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단일전류센서를 이용한 교류전동기 구동에서 전동기 상수동정과 그 오차

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Parameters identification and their errors for AC motor drive systems using the single current sensor technique

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ABSTRACT

An estimation scheme is used for solving two practical problems of the single current sensor technique. To improve the effect of parameter uncertainties, the method that identifies motor parameters for AC motor drive systems using the single current sensor technique is presented. And, the parameter identification error and its cause are examined. It gives good performances for identifying parameters and reconstructing phase currents.

1. Introduction

The AC motor drive system with the field oriented control(FOC) can be compared with the DC motor drive system from the view point of control performance. The speed and flux controls are essential for the FOC, which needs q- and d-axes current control, respectively. Since motor parameters are unknown and varied with an operating point, the uncertainties and variations of motor parameters make a control performance of system worse. Also, though the predictive current control has good performance and switching characteristics, it has a poor performance with the uncertainty and variation of motor parameter. The problem can be solved by employing of the parameter identification.

In this paper, the parameter identification method for AC motor drive system using the single current sensor technique is presented and parameter identification errors and their causes are examined in the parameter identification scheme.

2. The Single Current Sensor Technique

The single current sensor technique is to reconstruct three phase currents from only one dc-link current sensor without phase current sensors[1]-[4]. The principle of this technique is known from (1).

$$i_{dc} = [\, S_a \;\; S_b \;\; S_c \,]\, [\, i_a \;\; i_b \;\; i_c \,]^t \tag{1}$$

However, this technique has two practical problems for applying to the AC motor drive systems[1]-[4]. One is a unreliable detection problem with a short duration of an active vector and the other is a phase shift problem. These problems can be solved by the modified SVPWM and the estimation scheme together with the parameter identification using Recursive Least Square Method(RLSM)[4].

3. Parameter Identification Error

The parameter identification method mentioned in [4] can be carried out using the Taylor's series expansion and RLSM. This method may have a parameter identification error due to the residue of the Taylor's series expansion, an error of the back EMF, and a undesired component of a sensed dc-link current. Let $\frac{R_s}{L_s}T_s$, $\frac{\hat{R}_s}{\hat{L}_s}\hat{T}_s$, $e^{-\frac{R_s}{L_s}T_s}$, and $e^{-\frac{\hat{R}_s}{\hat{L}_s}T_s}$ be $X, \hat{X}, Y$, and $\hat{Y}$, respectively, then Y can be expressed as follows:

$$Y = 1 - X + \varepsilon \tag{2}$$

where ε is a residue after the first-order Taylor series expansion is applied. The real (k+1)-th current can be expressed as follows:

$$i(k+1) = Yi(k) + \frac{V-E}{R_s}(1-Y) \quad (3)$$

Showing Fig. 1-4, the results of the first-order Talylor's series expansion are different from the full and second order one. Although, the second order system is almost equal to the full order system, the first order system is generally used for solving the system equation because of simplexity. The variation of the resistance gives a little effect to the estimation current error compared with the variation of the inductance and the back EMF. Therefore, a good identification of the inductance is needed for a good performance. It is recommended that T_s/T_c is under 0.1 for having a 10% estimation current error.

3.1 The parameter identification error due to the residue of the first-order Taylor's series expansion

The estimated (k+1)-th current can be expressed as follows:

$$\hat{i}(k+1) = (1-\hat{X})i(k) + \frac{V-\hat{E}}{\hat{R}_s}\hat{X}. \quad (4)$$

Because $i(k+1)$ of (3) and $\hat{i}(k+1)$ of (4) are identical even any value of $i(k)$ and $(V-E)$ if E equal $\hat{E}$, the relations of a real and an identified parameter can be obtained as follows:

$$1-X+\varepsilon = 1-\hat{X} \quad (5)$$

$$\frac{X-\varepsilon}{R_s} = \frac{\hat{X}}{\hat{R}_s}. \quad (6)$$

Arranging (5) and (6), the following equations can be obtained.

$$X = \hat{X} + \varepsilon \quad (7)$$

$$\frac{X-\varepsilon}{R_s} = \frac{X}{R_s}\left(1-\frac{\varepsilon}{X}\right) = \frac{T_s}{L_s}\left(1-\frac{\varepsilon}{X}\right) \quad (8)$$

$$\varepsilon = \frac{1}{2!}\left(\frac{R_sT_s}{L_s}\right)^2 - \frac{1}{3!}\left(\frac{R_sT_s}{L_s}\right)^3 \approx \frac{1}{2!}\left(\frac{R_sT_s}{L_s}\right)^2 = \frac{X^2}{2} \quad (9)$$

From (5)~(8),

$$R_s = \hat{R}_s \quad (10)$$

$$L_s = \hat{L}_s\left(1-\frac{\varepsilon}{X}\right) = \hat{L}\Delta \approx \hat{L}_s\left(1-\frac{X}{2}\right). \quad (11)$$

From (10) and (11), the inductance is identified larger than a real value and the resistance has no identification error. If Δ is close to 1, that is to say, $X = \frac{R_sT_s}{L_s}$ is close to 0, the identification error of the inductance becomes smaller. In conclusion, the identification error of the resistance due to the residue of the first-order Taylors series expansion is 0, the identified inductance value is larger than a real value and is getting closer to a real value as $X = \frac{R_sT_s}{L_s}$ becomes smaller in positive value.

Fig. 5 and 6 show the parameter estimation errors corresponding to the variation of T_s/T_c for several types of Taylor's series expansion. As known in (10) and (11), the parameter error of an inductance is large where the parameter error of a resistance is almost 0. From these results, it is noted that small T_s/T_c gives small parameters errors.

3.2 The parameter identification error due to the uncertainty of Back EMF

It is difficult to obtain the back EMF from a voltage sensor because there is no open circuit to sense the back EMF for an three-phase inverter system with 180° firing. Therefore, the back EMF is obtained from motor parameters and a motor angular speed. The back EMF value obtained from this is apt to differ from a real value, and this gives a parameter identification error. If the error of the back EMF is δE, the estimated back EMF $\hat{E}$ is equal to $E+\delta E$. Introducing this into (3) and (4), the following equations can be obtained.

$$\hat{i}(k+1) = (1-\hat{X})i(k) + \frac{V-E-\delta E}{\hat{R}_s}\hat{X} \quad (11)$$

$$i(k+1) = (1-X+\varepsilon)i(k) + \frac{T_s}{L_s}(V-E)\left(1-\frac{\varepsilon}{X}\right) \quad (12)$$

The identified resistance and inductance can be from (3), (11), (12) as follows:

$$\hat{R}_s = \left[1-\frac{\delta E}{V-E}\right]R_s \quad (13)$$

$$\hat{L}_s = \left[1-\frac{\delta E}{V-E}\right]\frac{1}{\Delta}L_s. \quad (14)$$

The parameter identification errors are larger as $\frac{\delta E}{V-E}$ becomes larger. This is shown in Fig. 7. That is to say, large back EMF error and small $(V-E)$ give large identification errors. Especially, the parameter identification errors are large when the motor is operated at high speed with a light load. And, at low speed, as the back EMF is very small and the error of the back EMF is also very small, the parameter identification error due to the error of the back EMF can be negligible.

3.3 The parameter identification error due to the undesirable components of i_{DC}

The undesirable components of a sensed dc-link current i_{DC} such as a snubber current and a reverse recovery diode current cause not only detection errors of phase currents as mentioned before, but also the parameter identification errors. Because the sensed current is the sum of the real current and these undesirable currents, (3) becomes as follows:

$$i(k+1)+\delta i_{k+1}=(1-\hat{X})[\,i(k)+\delta i_k]+\frac{T_s}{\hat{L}}(V-E-\delta E) \quad (15)$$

where δi_k is the undesirable component at the k-th instant.

The following equation is derived from (3) and (12).

$$\delta i_{k+1}-(1-\hat{X})\delta i_k=(X-\hat{X}-\varepsilon)i(k)+\frac{T_s}{\hat{L}_s}(V-E-\delta E)-\frac{T_s}{L_s}(V-E)\left(1-\frac{\varepsilon}{E}\right) \quad (16)$$

If the effects of the approximation using the Taylor's series expansion and the variation of back EMF are ignored, that is to say, $\varepsilon=0$ and $\delta E=0$, and (16) becomes (17).

$$\left\{\left[\frac{1}{\hat{L}_s}-\frac{1}{L_s}\right]T_s-\frac{\delta i_0}{(V-E)}\right\}(V-E)+\left\{(X-\hat{X})-\frac{\delta i_0}{i(k)}\right\}i(k)=0 \quad (17)$$

where $2\delta i_0=\delta i_{k+1}-(1-\hat{X})\delta i_k$. To satisfy (17) with any values of $i(k)$ and $(V-E)$, the inner parts of { } should be zeroes.

$$\hat{X}=X-\frac{\delta i_0}{i(k)} \quad (18)$$

$$\frac{1}{\hat{L}_s}=\frac{1}{L_s}+\frac{\delta i_0}{(V-E)T_s} \quad (19)$$

Investigating (18) and (19), 'the estimated parameters $\hat{X}$ and $\hat{L}_s$ are smaller(larger) than the real values in the case of positive(negative) δi_0. Therefore, $\hat{R}_s/R_s$ is smaller(larger) than $\hat{L}_s/L_s$ in the case of positive(negative). This is also shown in Fig. 8.

4. Conclusions

The estimated values of inductance are larger than the real value and the estimated resistance value equals the real value when an approximation using Taylor's series expansion is used for solving a system equation. And, due to the positive error of the back EMF or the positive undesirable component of i_{DC}, the parameters are estimated smaller than the real value. To obtain a good identification of parameter, small T_s/T_c is recommended. And, a proper operating condition is required to reduce the effect of the back EMF, for instance, parameters should not be identified at high speed and light load.

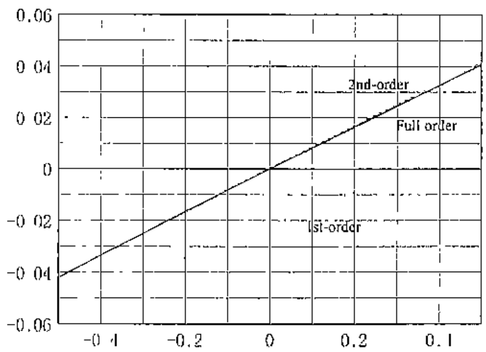

Fig. 1 Estimation Current Error vs Resistance Variation corresponding to Taylor's Series Expansion

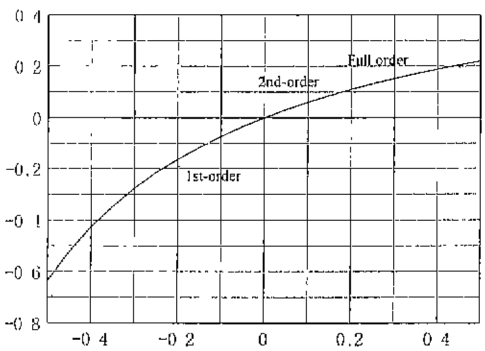

Fig. 2 Estimation Current Error vs Inductance Variation corresponding to Taylor's Series Expansion

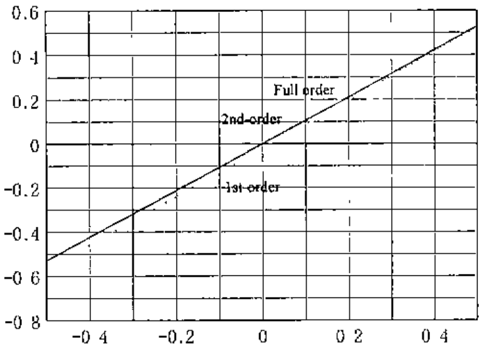

Fig. 3 Estimation Current Error vs BEMF Variation corresponding to Taylor's Series Expansion

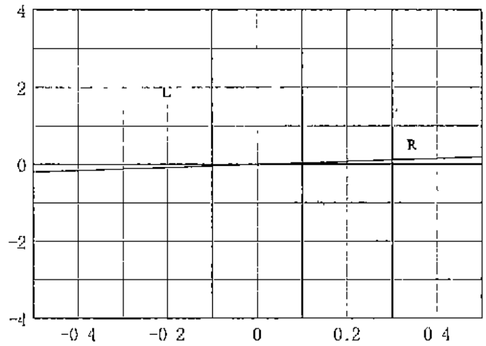

Fig 7 Parameter Identification Error due to the Back-EMF Variation

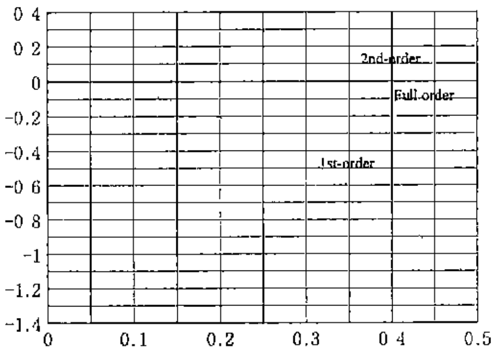

Fig 4 Estimation Current Error vs Ts/Tc corresponding to Taylor's Series Expansion

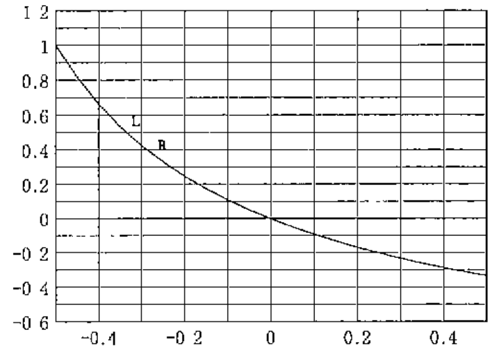

Fig 8 Parameter Identification Error due to the undesirable current(Constant Rate)

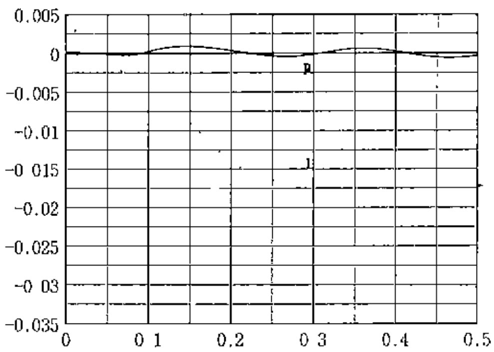

Fig 5 Parameter Identification Error vs Ts/Tc (due to the Taylor's Series Expansion)

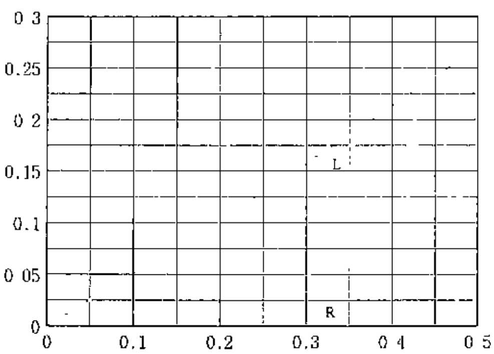

Fig 6 Parameter Identification Error vs. Ts/Tc (due to the 1-st order Taylor's Series Expansion)

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