Precise Estimation of Rotor Time Constant Based on Vector Control

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Abstract
Nowadays motor vector control is applied widely, but in fact motor parameter which has much effect on vector will change at any moment, which affects precision of vector control. A new method is proposed, rotor time constant can be estimated by using torque and flux current and the change of stator and rotor flux angle. Simulation show the method can compute instantaneous parameters and improve precision of vector control.
Keywords: rotor time constant; vector control; stator and rotor flux angle

1. Introduction

Rotor-Flux-Oriented vector control is widely used for high performance induction motor drive and can provide the decoupled controllability for stator current by coordinate transformation. And stator current is decomposed to torque-producing current and flux producing current, they control separate rotor flux and torque. So Rotor Flux Oriented vector control can control induction motors better. But induction motor is a time varying system. Parameters for example rotor resistance and inductance will change when a motor is running. A problem how to improve parameters precision need solve. Rotor time constant is the ratio of rotor inductance and resistance. But rotor time constant is mutative because of rotor resistance and inductance will change when a motor is running. This paper proposed a way which can calculate rotor time constant.

2. motor vector control model

Math model in the reference frame rotating with an arbitrary angle [3]:
Voltage equations

$$\begin{aligned} U_{d1} &= r_1 i_{d1} + \rho\varphi_{d1} - \varphi_{q1}\rho\theta \\ U_{q1} &= r_1 i_{q1} + \rho\varphi_{q1} + \varphi_{d1}\rho\theta \end{aligned} \tag{1}$$

$$\begin{aligned} 0 &= r_2 i_{d2} + \rho\varphi_{d2} - \varphi_{q2}\rho\theta_2 \\ 0 &= r_2 i_{q2} + \rho\varphi_{q2} + \varphi_{d1}\rho\theta_2 \end{aligned} \tag{2}$$

Flux equations

$$\begin{aligned} \varphi_{d1} &= L_s i_{d1} + L_m i_{d2} \\ \varphi_{q1} &= L_s i_{q1} + L_m i_{q2} \end{aligned} \tag{3}$$

$$\begin{aligned} \varphi_{d2} &= L_s i_{d2} + L_m i_{d1} \\ \varphi_{q2} &= L_s i_{q2} + L_m i_{q1} \end{aligned} \tag{4}$$

Angle equation

$$\theta = \arctan\frac{\psi_{d2}}{\psi_{q2}} \tag{5}$$

Errors in these parameters for example L, r may make a few degrees of angle error in the flux angle, and these issues were well explained in [5].

3. Estimation of rotor time

Constant

We use the method as follows to solve rotor time constant[1].

The q-axis stator current is also represented as follows in the rotor-flux reference frame.

$$i_{qs} = -\frac{L_r}{L_m} i_{qr} \tag{6}$$

Where i_{qs} and i_{qr} are d q-axes (rotor-flux reference frame) currents.

The slip equation of the induction motor can be derived using equation (6) as follows.

$$\omega - \omega_r = -\frac{R_r i_{qr}}{\varphi_{dr}} = \frac{R_r}{\varphi_{dr}} \frac{L_m}{L_r} i_{qs} \tag{7}$$

When the rotor flux is kept constant, the right side of the equation (7) can be rewritten as

$$\begin{aligned} \omega - \omega_r &= \frac{R_r}{\varphi_{dr}} \frac{L_m}{L_r} i_{qs} = \frac{R_r}{L_m i_{ds}} \frac{L_m}{L_r} i_{qs} \\ &= \frac{R_r}{L_r} \frac{i_{qs}}{i_{ds}} = \frac{1}{\tau_r} \frac{i_{qs}}{i_{ds}} \end{aligned} \tag{8}$$

When we have known d q-axes currents and slip frequency, rotor time constant can be derived by using the equation (8).

But this equation needs more high precisions of d q-axes current, also the slip frequency which is a part of the denominator of the time constant may be not reliable since it must be quite small for usual induction motor, and the result derived from encoder has also error. We solve this problem using integration. Integrating both sides of (8) during a certain time interval [t1, t2], the rotor time constant can be evaluated as (9).

$$\tau_r = \frac{1}{[\theta(t2)] - [\theta(t1)] - [\theta_r(t2)] - [\theta_r(t1)]} \int_{t1}^{t2} \frac{i_{qs}}{i_{ds}} dt \tag{9}$$

In order to reduce the rotor flux angle error effect, the proposed estimation method starts working after the speed of the motor reaches near its rated value. With the larger time interval, the more accurate displacement angle of the rotor flux, $[\theta(t2)] - [\theta(t1)]$ can be obtained. In addition, $[\theta_r(t2)] - [\theta_r(t1)]$ can be obtained from the encoder.

The integration of the d-q axes currents ratio makes this method more immune to the current measurement noises.

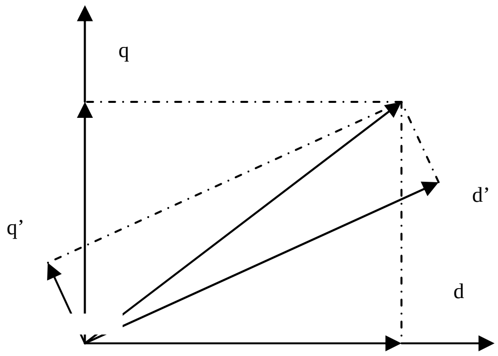

Fig. 1: Motor current vector due to the rotor flux angle estimation error

Precision of rotor time constant needs higher precision of current angle. Errors of current angle also affect precision of rotor time constant. Fig.1 shows current angle has error. Equations as follows can be derived.

$$\begin{aligned}\frac{\tau_r^{'}}{\tau_r} &= \frac{\tan(\theta_i - \theta_{err})}{\tan\theta_i} = \frac{\tan\theta_i - (\tan^{'}\theta_i)\theta_{err}}{\tan\theta_i} \\ &= 1 - \frac{\theta_{err}}{\sin\theta_i \cos\theta_i} = 1 - \frac{2\theta_{err}}{\sin 2\theta_i}\tan(\theta_i - \theta_{err})/\omega_{slip} \\ &= \omega - \omega_r\end{aligned} \quad (10)$$

$$\tau_r = \frac{i_{qs}}{i_{ds}}/\omega_{slip} = \tan(\theta_i)/\omega_{slip} \quad (11)$$

where $\omega_{slip} = \omega - \omega_r$

The motor currents are transformed into the rotor flux reference frame using not the real rotor flux angle but the estimated rotor flux angle.

$$\tau_r^{'} = \frac{i_{qs}^{'}}{i_{ds}^{'}}/\omega_{slip} = \tan(\theta_i - \theta_{err})/\omega_{slip} \quad (12)$$

Assuming that the angle error is reasonably small, the ratio of the estimated rotor time constant and the real rotor time constant can be derived as follows.

$$\begin{aligned}\frac{\tau_r^{'}}{\tau_r} &= \frac{\tan(\theta_i - \theta_{err})}{\tan\theta_i} = \frac{\tan\theta_i - (\tan^{'}\theta_i)\theta_{err}}{\tan\theta_i} \\ &= 1 - \frac{\theta_{err}}{\sin\theta_i \cos\theta_i} = 1 - \frac{2\theta_{err}}{\sin 2\theta_i}\end{aligned} \quad (13)$$

From (13), it should be noted that to make the d-q currents be same is the best way in order to minimize the effect of the rotor flux angle error because it makes the ratio in (13) as close to unity as possible. Angle during the V/F operation is adjustable by tuning the acceleration time. In other words, tuning both current components to be same each other can be achieved by adjusting the time scale of the voltage profile. Higher acceleration profile makes the q-axis current relatively larger than d-axis current because it needs more torque to accelerate the rotor. On the contrary, lower acceleration profile makes the q-axis current relatively smaller than the d-axis current.

4. Simulation results

Fig.2 is estimation model of rotor time constant, 4,5,6 stand for instantaneous state at the time t1. And 1,2 is continuous state variable from t1 to t2. The model is based on
equation (9).

4.1 Motor Parameters

rotor time constant 0.156sec
stator and rotor inductance 35.5mH
rotor resistance 0.228ohm
mutual inductance 37.4mH

4.2 Simulation Model

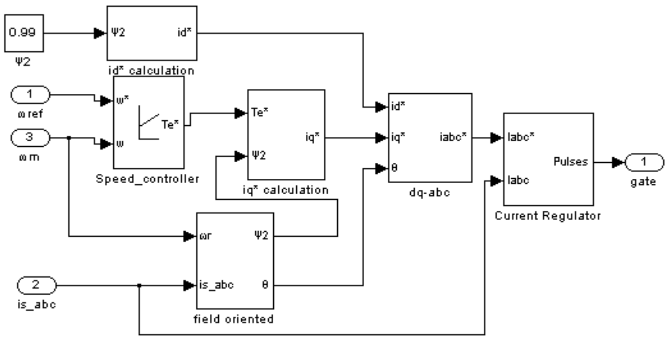

Fig.2 vector control model

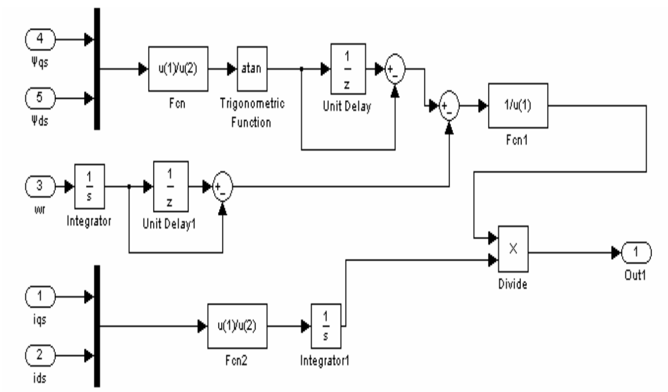

Fig.3 Estimation model of rotor time constant

4.3 Simulate Result

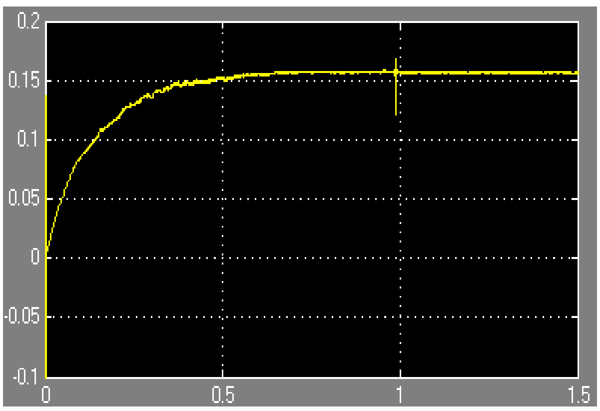

Fig.4 rotor time constant simulation result

Fig.4 shows the simulation result of the proposed rotor time constant estimation algorithm. As shown in the result, the estimated rotor time constant rapidly converges to the real value in spite of the errors of the pre-estimated parameters.

Conclusion

The paper based on motor vector control model proposed a new way to estimation rotor time constant by using d q-axes and slip frequency. Simulation result shows the method can improve precision of rotor time constant.

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