt} = \mu\psi_d i_q - \frac{T_L}{J} - \frac{B}{J}\omega = \mu_N\psi_d i_q + \left[\triangle\mu\psi_d i_q - \frac{T_L}{J} - \frac{B}{J}\omega\right] \tag{5}$$

where $\overline{U}(t) = \triangle\mu\psi_d i_q - \frac{T_L}{J} - \frac{B}{J}\omega$ $\overline{U}(t)$ is uncertainty, T_L and J are unknown parameters, μ is torque constant in which μ_N is nominal value and $\triangle\mu_N$ is unknown value.

$$\frac{d\omega}{dt} = \mu_N\psi_d i_q + \overline{U}(t) \tag{6}$$

2.4 NDO design

A new state variable for NDO is designed as

$$\bar{a} = \hat{\overline{U}}(t) - G\omega \tag{7}$$

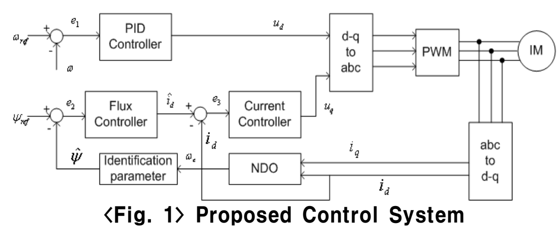
NDO is formulated as $\hat{\overline{U}}(t) = \bar{a} + G\omega$

$$\dot{\bar{a}} = -G\bar{a} - G(\mu_N\psi_d i_q + G\omega) \tag{8}$$

The disturbance observer error is given as

$$e_{\overline{U}}(t) = \overline{U}(t) - \hat{\overline{U}}(t) \tag{9}$$

From (7) and (11, we get the equation of disturbance observer as



<Fig. 1> Proposed Control System

$$e_{\dot{\overline{U}}} = \dot{\overline{U}}(t) + G(a+\mu_N\psi_d i_q + G\omega) - G\omega^{\cdot}$$
$$= -Ge_{\overline{U}} + \dot{\overline{U}}(t) \quad (10)$$

For $\overline{U}^{\cdot}(t)=0$,the NDO error $e_{\overline{L}}$ will converge to zero. But for $\overline{U}^{\cdot}(t) \neq 0$,it may not converge to zero.

$$e_{\overline{U}} = W^{*\,T}\phi(\tilde{\omega}) + \varepsilon \quad (11)$$

Where ε represents the network reconstruction error and W^{*} represents the value that minimizes $|\varepsilon|$ for all $\tilde{\omega}$.
Using (13),the $e_{\overline{U}}$ can be defined as

$$\widehat{e_{\overline{U}}} = \widehat{W^T}\phi(\tilde{\omega}) \quad (12)$$
$$\overline{U}(t) = \widehat{\overline{U}}(t) + W^{*\,T}\phi(\tilde{\omega}) + \varepsilon$$

The state observer is proposed as

$$\dot{\hat{\omega}} = \mu_N\psi_d i_q + \widehat{\overline{U}}(t) + \widehat{e_{\overline{U}}} + k_{\circ}(\omega - \hat{\omega}) \quad (13)$$

where $k_{\circ} > 0$ is state observer gain
The state observer error can be defined as

$$\tilde{\omega} = \omega - \hat{\omega} \quad (14)$$

From (7) and (15),the state observer error can be derived as

$$\dot{\tilde{\omega}} = -k_{\circ}\tilde{\omega} + \widetilde{W^T}\phi(\tilde{\omega}) + \varepsilon \quad (15)$$

2.5 Design Steps

$$\text{Speed error}: \quad e_1 = \omega - \omega_{ref} \quad (16)$$
$$\text{Flux error}: \quad e_3 = \psi_d - \psi_{opt}$$

The error dynamics equation:

$$e_1^{\cdot} = \omega^{\cdot} - \omega_{ref}$$
$$= \mu_N\psi_d i_q + \overline{U}(t) - \omega_{ref}$$
$$e_3 = \psi_d - \psi_{opt} \quad (17)$$
$$= -(\alpha_N + \hat{\theta})\psi_d + (\alpha_N + \hat{\theta})Mi_d - \psi_{opt}^{\cdot}$$

the following Lyapunov function candidate is chosen

$$V_1 = \frac{1}{2}e_1^2 + \frac{1}{2}e_3^2$$
$$= e_1(\alpha_1^* + \overline{U}(t) - \omega_{ref}) + e_3[-(\alpha_N + \hat{\theta})\psi_d + \alpha_3^* - \psi_{opt}] \quad (18)$$

where $\alpha_1^* \doteq \mu_N\psi_d i_q$ and $\alpha_3^* \doteq (\alpha_N + \hat{\theta})Mi_d$
The stabilizing function is described as

$$\alpha_1 = -k_1 e_1 + \omega_{ref}^{\cdot} - \overline{U}(t)$$
$$= -k_1 e_1 + \omega_{ref}^{\cdot} - \widehat{\overline{U}}(t) - e_{\overline{U}}$$
$$\alpha_3 = -k_3 e_3 + \psi_{opt}^{\cdot} + (\alpha_N + \hat{\theta})\psi_d \quad (19)$$

Putting the values of (14) in (13),we get

$$V_1^{\cdot} = -k_1 e_1^2 - k_3 e_3^2 + e_2 e_3 + (\widetilde{W^T}\phi + \varepsilon)e_1 \quad (20)$$

Current Control
The error signal is defined as

$$e_2 = (\alpha_N + \hat{\theta})Mi_d - \alpha_3 \quad (21)$$

Time derivative of (16) can be given as

$$e_2^{\cdot} = \psi_2 + \frac{(\alpha_N + \hat{\theta})M}{\sigma L_s}v_d \quad (22)$$

where

$$\phi_1 = k_1(-k_1 e_1 + e_2) - \omega_{ref}^{\cdot\cdot} - \mu_N n_p \omega\psi_d(\beta\psi_d + i_d)$$
$$+ \dot{\widehat{\overline{U}}} - \mu_N\psi_d i_q[(\alpha_N + \hat{\theta})(\beta M + 1) + \frac{R_s}{\sigma L_s}]$$
$$\phi_2 = k_3(-k_3 e_3 + e_4) - \Psi_{dr}^{\cdot\cdot} + \dot{\hat{\theta}}(\psi_d - Mi_d) \quad (23)$$
$$+ (\alpha_N + \hat{\theta})^2[(\beta M + 1)(\psi_d - Mi_d) + M^2\frac{i_q^2}{\psi_d}]$$
$$+ (\alpha_N + \hat{\theta})M[n_p\omega i_q - \frac{R_s}{\sigma L_s}i_d]$$

Now the following Lyapunov function candidate is chosen

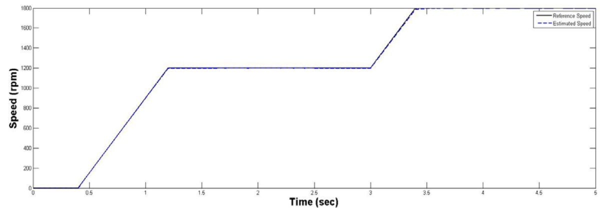
$$V_2 = V_1 + \frac{1}{2}e_2^2 + \frac{1}{2}\tilde{\omega}^2 \quad (24)$$

Choosing the control law as

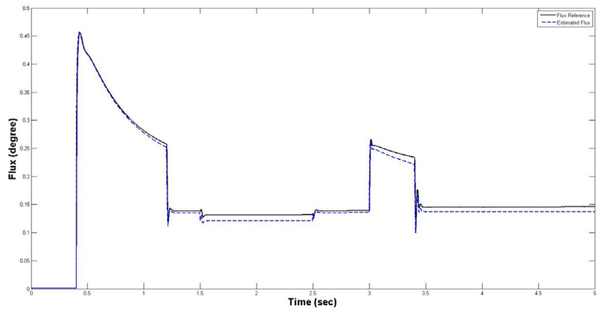
$$u_q = \frac{\sigma L_s}{\mu_N\psi_d}(e_1 + \phi_1) \quad (25)$$

2.5 SIMULATION

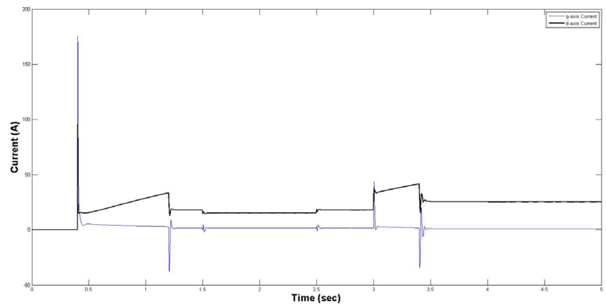
The proposed control algorithm has been simulated for 2.2KW IM. Fig. 2 shows the speed tracking performance It is clear the estimated speed follow the reference speed closely Fig. 3 shows the flux amplitude tracking performance, while the d-q axis currents are shown in Fig. 4.



<Fig. 2> Speed Tracking Performance



<Fig. 3> Optimal Flux Tracking Performance



<Fig. 4> d-q Axis Currents

3. Conclusion

The proposed controller can archive both the flux and speed tracking of IM with uncertainties. Rotor resistance is estimated using NDO. The model uncertainty and system non linearity are treated as disturbances. Simulation results show that controller with nonlinear disturbance observer has more superior tracking performance and this method is effective so the proposed method can be applied in real time vector control of IM motor drive.

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