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Study on the Electronic Magnetic Field Oriented Control Based on D-axis Current

[1] Hongyu Feng, [1] Shitao Yan, [2] Changlin Song
[1] Henan Institute of Science and Technology, 453003, China
[2] Xihua University, 610000, China
[1] Tel.: 15136731568,
[1] E-mail: feng_hongyu@126.com

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Abstract: In order to improve the magnetic field orientation accuracy and system performance, the electronic field oriented control has been a hot research field of the induction motor speed control. Although the vector control of AC machines has many excellent properties, the researchers have been attempting to simplify the calculating steps and the structure of the control system to improve the accuracy of filed-oriented and the performance of AC machine drives. Based on the analysis of the conventional induction motor magnetic field oriented control, this paper puts forward a novel method of stator magnetic field orientation control. By analytical methods, the given current of d-axis can be calculated directly, and the stator flux can be controlled precisely. This method has a fast flux and torque response, and the control performance is unaffected by the rotor parameters. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Induction motor, Electronic magnetic field, Oriented control, Torque.

1. Introduction

Since the induction motor magnetic field oriented control came forward for the first time in the 1970s, the remarkable achievements have been seen in perfecting control theory, improving control algorithm and so on. Especially with the application of latest achievements about the microelectronic technology and the use of the high-performance power electronic device, the magnetic field oriented control has been widely applied in the industrial field. However, in order to simplify the structure of the calculation and control system, and improve the precision and system performance [1] of the magnetic field oriented control, researchers in this field are still making persistent efforts.

In 1977, Plunkett first proposed the thought of flux and torque direct regulation, at that time, it just need to detect the stator flux directly. In the midst time of 1980s, Germany and Japan scientists firstly developed a novel AC machines control scheme named as direct torque control [2]. In recent years, intelligent control is a very active area of research, Application of computer simulation technology is also increasingly widespread, and Zhejiang University also made a lot of research work about how to control AC motor speed.

It commonly accepted that, the stator magnetic field oriented control naturally has become a research hotspot in the induction motor speed control field because the system control performance of the rotor magnetic field oriented control, is easily influenced by rotor parameters. The main method is adding decoupling device [3] to the control channel of the d-axis stator flux, in order to achieve the dynamic compensation about the current of d-axis. But there are still troubles in achieving the precise flux control. Considering these troubles, this article puts forward a new method of stator magnetic field oriented control, which directly calculates the current of the d-axis through analytical methods. In addition, it offers the analytic expressions in calculating the current of d-axis and emulated experimental results.

2. Conventional Stator Magnetic Field Oriented Control

For the stator magnetic field oriented control doesn't achieve completely the decoupling control, its system dynamic performance may be affected to some extents. In order to eliminating the influence of torque control on the flux, a decoupling device in flux control channel is designed. The block diagram of system is shown as Fig. 1 [4].

According to the induction motor equation and the flux on the votary coordinate system, the reference axis is put on the stator magnetic field direction, so $\psi_{sd}=\psi_s$, $\psi_{sq}=0$ the following equation can be derived.

$$(1+\tau_r p)\psi_{sd}=(1+\sigma\tau_r p)L_s i_{sd}-\omega_{sl}\sigma\tau_r L_s i_{sq} \quad (1)$$

$$(1+\sigma\tau_r p)L_s i_{sq}=\omega_{sl}\tau_r(\psi_{sd}-\sigma L_s i_{sd}) \quad (2)$$

$$T_e=\frac{3P}{4}\psi_{sd}i_{sq} \quad (3)$$

where ψ_{sd},ψ_{sq} are the stator flux components, i_{sd},i_{sq} are the stator current components, ω_{sl} is the slip angular velocity, L_s is the stator inductance, L_m is the stator transformer, rotor transformer, p is the differential calculus, τ_r is the rotor time component, P is the motor winding pole number, $\sigma=1-L_m^2/(L_sL_r)$ is the magnetic leakage factor.

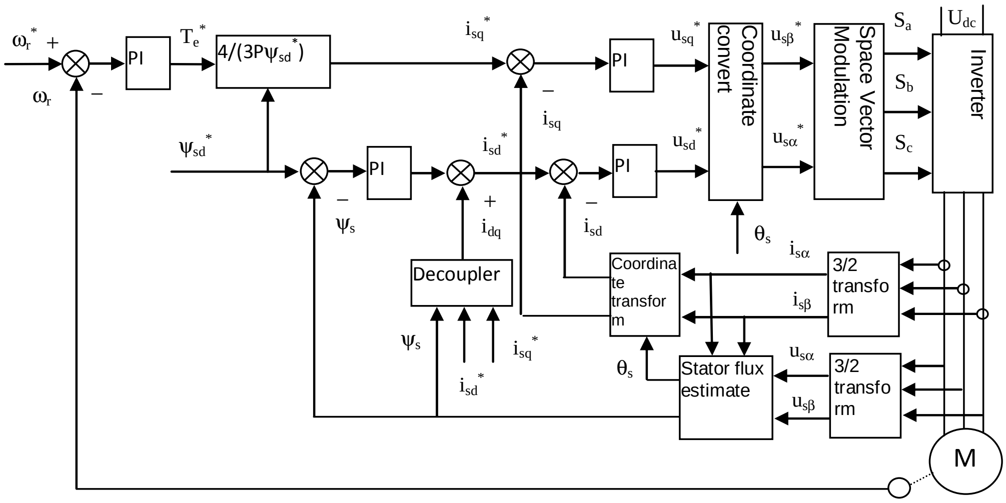


Fig.1. Traditional stator field oriented control system block diagram.

Seen from (3), if stator flux ψ_{sd} is a constant, the torque is proportionate to the q current i_{sq}. Under the condition of stator magnetic field oriented, the calculation can be simplified greatly, so it is easy to observe and control the stator flux. If only the q current coupling effect in (1) is eliminated, the absolute slip angular velocity ω_{sl} can be calculated from (2), but, decoupling Components need induced. Supposed that $i_{sd}=k_{IP}(\psi_{sd}^*,\psi_{sd})+i_{dq}$, flux regulator output is $k_{IP}(\psi_{sd}^*,\psi_{sd})$, the equation can be derived combined with (1). The superscript "*" stands for system given value.

$$(1+\tau_r p)\psi_{sd}=(1+\sigma\tau_r p)L_s k_{IP}(\psi_{sd}^*,\psi_{sd})+(1+\sigma\tau_r p)L_s i_{dq}-\omega_{sl}\tau_r\sigma L_s i_{sq} \quad (4)$$

If only $(1+\sigma\tau_r p)L_s i_{dq}-\omega_{sl}\tau_r\sigma L_s i_{sq}=0$, the q current coupling effects will be eliminated , and the coupling equation as follows can be get.

$$i_{dq}=\frac{L_s\sigma i_{sq}^{*\,2}}{\psi_{sd}-\sigma L_s i_{sd}^*} \quad (5)$$

Based on the equation (5), decoupling components do not contain rotor resistance, so system control can be unaffected by it. This is the main advantage of the novel method [5, 6]. Seen from Fig. 1, the variables decoupling device input is the difference between the given flux and the flux observation via the PI regulator. When the estimated flux deviation occurs, the d axis input current will be changed by the PI regulator variables [7], thereby controlling the stator flux is achieved. However the import of PI regulator in flux control channel will delay the output of flux controlled variables, during the dynamic process, the q axis cannot completely offset by the decoupling device, so that stator flux fluctuation will occur. It is the disadvantage of the control method that can not be avoided.

3. Direct Solver Based on the D-axis Current Stator Field Oriented Control

In the stator field oriented control which is added decouple mentioned above, the output of PI regulator is used as the input of d-axis current. So the flux of control has been delayed [8, 9]. In order to heighten the performance of stator field, the analytical method will be used to calculate d-axis current in this paper.

Put the slip velocity which was calculated in the equation (2) into the equation (1), so we can obtain the following equation,

$$(1+\tau_r p)\psi_{sd} = (1+\sigma\tau_r p)L_s i_{sd} - \frac{(1+\sigma\tau_r p)L_s i_{sq}}{\tau_r(\psi_{sd}-\sigma L_s i_{sd})}\sigma\tau_r L_s i_{sq} \qquad (6)$$

Because of the differential terms in the equation (6), the calculation is difficult. However if the stator flux is regarded as a constant variable, the situation will be changed [10]. That is to say, when the stator flux ψ_{sd} is a constant, $(1+\tau_r p)\psi_{sd}$ is equivalent to $(1+\sigma\tau_r p)\psi_{sd}$, so the formula (6) can be converted into:

$$(1+\sigma\tau_r p)\psi_{sd} = (1+\sigma\tau_r p)L_s i_{sd} - \frac{(1+\sigma\tau_r p)L_s i_{sq}}{\tau_r(\psi_{sd}-\sigma L_s i_{sd})}\sigma\tau_r L_s i_{sq} \qquad (7)$$

Hence,

$$L_s^2\sigma i_{sd}^2 - (1+\sigma)L_s\psi_{sd} i_{sd} + \psi_{sd}^2 + L_s^2 i_{sq}^2\sigma = 0 \qquad (8)$$

Then by calculating the equation (8), an analytic expression about i_{sd} can be reached,

$$i_{sd} = \frac{(1+\sigma)L_s\psi_{sd} - \sqrt{[(1+\sigma)L_s\psi_{sd}]^2 - 4L_s^2\sigma(\psi_{sd}^2 + L_s^2 i_{sq}^2\sigma)}}{2L_s^2\sigma} \qquad (9)$$

So a system box diagram is shown as Fig. 2.

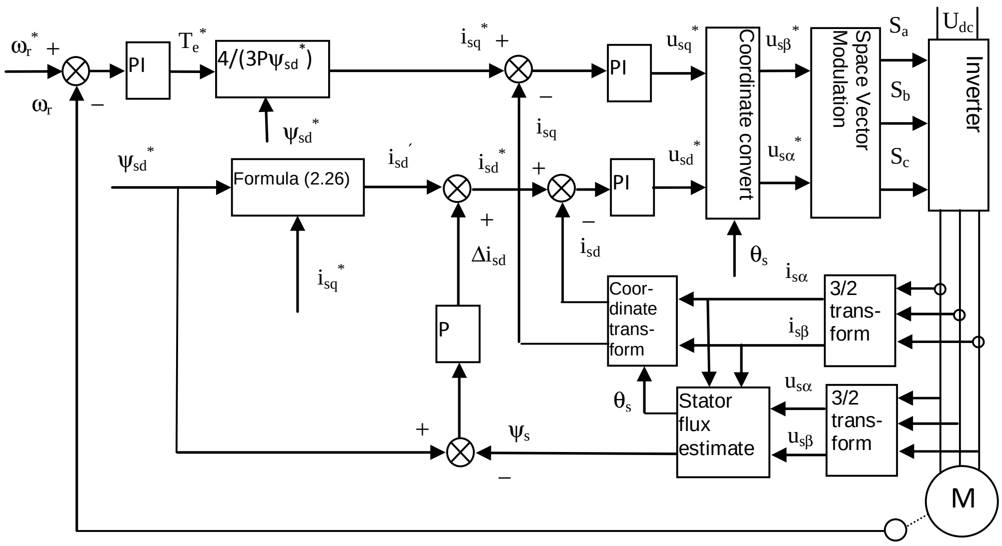


Fig. 2. D-axis control system block diagram based on the current stator flux.

From Fig. 2, it is known that the given torque is obtained by calculating the difference between velocity ω_r^* and feedback speed ω_r. Through the stator flux amplitudes ψ_s^*, the current i_{sq}^* given by q-axis can be calculated [11, 12].

Due to the equation (9) is obtained in the condition of the constant ψ_{sd}, the stator flux is not set up completely, but keeping in the rising process. This does not meet the conditions of a constant. In other words, the flux should rise in a certain extent and use the control method mentioned above. Besides, the current ψ_{sd} given by d-axis should be made up. The method is that calculate the difference between given flux amplitude through proportional regulator. The value is made up in the dynamic process, but in the static process, the output of the proportional regulator should be zero [13, 14].

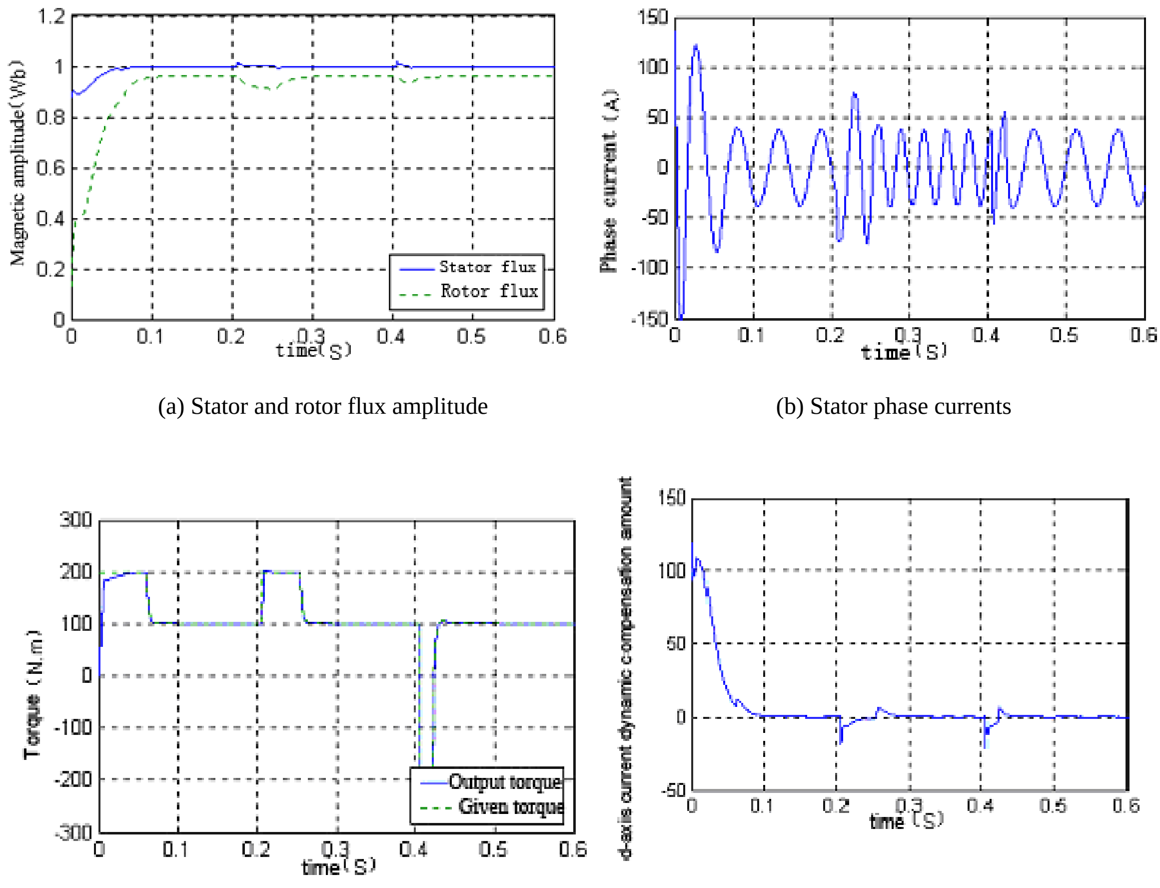
4. Simulation Results and Discussion

Motor Parameters:
The stator leakage inductance: 2.0 mH;
Rotor leakage inductance: 3.0 mH;

Mutual sense: 85.0 mH;
Stator resistance: 0.4 Ω;
Rotor resistance: 0.5 Ω;
Number of pole pairs: 2;
Moment of inertia: 0.1 Kg.m^2

It can be seen from Fig. 3 that this method has a great improvement in the flux control compared with the traditional stator magnetic field oriented control which added decouple, based on the stator flux from the simulation result, which primarily reflect in the stability and the torque response of the stator flux dynamic process shown in the Fig. 3 (c).

Because there is not any integral regulator in the flux control, and the d-axis current is got by direct count though the expression (9), in the homeostatic situation, the d-axis current can be a static controlled shown in the Fig. 3(d), the d-axis current compensation will has output only in the rapid change and load change, in the homeostatic situation the output is zero, which indicates that the d-axis current got by the expression (9) can remove the q-axis current oupling.



(a) Stator and rotor flux amplitude

(b) Stator phase currents

(c) Given the torque of the motor

(d) D-axis current dynamic compensation amount

Fig. 3. Running result of electronic magnetic field oriented control base on d-axis current

5. Conclusions

This article has a specific study of the stator magnetic field oriented control based on the direct count d-axis current. The fast flux and torque control has been achieved, and the stator flux amplitude can keep better constant in the dynamic situation. Through using this method, the control performance is unaffected by the rotor resistance change. The main shortage is that it needs to solve a quadratic equation, so a great deal of calculation is needed. This problem can be solved by the higher-performance DSP.

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