Sequential Parameter Estimation Scheme for a PWM Inverter-fed IPMSM Control

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Abstract. A sequential estimation of electrical parameters for a PWM Inverter-fed interior permanent magnet synchronous machine (IPMSM) control is presented. As compared with other adaptation schemes such as a recursive least square method (RLSM), the proposed model reference adaptive control (MRAC) based parameter estimation is not sensitive to noise. Also, it does not require a strict condition like the persistent excitation. The effectiveness is verified through the simulations.

Keywords: IPMSM Control, Sequential estimation, MRAC, PWM Inverter.

1 Introduction

In general, an interior permanent magnet synchronous machine (IPMSM) control systems are faced with unavoidable and immeasurable disturbances or some parameter variations [1]. Coupling the load to the machine shaft may cause the variations of the inertia and friction coefficient besides the load variation. The flux linkage varies nonlinearly with the temperature rise, and also, with the external field produced by the stator current due to the nonlinear demagnetization characteristics of the magnet. The stator resistance varies according to operating temperature. When these controller parameters are mismatched with the real parameters, a satisfactory performance cannot be obtained [2]. To guarantee the robust response against the parameter variation, the controller parameters should be adaptively changed according to the variation of plant parameters. Furthermore, the exact information on the parameters is very important to implement a sensorless control scheme or to diagnose a fault in a drive system [3], [4].

In an initial set-up of most servo controllers, a proper tuning process for the parameter and gain is needed since the machine parameters of drive systems may vary according to the load and operating conditions. For this tuning process, a time-consuming trial and error method has been often employed. Thus, executing an auto-tuning process in a short time at initial set-up of servo systems is highly desirable to estimate main machine parameters at one time.

This paper presents a sequential estimation of electrical parameters for a PWM inverter-fed IPMSM control where the flux linkage and stator resistance are

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sequentially estimated using the state observer and model reference adaptive control (MRAC) scheme. The simultaneous estimation of several machine parameters is generally not simple. To avoid the limitation of estimating parameters simultaneously in the conventional method, a sequential parameter estimation algorithm is proposed where dominant machine parameters are estimated one by one, based on the fixed sequential routine that only one parameter is estimated during each interval. Since various works that effectively estimate only the specific interested parameter of machines are well known in many literatures [1], [2], this can be an effective way of estimating main machine parameters at one time. As compared with other adaptation schemes such a recursive least square method (RLSM), the proposed scheme is not sensitive to noise. Also, it does not require a strict condition like the persistent excitation. Considering that the most servo control system has a current reference in a step waveform, it can be a very effective way of estimating electrical parameters. The effectiveness is verified through the simulations.

2 Modeling and Sequential Parameter Estimation

An IPMSM consists of permanent magnets and three phase stator windings. The voltage equations of an IPMSM are described as follows:

$$v_{qs} = R_s i_{qs} + L_{qs}\dot{i}_{qs} + L_{ds}\omega_r i_{ds} + \lambda_m \omega_r \,. \quad (1)$$

$$v_{ds} = R_s i_{ds} + L_{ds}\dot{i}_{ds} - L_{qs}\omega_r i_{qs} \,. \quad (2)$$

Using i_{qs} and i_{ds} as state variables, the state equation of the IPMSM can be expressed as follows:

$$\dot{i}_s = A i_s + B v_s + d \,. \quad (3)$$

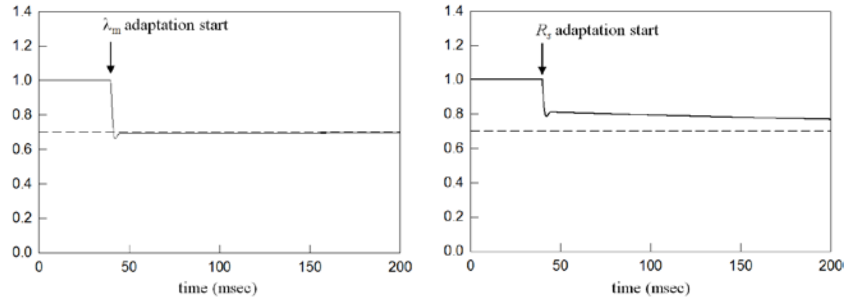
where $i_s = [i_{qs} \quad i_{ds}]^T$, $v_s = [v_{qs} \quad v_{ds}]^T$

The full state current observer which estimates stator currents can be expressed as

$$\dot{\hat{i}}_s = \hat{A}\hat{i}_s + B v_s + \hat{d} + G(\hat{i}_s - i_s) \,. \quad (4)$$

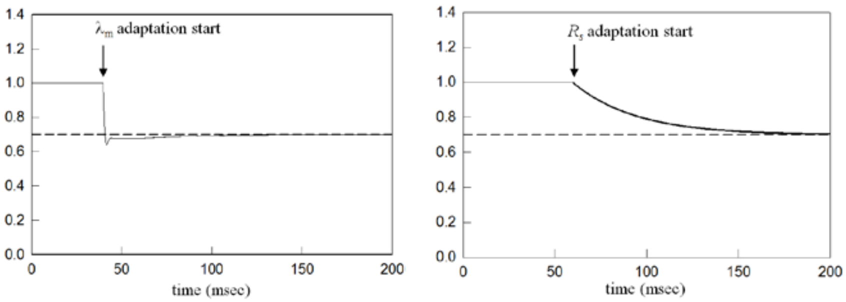
where "$\wedge$" denotes the estimated quantities and G is an observer gain matrix. $\hat{A}$ and $\hat{d}$ are the matrices in which R_s and λ_m are replaced by the estimated values $\hat{R}_s$ and $\hat{\lambda}_m$, respectively.

To estimate the stator resistance and flux linkage, an MRAC technique is used. The state equation of the IPMSM is used for a reference model and the full state current observer is used for an adjustable model. The errors between the reference model and adjustable model can be used to drive the adaptation mechanism and to update the parameters in the adjustable model. When $\hat{R}_s$ and $\hat{\lambda}_m$ are used in the current observer, the error dynamics can be obtained by subtracting (4) from (3) as follows:



(a) (b)

Fig. 1. Performance of the simultaneous parameter estimation with the initial parameter error of 30%. (a) Estimation of flux linkage. (b) Estimation of stator resistance.



(a) (b)

Fig. 2. Performance of the proposed sequential parameter estimation scheme with the initial parameter error of 30%. (a) Estimation of flux linkage. (b) Estimation of stator resistance.

$$\dot{e} = (A+G)e - W \ . \qquad \textbf{(5)}$$

where $e = i_s - \hat{i}_s$, $W = -\Delta A \cdot \hat{i}_s - \Delta d$, and ΔA and Δd are the error matrices caused by the parameter variations.

Based on (5), the MRAC system can be constructed, which consists of a linear time invariant forward block and a nonlinear feedback block. This system is hyperstable if the forward transfer function matrix is strictly positive real and the input-output inner product of nonlinear feedback block satisfies the Popov's integral inequality [5]. With the stable error dynamics, the forward transfer matrix $[sI-(A+G)]^{-1}$ is always strictly positive real. From the Popov's integral inequality, the stator resistance and flux linkage can be estimated as follows:

$$\hat{R}_s = -\left(k_{PR} + k_{IR}/s\right)\cdot(e^T B \cdot \hat{i}_s) \ . \qquad \textbf{(6)}$$

$$\hat{\lambda}_m = -\left(k_{P\lambda} + k_{I\lambda} / s\right) \cdot (e_{qs}\omega_r) \ . \tag{7}$$

3 Simulation Results

Fig. 1 shows the simultaneous estimation of the flux linkage and stator resistance with the initial parameter error of 30%. The estimation starts at 40 [msec] at the same time. While the estimation of the flux linkage shows a good convergence, the estimation of the stator resistance is not so good. Fig. 2 shows the proposed sequential parameter estimation for the flux linkage and stator resistance at the same condition. The flux linkage is first estimated at 40 [msec] because it has a dominant influence on current control and observer. Once the flux linkage estimation is accomplished, the estimation of the stator resistance starts at 50 [msec]. Using this scheme, a stable parameter estimating performance can be obtained without an estimation failure or difficulty in choosing the estimation gains as in the simultaneous estimation scheme.

4 Conclusions

This paper presents a sequential estimation of electrical parameters for a PWM inverter-fed IPMSM control where the flux linkage and stator resistance are sequentially estimated using the state observer and MRAC scheme. Using this scheme, a stable parameter estimating performance can be obtained without an estimation failure or any difficulty in choosing the estimation gains as in the simultaneous estimation technique.

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References

1. Yang, G., Chin, T.H.: Adaptive-speed Identification Scheme for a Vector-controlled Speed Sensorless Inverter-induction Motor Drive. IEEE Trans. Indus. Applicat. 29, no. 4, 820--825 (1993)
2. Kim, K.H.: Nonlinear Speed Control for a PM Synchronous Motor with a Sequential Parameter Auto-tuning Algorithm. IEE Electr. Power Appl. 152, no. 5, 1253--1262 (2005)
3. Wu, R., Slemon, G.R.: A Permanent Magnet Motor Drive without a Shaft Sensor. IEEE Trans. Indus. Applicat. 27, no. 5, 1005--1011 (1991)
4. Grubic, S., Aller, J.M., Bin, L., Habetler, T.G.: A Survey on Testing and Monitoring Methods for Stator Insulation Systems of Low-voltage Induction Machines Focusing on Turn Insulation Problems. IEEE Trans. Indus. Electr. 55, no. 12, 4127--4136 (2008)
5. Landau, Y.D.: Adaptive Control - The Model Reference Approach. Marcel Dekker, New York (1979)