Adaptive Induction Machine Current Control Using Internal Model Principle

Cheng-Jin Zhang

Abstract—**The inner loop current control plays a key role in the high performance sensorless induction machine control. An adaptive current control scheme for the induction machine is proposed in this report. After employing nonlinear feedforward decoupling technique the controller is constructed along with internal model principle to gain zero steady state error of the machine stator currents. The dead-zone technique is utilized in the gradient adaptive law to enhance the robustness of the control system. The simulation results carried out with MATLAB/SIMULINK are presented to show the effectiveness of the closed-loop current control system.**

I. Introduction

FOR high performance control of a sensorless induction machine a widely used approach is indirect rotor flux oriented vector control [1]. The torque performance of a vector controlled induction drive highly depends on the quality of the applied current control strategy. A current controller, which can modify its behavior in response to changes in the dynamics of the induction machine and disturbances, is desirable for a high performance vector control system.

Among the induction machine current control methods [2], PI regulator does not achieve good dynamic performance due to the inherent phase lag of a PI controller. Hysteresis controller's steady state performance is poor [3]. And predictive and deadbeat current control algorithms suffer from sensitivity to model parameter variations due to the thermal or skin effect of the resistance and the saturation of the inductances [4].

In this report a novel adaptive current control scheme for the induction machine is presented. The time-varying pole placement control design strategy [5] is applied to the reduced machine model in the stationary reference frame. The gradient adaptation law is employed to capture the model parameter variations so that the robustness of the control system is enhanced. The simulation study has been carried out to verify the robust stability and the dynamic performance of the proposed control system.

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II. Model Reduction and Parameterization

After employing nonlinear feedforward decoupling technique [1], the stationary reference frame electrical machine model can be written as follows:

$$A(s)i_{dss} = B(s)v_{dss}\,, \tag{1a}$$

$$A(s)i_{qss} = B(s)v_{qss}\,, \tag{1b}$$

where v_{dss}, v_{qss} are *d*- and *q*-axis stator voltages, i_{dss}, i_{qss} are *d*- and *q*-axis stator currents, $A(s) = s + a$, $B(s) = b$, $a = \frac{R_s}{\sigma L_s} + \frac{R_r L_m^2}{\sigma L_s L_r^2}$, $b = \frac{1}{\sigma L_s}$, L_s, L_m, L_r are stator, magnetizing and rotor inductances, $\sigma = 1 - L_m^2 / L_s L_r$, R_s, R_r are stator and rotor resistances, and *s* is differential operator.

We only consider the controller design of (1a) and that of (1b) is similar. We introduce a filter $1/F = 1/(s+f)$, where $f > 0$, and define the following:

$$\begin{aligned} y_{dss} &= (1/F)i_{dss}\,, \\ u_{dss} &= (1/F)v_{dss}\,. \end{aligned} \tag{2}$$

It is derived from (1a) and (2) that

$$\begin{aligned} i_{dss} &= [F - A(s)]y_{dss} + B(s)u_{dss} + \eta_{dss} \\ &= \phi^T\theta + \eta_{dss} \end{aligned} \tag{3}$$

where $\phi^T = [y_{dss}, \quad u_{dss}]$, η_{dss} is the modeling error arisen from the commuting operations between $1/F$, A and B, and $\theta^T = [\theta_1, \quad \theta_2] = [f - a, \quad b]$.

For some known small constant $\varepsilon \geq 0$ and let $\sigma_0 \in (0, \quad \bar{\sigma}_0)$ where $\bar{\sigma}_0 = \min\{1, \quad f\}$, we can have

$$|\eta_{dss}(t)| \leq \varepsilon\rho(t) = d(t)\,, \tag{4}$$

where

$$\rho(t) = \sup_{0\leq\tau\leq t}\{\|\phi(\tau)\|\exp\{-\sigma_0(t-\tau)\}\}. \tag{5}$$

III. Adaptive Controller Design

Denote $\hat{\theta}$ as the estimate of parameter vector θ and estimation error as

$$e = i_{dss} - \phi^T \hat{\theta}$$
$$= \phi^T \tilde{\theta} + \eta_{dss} \, , \qquad (6)$$

where $\tilde{\theta} = \theta - \hat{\theta}$ is the estimation error of the parameter vector. We utilize dead-zone technique to monitor the size of the estimation error and adapt only when the estimation error is large relative to the modeling error η_{dss} .

$$\frac{d\theta}{dt} = \frac{\alpha\phi(t)g(t)}{1+\phi^T(t)\phi(t)} \qquad (7)$$

where α is an adaptation gain,

$$g(t) = \begin{cases} 0 & \text{if } e(t)=0 \\ e(t)\max\left\{\dfrac{|e|-d(t)}{|e|}, 0\right\} & \text{if } e(t)\neq 0 \end{cases} \qquad (8)$$

Within the stationary reference frame the signal i^*_{dss} (or i^*_{qss}) to be tracked satisfies:

$$Q(s)i^*_{dss} \equiv 0 \, , \qquad (9)$$

where $Q(s) = s^2 + \omega_0^2$, ω_0 the frequency of reference signal i^*_{dss} (or i^*_{qss}).

The pole placement controller is then given by

$$P(s)Q(s)v_{dss} = L(s)\left(i^*_{dss} - i_{dss}\right), \qquad (10)$$

$L(s)$, $P(s)$ are polynomials of degree 2 and 0 respectively, obtained by solving the Bezout equation

$$P(s)Q(s)\hat{A}(s) + L(s)\hat{B}(s) = A^*(s) \, , \qquad (11)$$

where $A^*(s)$ is the desired closed-loop stable polynomial of degree 3. $\hat{A}(s)$, $\hat{B}(s)$ are polynomials $A(s)$, $B(s)$ with the parameters replaced by their estimates from (7)- (8).

IV. Simulation Studies

The machine model parameters and the design parameters are summarized as:

$$R_s = 0.55\,\Omega,\ R_r = 0.75\,\Omega, L_m = 0.063 \text{ H},$$
$$L_s = L_r = 0.068\,\text{H}, a_1 = 1800 \, , \ a_2 = 1.8\times 10^6 \, ,$$
$$a_3 = 10^7 \, , \lambda_1 = 10 \, , \ \lambda_2 = 25 \, , \ f = 10 \, , \ \alpha = 50 \, .$$

The machine reference currents are set as $i^*_{dse} = 9$ A and a q-axis square wave of +/-4.5A, 2Hz current command is utilized to verify the transient performance. The parameters are initialized as $\hat{a}(0) = 110$, $\hat{b}(0) = 80$. It is shown in Fig.1, 2 that the system performance is good with zero steady state error and quick dynamic response.

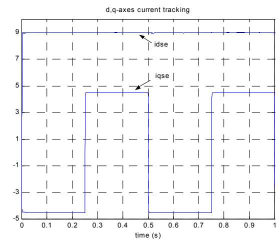

Fig. 1: Current Tacking

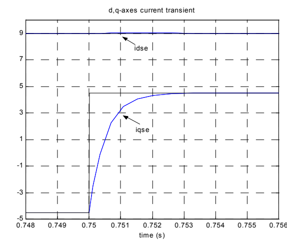

Fig. 2: Current Transient

In order to examine the performance of the current control system with the varying machine parameters 50% abrupt increases of the model parameters are made during the simulation. Fig. 3 shows that the controller rapidly adapts to the condition changes and therefore is robust with respect to the machine parameter uncertainties.

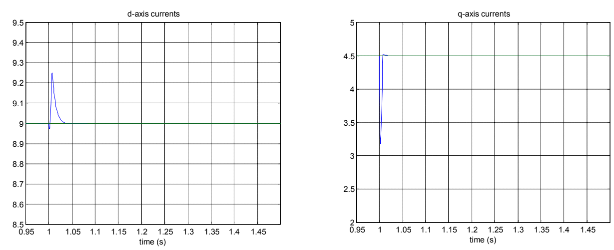

Fig. 3: Synchronous d, q-axes Currents with Parameter Jump

V. Conclusion

In this report, it has been demonstrated that the proposed control scheme is capable of adapting to the machine parameters and achieves good current control. The adaptive controller has been illustrated to be robust to machine parameter variations due to the application of the dead-zone and filtering techniques. The simulation results have shown that the control system has quick dynamic performance and zero steady state current tracking errors.

References

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