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파라미터 산정과 영구자석 동기전동기 제어를 위한 MRAS Speed 와 Stator Flux Linkage 추정량

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A MRAS Speed and Stator Flux Linkage Estimator for Permanent Magnet Synchronous Motor drives with parameter identification

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Abstract - The paper makes an investigation on a speed and stator flux linkage estimator for permanent magnet synchronous motor (PMSM) sensorless drives using the technology of model reference adaptive system (MRAS). The designed estimator including two models and two adaptive estimating laws is proved to be stable by the Popov hyper-stability theory. The speed, the stator flux linkage and the resistance are estimated accurately by the proposed estimator while overcoming the shortcoming of the traditional one. The experiment results demonstrate its effectiveness.

2. Introduction

In the recent years, many techniques of the flux and speed estimation developed are based on the voltage model, the current model, or a combination of both [1]. The estimating method based on the current model usually applied in a low speed drive has a advantage of eliminating the sensitivity to the motor resistance variation [2], which need to know the stator currents and rotor position. The voltage model based estimator is often used in a high speed drive. However, at a low speed, a degradation of estimating performance for the DC offset of the measured phase current and resistance variation will arise [3]. In the paper, a MRAS estimator containing two models of a current model and a voltage model is investigated, which has a phase-locked loop structure. The rotor position calculated by the estimated speed is used to the coordinate conversion of the input voltages and currents. The speed and the resistance are estimated accurately by two adaptive laws derived by Popov hyper-stability theory. The estimated flux linkage of the proposed estimator is achieved with a good steady performance compared with the traditional one.

3. The proposed estimation scheme

In the designed estimator, a current model in terms of the current and stator flux linkage is defined as a reference model given by

$$\begin{cases} \psi_d = L_s i_d \\ \psi_q = L_s i_q + \psi_f \end{cases} \tag{1}$$

where ψ_d, ψ_q, i_d and i_q are the stator flux linkages and currents in the rotating frame, L_s and ψ_f are the inductance and the rotor magnet flux linkage respectively. The current model also has a problem of not overcoming the DC offset of the measured currents and cannot be used for estimating the stator flux linkage separately. Thus, we introduce a voltage model in a matrix form

$$\frac{dX}{dt} = AX + Bu \tag{2}$$

as a regulating model in the rotating frame where

$$X = \begin{bmatrix} \psi_d \\ \psi_q \end{bmatrix}, u = \begin{bmatrix} u_d + \dfrac{R_s}{L_s}\psi_f \\ u_q \end{bmatrix}, A = \begin{bmatrix} -\dfrac{R_s}{L_s} & \omega \\ -\omega & -\dfrac{R_s}{L_s} \end{bmatrix}, B = I$$

and u_d and u_q are the stator voltages in the rotating frame. In (2), to estimate the resistance and rotor speed, we choose the stator flux linkages of ψ_d and ψ_q in the rotating frame as the estimated variable and the resistance R_s and the speed ω as the regulated object, the voltage model (2) cam be rewritten as

$$\frac{d\hat{X}}{dt} = \hat{A}\hat{X} + B\hat{u} - G(X - \hat{X}) \tag{3}$$

where

$$\hat{X} = \begin{bmatrix} \hat{\psi}_d \\ \hat{\psi}_q \end{bmatrix}, \hat{u} = \begin{bmatrix} u_d + \dfrac{\hat{R}_s}{L_s}\psi_f \\ u_q \end{bmatrix}, \hat{A} = \begin{bmatrix} -\dfrac{\hat{R}_s}{L_s} & \hat{\omega} \\ -\hat{\omega} & -\dfrac{\hat{R}_s}{L_s} \end{bmatrix}$$

where G is a constant coefficient matrix.

Defining the state error e, the error coefficient matrix ΔA and the error input matrix Δu as

$$e = \begin{bmatrix} e_1 \\ e_2 \end{bmatrix} = X - \hat{X} = \begin{bmatrix} \psi_d - \hat{\psi}_d \\ \psi_q - \hat{\psi}_q \end{bmatrix} \tag{4}$$

$$\Delta A = \hat{A} - A = \begin{bmatrix} -\dfrac{\Delta R_s}{L_s} & \Delta\omega \\ -\Delta\omega & -\dfrac{\Delta R_s}{L_s} \end{bmatrix} = -\frac{\Delta R_s}{L_s} I - \Delta\omega J$$

$$\Delta u = \hat{u} - u = \begin{bmatrix} \dfrac{\Delta R_s}{L_s}\psi_f \\ 0 \end{bmatrix} = \frac{\Delta R_s}{L_s}\psi_f I_0$$

where the error resistance $\Delta R_s = \hat{R}_s - R_s$ and the error speed $\Delta\omega = \hat{\omega} - \omega$.

Thus, based on equations (2) and (3), the time derivative of the state error in (4) is

$$\frac{de}{dt} = (A + G)e - \Delta A\hat{X} - B\Delta u \tag{5}$$

Defining a output vector as

$$\varpi = \Delta A\hat{X} + B\Delta u \tag{6}$$

and substituting (6) into (5), yielding

$$\begin{cases} \dfrac{de}{dt} = (A + G)e - I\varpi \\ \nu = De \end{cases} \tag{7}$$

where ν is an input vector and D is a coefficient matrix.

Defining $D = I$, then $\nu = Ie = e$. According to the Popov hyper-stability theory, if the following conditions

(I) $H(s) = D(sI - \hat{A} - G)^{-1}$ is a strictly positive matrix.

(II) $\forall t_0 \geq 0$, $\eta(0, t_0) = \int_0^{t_0} (\nu^T \varpi) dt \geq -\gamma_0^2$, where γ_0^2 is a finite positive constant, which is independent of t_0, are satisfied

Thus, $\lim_{t\to\infty} e(t) = 0$ and the error dynamic system (7) is stable.

In a designed error system (7), if one choosing an appropriate constant matrix G, the stable condition I mentioned above can be easily satisfied. According to the stable condition II, substituting (5) into a variable $\nu^T\varpi$, yielding

$$\nu^T\varpi = e^T\Delta A\hat{X} + e^T B\Delta u \tag{8}$$

Substituting (6) into (8), this gives

$$\nu^T \varpi = -e^T\left(\frac{\Delta R_s}{L_s} I + \Delta\omega J\right)\hat{X} + \frac{\Delta R_s}{L_s}\psi_f e^T I_0 \tag{9}$$

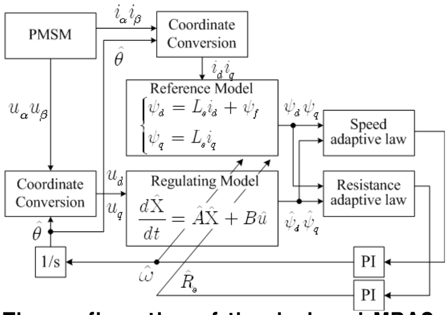
Defining the following equation as

$$\lambda_1 \frac{d(\Delta R_s)^2}{dt} = \frac{\Delta R_s}{L_s} M\,, \quad \lambda_2 \frac{d(\Delta\omega)^2}{dt} = \Delta\omega\, N \tag{10}$$

where $M = -e^T I\hat{X} + \psi_f e^T I_0$, $N = -e^T J\hat{X}$, λ_1 and λ_2 are two positive constants. Substitute (10) into (9), the stable condition II mentioned above can also be satisfied when three constants of γ_0^2, λ_1 and λ_2 are chosen appropriately. Thus, equations (10) can now be solved for the designed adaptive laws of $\hat{R}_s$ and $\hat{\omega}$. To speed the response of them, the proportional term is added. Thus, the final speed and resistance adaptive laws are given as

$$\hat{R}_s = k_{p1}M + k_{i1}\int (M)dt, \quad \hat{\omega} = k_{p2}N + k_{i2}\int (N)dt \tag{11}$$

where k_{p1}, k_{p2}, k_{i1} and k_{i2} are four positive constants.

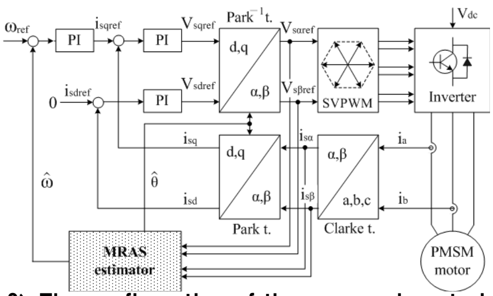


<Fig. 1> The configuration of the designed MRAS estimator

The configuration of the designed MRAS estimator for a PMSM motor is shown in Fig. 1. From the equations (7) to (11), It is known that Popov hyper-stability theory can ensure the stability of the designed estimating system if we choose the appropriate constant coefficient in (3), (10) and (11). In the system, while the regulating object of the speed and the resistance is changed synchronously, the regulating model tracks the reference model continuously. That is, when the designed system is stable, the regulating model is close to the actual motor system.

4. Experiment results

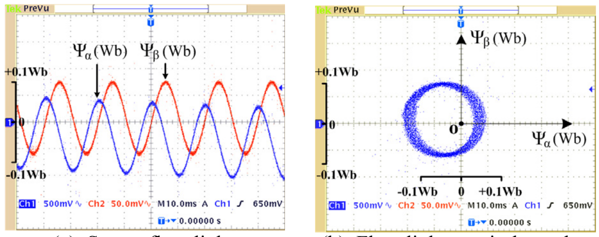
To verify the proposed scheme, its experiment is carried out in a sensorless PMSM drive. The vector control scheme having idref=0 is used in the drive shown in the Fig. 2.



<Fig. 2> The configuration of the proposed control system

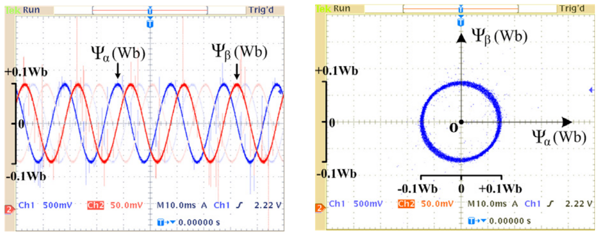
The motor parameters are: the DC link voltage 24V, the armature resistance 0.79, the inductance 1.2mH and the number of poles 8. The PWM switching frequency of the inverter is set as 10KHz. The reference speed of the motor is set to 300rpm. To reduce the startup current of the motor, a step signal of input speed command is transformed to a ramp signal with a slope value of 0.1. The experiment is implemented in a DSP of TMS320F28035 and its experimental results of the drive system in Fig. 2 with a traditional and proposed scheme are shown in Fig. 3 and 4 respectively.

In the traditional estimator [3], an integration is used to derive the flux linkage. However, The integration will large the error and the integration process will integrate these errors and unless reset, they will grow to large values leading to instability. When there exists a DC offset of the measured currents and voltages or an unknown initial value of the stator flux linkage, the estimated stator flux linkage from a traditional estimating scheme [3], shown in the Fig. 3(a), are divergent and the origin of its planar circle path shown in Fig. 3(b) leaves that of coordinates. Thus, the method to estimate the flux linkage with an integration is invalid. The proposed estimator has the advantage of overcoming the limitation of the traditional integration. The estimated flux linkage shown in Fig. 4(a) and (b) have a good steady performance and the origin of its planar circle path is fixed in that of coordinates. Simultaneously, the speed and position errors in Fig. 4(c) are closed to zero quickly. The speed and the resistance are estimated accurately in Fig. 4(d). The motor speed quickly reaches its reference value in 0.25 second and the startup process has a fast dynamic performance.

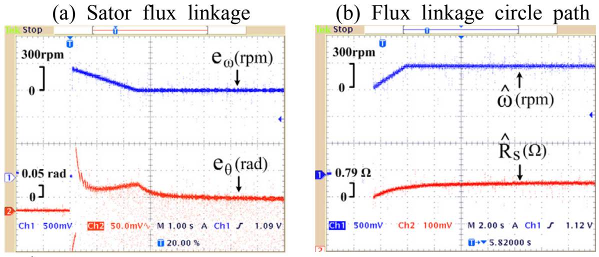


(a) Stator flux linkage (b) Flux linkage circle path

<Fig. 3> the experiments results of a traditional scheme



(a) Sator flux linkage (b) Flux linkage circle path



(c) Speed and position error (d) Speed and resistance

<Fig. 4> The experiments results of the proposed scheme

5. Conclusions

A MRAS speed estimator for sensorless vector control of PMSM drives is presented in this paper. The designed MRAS estimator has a phase-locked loop structure, which contains two models. Two derived adaptive laws are used to estimate the speed and the resistance simultaneously. The proposed scheme achieves a accurate speed and stator flux linkage estimation compared with the traditional method, which is verified by the experiment results.

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