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Calculate Magnetic Flux of induction motors using real-time Microcontrollers

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Abstract
Nowadays, The three-phase AC induction motor (IMs), are widely used in industrial applications. In IM-driven systems requiring high control quality, the field-oriented control (FOC) method is often applied. In order to use the FOC control structure, it is required to identify the generated magnetic flux of the motor accurately. In this paper, the authors deal with the method calculate magnetic flux of Induction Motors using real-time microcontrollers.

Keywords: IM, C2000, FOC

1. Introduction

For specific applications that require operators or researchers, intervention in the control structure to customize the technology process is necessary. C2000 DSP with an open structure, strong computing power [1-13] and competitive price opens up the prospect of building a complete control structure for the IM motor. With the permanent magnet (PM) motor, [14-21] the magnetic flux of the motor was pre-formed because the rotor is made of permanent magnets. Therefore, it is possible to implement the FOC control structure when the angle of magnetic flux is precisely determined. The magnetic flux of the IM motor is formed when the motor is powered.

2. Methodology

Equations for the flux of stator and rotor is shown in equation (1).

$$\begin{cases} \boldsymbol{\psi}_s = L_s \mathbf{i}_s + L_m \mathbf{i}_r \\ \boldsymbol{\psi}_r = L_m \mathbf{i}_s + L_r \mathbf{i}_r \end{cases} \tag{1}$$

In which:
$L_s = L_m + L_{\sigma s}$ and $L_r = L_m + L_{\sigma r}$. Ls is stator inductance, Lm is mutual inductance, Ls stator inductance, Lr rotor inductance, Lm mutual inductance, Lσs and Lσr are stator and rotor inductors, i_s is stator current, and i_s is rotor current. The IM motor in this study is a squirrel-cage induction motor, so the rotor voltage is zero. Therefore, equations for the stator and rotor voltages are as follows:

$$\boldsymbol{u}_s = R_s \boldsymbol{i}_s + \frac{d\psi_s}{dt} + j\omega_s \boldsymbol{\psi}_s \tag{2}$$

$$0 = R_r \boldsymbol{i}_r + \frac{d\psi_r}{dt} + j\omega_r \boldsymbol{\psi}_r` \tag{2}$$

In which $\omega_r = \omega_s - \omega$, with ω_r is the slip velocity, ω_s is the synchronous velocity, and ω is the rotor velocity.
From (1), (2) and (3), we have:

$$\begin{cases} \boldsymbol{u_s} = R_s \boldsymbol{i_s} + \frac{d\boldsymbol{\psi_s}}{dt} + j\omega_s \boldsymbol{\psi_s} \\ 0 = R_r \boldsymbol{i_r} + \frac{d\boldsymbol{\psi_r}}{dt} + j\omega_r \boldsymbol{\psi_r} \\ \boldsymbol{\psi_s} = L_s \boldsymbol{i_s} + L_m \boldsymbol{i_r} \\ \boldsymbol{\psi_r} = L_m \boldsymbol{i_s} + L_r \boldsymbol{i_r} \end{cases} \tag{3}$$

Eliminating the rotor current and the stator flux from (4), we obtain a set of equations describing the motor on the coordinate system dq as follows:

$$\begin{cases} \frac{di_{sd}}{dt} = -\left(\frac{1}{\sigma T_s} + \frac{1-\sigma}{\sigma T_s}\right) i_{sd} + \omega_s i_{sq} \\ + \frac{1-\sigma}{\sigma T_r} \psi'_{rd} + \frac{1-\sigma}{\sigma} \omega \psi'_{rq} + \frac{1}{\sigma L_s} u_{sd} \\ \frac{di_{sq}}{dt} = -\omega_s i_{sd} - \left(\frac{1}{\sigma T_s} - \frac{1-\sigma}{\sigma T_r}\right) i_{sq} \\ - \frac{1-\sigma}{\sigma} \omega \psi'_{rq} + \frac{1-\sigma}{\sigma T_r} \psi'_{rq} + \frac{1}{\sigma L_s} u_{sq} \\ \frac{d\psi'_{rd}}{dt} = \frac{1}{T_r} i_{sd} - \frac{1}{T_r} \psi'_{rd} + (\omega_s - \omega) \psi'_{rq} \\ \frac{d\psi'_{rd}}{dt} = \frac{1}{T_r} i_{sq} - (\omega_s - \omega) \psi'_{rd} - \frac{1}{T_r} \psi'_{rq} \end{cases} \tag{4}$$

Selecting the rotation system dq with q axis perpendicular to the flux generated by the rotor, we have $\psi_{rd} = 0$.
Substituting ψ_{rd} into (5), we have:

$$\frac{di_{sd}}{dt} = -\left(\frac{1}{\sigma T_s} + \frac{1-\sigma}{\sigma T_s}\right) i_{sd} + \omega_s i_{sq} + \frac{1-\sigma}{\sigma T_r} \psi'_{rd} + \frac{1}{\sigma L_s} u_{sd} \tag{5}$$

$$\frac{di_{sq}}{dt} = -\omega_s i_{sd} - \left(\frac{1}{\sigma T_s} - \frac{1-\sigma}{\sigma T_r}\right) i_{sq} - \frac{1-\sigma}{\sigma} \omega \psi'_{rd} + \frac{1}{\sigma L_s} u_{sq} \tag{6}$$

$$\frac{d\psi'_{rd}}{dt} = \frac{1}{T_r} i_{sd} - \frac{1}{T_r} \psi'_{rd} \tag{7}$$

$$0 = \frac{1}{T_r} i_{sq} - (\omega_s - \omega) \psi'_{rd} \tag{8}$$

From this, we determine the torque equation and the equations for calculating and controlling rotor flux:

$$m_M = \frac{3}{2} z_p (1-\sigma) L_s \psi'_{rd} i_{sq} \tag{9}$$

and

$$0 = i_{md} + T_r \frac{di_{md}}{dt} - i_{sd} \tag{10}$$

$$0 = \omega_r T_r i_{md} - i_{sq} \tag{11}$$

$$i_{md} = \frac{\psi_{rd}}{L_m} \tag{12}$$

Thus, i_{sd} is to control flux, and i_{sq} is to control torque.
The magnetic flux model is crucial to motor control. That is, the magnetic flux model provides all state variables for motor control. It also provides the coordinate transfer angle for the voltage and current coordinate transformations. For microcontrollers, the ability to perform calculations depends on the sampling time. As a result, selecting of the microcontroller and the control algorithm directly determines the control quality of the drive system using the IM motor.
Equation (8) is used to determine the rotor flux. Therefore, the formula to calculate the magnetic flux becomes:

$$\psi_{rd} = L_m \int \left(\frac{1}{T_r} i_{sd} - \frac{1}{T_r} \psi_{rd}\right) dt \tag{13}$$

To apply to microcontroller easily, the above equation is discretized as follows:

$$\psi_{rd}(k) = L_m \begin{pmatrix} \frac{T_s}{T_r} i_{sd}(k-1) \\ -\left(1-\frac{T_s}{T_r}\right)\psi_{rd}(k-1) \end{pmatrix} \tag{14}$$

The condition for the equation (14) to be exact is that the dq coordinate system must be in sync with the rotation angle of the rotor flux, and the d-axis must have the same direction with the magnetic flux vector. This leads to the need to calculate an accurate angle of the rotor flux. Based on equation (9), it is easy to determine the value of the synchronous angular velocity as follows:

$$\omega_s = \frac{1}{T_r}\frac{i_{sq}}{\psi'_{rd}} + z_p\omega \tag{15}$$

Discretizing the above equation, we get:

$$\omega_s(k+1) = \frac{1}{T_r}\frac{i_{sq}(k-1)}{\psi'_{rd}(k-1)} + z_p\omega(k-1) \tag{16}$$

Experimental results are shown in Fig 1. The error between the two values is the angle error of the synchronous magnetic field and the rotor flux.

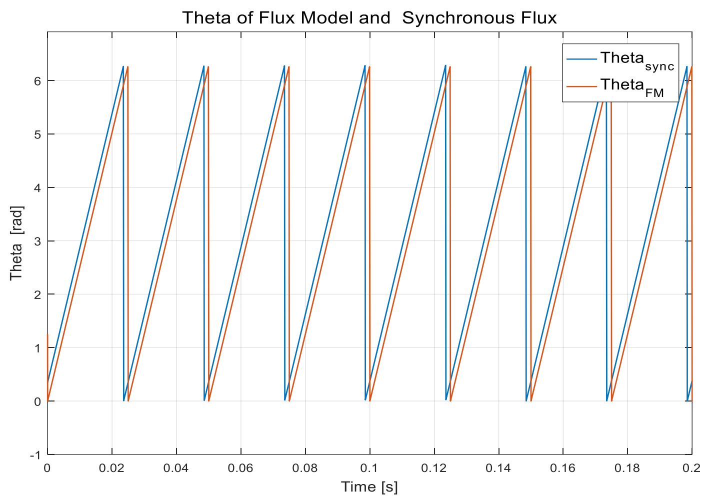

Fig 1: Experimental results of measuring the magnetic flux angle

3. Conclusion

Experimental results have proved the calculation ability of algorithms for magnetic flux models of three-phase asynchronous motors of C2000 series microcontrollers. The construction of an accurate magnetic flux model allows implementing the FOC control structure for the IM motor.

4. Acknowledgment

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