MAGNETIC FLUX MODEL OF INDUCTION MOTOR

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Abstract

In the Electrical drives system using induction motor requiring high control quality, the field-oriented control (FOC) method is often applied. Using the FOC control structure, it is necessary to identify the generated magnetic flux of the motor accurately. In this paper, the authors deal with building the magnetic flux model of the IM motor.

Keyword: IM, FOC, PWM.

1.INTRODUCTION

With the permanent magnet (PM) motor, [1] 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. This leads to determining the value of the flux of IM motors becomes more difficult than the PM motors. There are two methods to control the IM. The first one uses the V/f principle [2-4], in which the flux does not need to be accurately determined. The other uses the FOC method [1,5-7], requiring construction of the magnetic flux model. The accuracy of the model relates to the control quality of the system.

2. THE ALGORITHM FOR THE MAGNETIC FLUX MODEL

References ought to be included in the finish of the paper, and its equivalent citation will be included the ord in equation (1).

$$\begin{cases} \boldsymbol{\psi}_\mathbf{s} = L_s \mathbf{i}_\mathbf{s} + L_m \mathbf{i}_\mathbf{r} \\ \boldsymbol{\psi}_\mathbf{r} = L_m \mathbf{i}_\mathbf{s} + L_r \mathbf{i}_\mathbf{r} \end{cases} \tag{1}$$

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:

$$\mathbf{u}_\mathbf{s} = R_s \mathbf{i}_\mathbf{s} + \frac{d\boldsymbol{\psi}_\mathbf{s}}{dt} + j\omega_s \boldsymbol{\psi}_\mathbf{s} \tag{2}$$

$$0 = R_r \mathbf{i}_\mathbf{r} + \frac{d\boldsymbol{\psi}_\mathbf{r}}{dt} + j\omega_r \boldsymbol{\psi}_\mathbf{r} \tag{3}$$

In which , with ωr is the slip velocity, ωs is the synchronous velocity, and ω is the rotor velocity.
From (1), (2) and (3), we have:

$$\begin{cases} \mathbf{u}_\mathbf{s} = R_s i_s + \frac{d\boldsymbol{\psi}_\mathbf{s}}{dt} + j\omega_s \boldsymbol{\psi}_\mathbf{s} \\ 0 = R_r \mathbf{i}_\mathbf{r} + \frac{d\boldsymbol{\psi}_\mathbf{r}}{dt} + j\omega_r \boldsymbol{\psi}_\mathbf{r} \\ \boldsymbol{\psi}_\mathbf{s} = L_s \mathbf{i}_\mathbf{s} + L_m \mathbf{i}_\mathbf{r} \\ \boldsymbol{\psi}_\mathbf{r} = L_m \mathbf{i}_\mathbf{s} + L_r \mathbf{i}_\mathbf{r} \end{cases} \tag{4}$$

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:

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

Selecting the rotation system dq with q axis perpendicular to the flux generated by the rotor, we have ψrd = 0.

Substituting ψrd into (5), we have:

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

$$\frac{di_{sq}}{dt} = -\omega_s i_{sd} - \left(\frac{1}{\sigma T_s} - \frac{1-\sigma}{\sigma T_r}\right) i_{sq} - \frac{1-\sigma}{\sigma} \omega \psi'_{rd} + \frac{1}{\sigma L_s} u_{sq} \quad (7)$$

$$\frac{d\psi'_{rd}}{dt} = \frac{1}{T_r} i_{sd} - \frac{1}{T_r} \psi'_{rd} \quad (2)$$

$$0 = \frac{1}{T_r} i_{sq} - (\omega_s - \omega) \psi'_{rd} \quad (3)$$

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

calculating and controlling rotor flux:

$$m_M = \frac{3}{2} z_p (1-\sigma) L_s \psi'_{rd} i_{sq} \quad (10)$$

and

$$0 = i_{md} + T_r \frac{di_{md}}{dt} - i_{sd} \quad (11)$$

$$0 = \omega_r T_r i_{md} - i_{sq} \quad (12)$$

$$i_{md} = \frac{\psi_{rd}}{L_m} \quad (13)$$

Thus, isd is to control flux, and isq is to control torque.

Equation (8) is used to determine the rotor flux. Therefore, the formula to calculate the magnetic flux becomes:

$$\psi_{rd} = L_m \int \left(\frac{1}{T_r} i_{sd} - \frac{1}{T_r} \psi_{rd}\right) dt \quad (14)$$

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

$$\psi_{rd}(k) = L_m \begin{pmatrix} \frac{T_s}{T_r} i_{sd}(k-1) \\ -\left(1 - \frac{T_s}{T_r}\right) \psi_{rd}(k-1) \end{pmatrix} \quad (15)$$

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:

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

Discretizing the above equation, we get:

$$\omega_s(k+1) = \frac{1}{T_r} \frac{i_{sq}(k-1)}{\psi'_{rd}(k-1)} + z_p \omega(k-1) \quad (17)$$

In induction motors, the angle of the rotor flux depends on the stator current. The initial angle of the rotor flux is zero resulting in the integral of the synchronous angle being the angle of the rotor flux [8-9].

In real applications, the process of collecting parameters such as Ia, Ib current always uses low pass filters. Therefore, the measured current signals will lag behind the actual current. The obtained angle of the magnetic flux model will be delayed compared to the actual value. To have an appropriate transfer angle, it is necessary to have an angle adjustment stage before the voltage coordinate transformation stage.

3. CONCLUSION

The construction of an accurate magnetic flux model allows the implementation of the FOC control structure for the IM motor. In our future projects, the FOC control method and advanced control algorithms on hardware platforms using real-time microcontrollers will be implemented and installed on real systems

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