Study of Decoupled Vector Control System of AC Induction Motor Using Internal Model Current Control

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Abstract: - This article, starting from the radical principle of the asynchronous inductive machine dynamic model and asynchronous machine rector decoupled control under the synchronous $d-q$ coordinate system, introduces the methods of internal model control and designs the stator current regulator based on rotor linkage-orientation and internal model control in detail. Considering asynchronous inductive machine field will show saturation to different extent with the changes of machine load (torque) in real system which will lead to the nonlinear of machine parameters, it analyzes the robustness from internal model current controller to this nonlinear parameters. Establish a simulation system for the whole asynchronous inductive machine vector control on this basis, and simulates and analyzes the systems under the conditions of ignore saturation magnetization and consider saturation magnetization. Results of simulation and analysis show, current internal model controller can supply good torque dynamic and static decoupled effect while model matched and unmatched as well.

Key words: vector transformation, decoupled control, field-orientation, internal model current control

1. Introduction

Alternating current asynchronous machine is a system of multi variable, strong couple, nonlinear and time varying. Its instantaneous torque is hard to control. So it's difficult to gain the same high dynamic timing performance as direct current machine. The technology [1][2] of vector transformation control, no matter it's rotor field-orientation[2], air interspaces field -orientation[3], or stator linkage-orientation[4] and stator pressure-orientation[5], its basic conception is to decompose stator current into vertical direct current excitation (without power) current and torque (with power) current through the changes of rotating coordinate, and go on independent closed loop adjustment on them separately to realize the decoupled control on alternating current asynchronous machine.

The existing methods of current control include current blocked loop control and PI adjustment control under stator coordinate and synchronous coordinate. Of which, the current PI adjustment control under synchronous coordinate can especially earn good steady performance. While this method will directly decouple the dynamic effect because of the couple between d and q introduced by coordinate change. In addition, the parameters adjustment of PI controller on , axis is traditionally debugged and got by experiment. On that, literature [6][7] bring in the internal model control (IMC) in industry process control to the current control of alternating machine, and gave the design process of current loop control parameters and results of relevant simulation and experiments by taking eternal-magnetic synchronous machine as example. However, analysis on the decoupled effect and robustness research of internal current control methods under the condition of parameters nonlinear caused by load change is seldom seen in the existing literature.

In view of that, the article, taking alternating current machine as example, introduces internal model control into current control on basis of the alternating inductive machine mathematical models under synchronous rotating coordinate, and designs the parameters of adjustor. Considering the machine magnetism saturation to different extent caused by load change in real course and so-caused nonlinear change of machine parameters, the writer theoretically analyzes the dynamic decoupled effect and robustness from internal current control methods to parameter nonlinear. Based on that, he composed alternating asynchronous machine dynamic model which consider the effect of magnetism saturation in MATLAB/SIMULINK, and set up the magnetic test-type alternating inductive machine vector control system based on rotor field-orientation and internal current model control and stimulated and researched it on conditions of considering whether the magnetism is saturation or not. Results prove the correctness and effectness of current controller and adjustor based on internal current model control methods and the robustness and good dynamic decoupled effect of machine parameters nonlinear change.

2. Internal model control

2.1 Asynchronous machine model under synchronous rotating $d-q$ coordinate system

Asynchronous machine mathematical model under synchronous coordinate system is expressed by vector as [6][7]

$$\begin{cases} \frac{d}{dt}\vec{\psi}_s(t) = -R_s\vec{i}_s(t) - j\omega_1\vec{\psi}_s(t) + \vec{v}(t) \\ \frac{d}{dt}\vec{\psi}_r(t) = -R_r\vec{i}_r(t) - j\omega_2\vec{\psi}_r(t) \end{cases} \quad (1)$$

$$\begin{cases} \vec{\psi}_s(t) = L_s\vec{i}_s(t) + L_m\vec{i}_r(t) \\ \vec{\psi}_r(t) = L_r\vec{i}_r(t) + L_m\vec{i}_s(t) \end{cases} \quad (2)$$

In the formula, $\vec{i}_s, \vec{\psi}_s$ and $\vec{i}_r, \vec{\psi}_r$ are current of stator and rotor and magnetism vector separately. $\vec{v}$ is the vector of stator pressure. R_s, R_r and L_s, L_r are resistance and self-induction of stator and rotor. L_m is mutual induction. ω_1 and $\omega_2 = \omega_1 - \omega_r$ are stator frequency and slippage frequency separately.

From formula (1) and (2), we can get

$$\begin{aligned} &L_\sigma \frac{d\vec{i}_s(t)}{dt} + [R_s + (\frac{L_m}{L_r})^2 R_r]\vec{i}_s(t) + j\omega_1 L_\sigma i_s(t) \\ &= \vec{v}(t) + \frac{L_m}{L_r}(\frac{R_r}{L_r} - j\omega_r)\vec{\psi}_r(t) \end{aligned} \quad (3)$$

Thereinto, $L_\sigma = L_s[1 - L^2_m/(L_s L_r)]$

Thereupon, under rotor field-orientation, $\psi_{rd} = \psi_r, \psi_{rq} = 0$, asynchronous inductive machine model can be expressed in ponderance of $d-q$

$$\begin{cases} v_d(t) = v'_d(t) - \frac{L_m}{L^2_r} R_r \psi_{rd} \\ v_q(t) = v'_q(t) + \omega_r \frac{L_m}{L_r} \psi_{rd} \end{cases} \quad (4)$$

In the formula, $R'_s = R_s + (\frac{L_m}{L_r})^2 R_r$

$$\begin{cases} v'_d(t) = R'_s i_{sd}(t) + L_\sigma \frac{di_{sd}(t)}{t} - \omega_1 L_\sigma i_{sq}(t) \\ v'_q(t) = R'_s i_{sq}(t) + L_\sigma \frac{di_{sq}(t)}{t} + \omega_1 L_\sigma i_{sd}(t) \end{cases} \quad (5)$$

Transform formula (5) of Laplace, we can get

$$\boldsymbol{U}(s) = \boldsymbol{G}^{-1}(s)\boldsymbol{Y}(s)$$

(6)

Thereinto, $\boldsymbol{U}(s) = \begin{bmatrix} V'_d(s) \\ V'_q(s) \end{bmatrix}, \boldsymbol{Y}(s) = \begin{bmatrix} I_{sd}(s) \\ I_{sq}(s) \end{bmatrix}$ (7)

$$\boldsymbol{G}(s) = \begin{bmatrix} sL_\sigma + R'_s & -\omega_1 L_\sigma \\ -\omega_1 L_\sigma & sL_\sigma + R'_s \end{bmatrix}^{-1} \quad (8)$$

2.2 Design of internal current controller

Introduce internal model control of project control on industry course into the design of current loop controller parameters. Internal model control and its equivalent structural chart are the same as chart 1 and 2[6] . In the chart, $\hat{G}(s)$ is internal model, $\boldsymbol{u}, \boldsymbol{y}$ are pressure and current vectors of vector control system and $\boldsymbol{w}$ is referenced current vector.

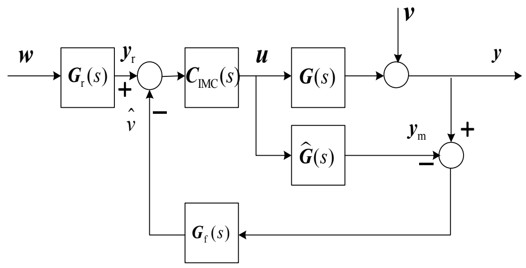

Fig.1 IMC structure

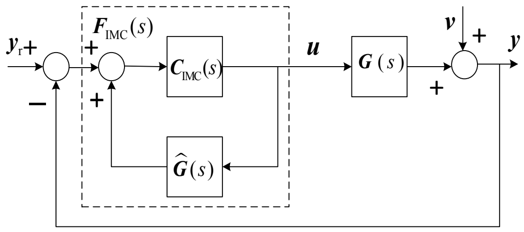

Fig.2 Equivalent diagram of IMC

From chart 2, we can get

$$\boldsymbol{F}_{\mathrm{IMC}}(s) = [\boldsymbol{I} - \boldsymbol{C}_{IMC}(s)\hat{\boldsymbol{G}}(s)]^{-1}\boldsymbol{C}_{\mathrm{IMC}}(s) \qquad □9□$$

From formula 8, we can get the minimum phasic system of $\hat{G}(s)$. Then we can get

$$\boldsymbol{C}_{IMC}(s) = \hat{\boldsymbol{G}}^{-1}(s)\boldsymbol{f}(s)$$

□10□

$$\boldsymbol{f}(s) = \frac{\alpha}{s+\alpha}\boldsymbol{I}$$

□11□

In the formula, α is the band width of current loop. And $\alpha = 2.2/t_r$. t_r is the ascending time of current.

From formula □9□10□11□, the current controller is

$$\boldsymbol{F}_{\mathrm{IMC}}(s) = [\boldsymbol{I} - \frac{\alpha}{s+\alpha}\boldsymbol{I}]^{-1}\hat{\boldsymbol{G}}^{-1}(s)\frac{\alpha}{s+\alpha}$$

$$= \frac{\alpha}{s}\hat{\boldsymbol{G}}^{-1}(s) = \alpha\begin{bmatrix} \hat{L}_\sigma(\frac{\hat{R}'_s}{s\hat{L}_\sigma}+1) & -\frac{\omega_1\hat{L}_\sigma}{s} \\ \frac{\omega_1\hat{L}_\sigma}{s} & \hat{L}_\sigma(\frac{\hat{R}'_s}{s\hat{L}_\sigma}+1) \end{bmatrix} \qquad □12□$$

In the formula, $\hat{R}'_s$□$\hat{L}_\sigma$ are estimated value of L_σ .

Obviously, we can confirm the design parameters of current loop controller so long as we know the control band width of current loop and machine parameters.

Generally speaking, machine model will mismatch the real objective because of the estimation error of parameters. But, because of

$$\boldsymbol{C}_{IMC}(0) = \hat{\boldsymbol{G}}^{-1}(0)\boldsymbol{f}(0) = \begin{bmatrix} \hat{R}'_s & -\omega_1\hat{L}_\sigma \\ \omega_1\hat{L}_\sigma & \hat{R}'_s \end{bmatrix}\boldsymbol{I} = \hat{\boldsymbol{G}}^{-1}(0) \qquad □13□$$

And

$$\frac{d}{dt}[\boldsymbol{C}_{IMC}(s)\hat{\boldsymbol{G}}(s)]|_{s=0} = \frac{d}{dt}[\hat{\boldsymbol{G}}^{-1}(s)\boldsymbol{f}(s)\hat{\boldsymbol{G}}(s)]$$
$$= \frac{d}{dt}[\frac{\alpha}{s+\alpha}]|_{s=0} = -\frac{1}{\alpha} \neq 0 \qquad □14□$$

It's obvious that there's no steady warp of step inputting and frequent value for the inductive machine current control system based on internal model control while model parameters mismatch the real model.

3. Systematic modeling

According to the above analysis, the writer composed the alternating asynchronous machine dynamic model of different magnetic saturation effect caused by different load by adopting the S function in MATLAB and established the simulation system of magnetism test-type alternating inductive machine vector control based on rotor field-orientation and internal current model control.

3.1 Vector control system model

Build a block diagram of the whole vector control system as diagram 3. The whole system composes speed loop (outer loop) and current loop (inner loop). The outputting of speed loop is the inputting of current loop. Current loop mainly realizes the decoupled control of rotor field-orientation torque based on internal model control. The ac-motor model in the diagram is composed by the writer by using the S function in MATLAB, considering the alternating asynchronous machine dynamic model of magnetic saturation effect caused under different load.

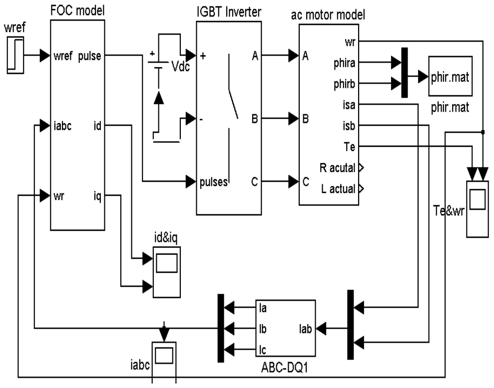

Fig.3 Vector-controlled system of AC motor

3.2 Design of internal current controller

From formula (12), we can get the structural block diagram of alternating inductive machine internal current model decoupled control realization. Please refer to diagram 4.

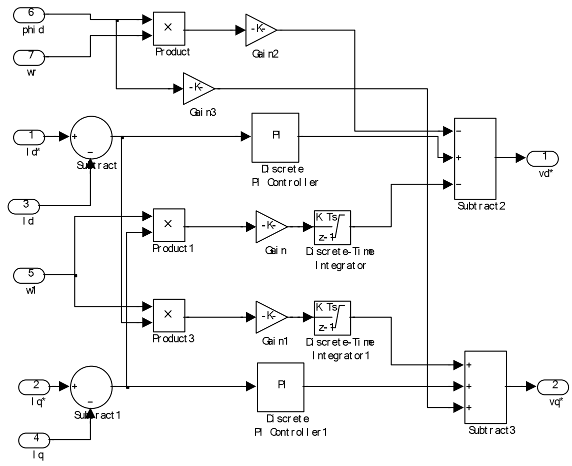

Fig.4 Current Internal-Model Controller

4. Simulation results

On conditions of ignoring and considering the magnetic saturation and effect under different load, we simulate and research the magnetic test-type asynchronous machine vector control based on rotor field-orientation and internal current model control on the machine shown in the appendix.

Diagram 5~7 and 8~10 are the simulation results of magnetic saturation effect ignoring and considering different load. Of which, the simulation results of diagram 5~7 well prove the torque dynamic and static decoupled performance of the vector control based on rotor lingage-orientation and internal current model control on condition of ignoring magnetic saturation effect. While, they simulate the air field saturation caused by load change on condition of synchronous machine's actual circulation while considering the nonlinear parameters (diagram 8~10) caused by machine magnetic saturation effect. Then, the current adjustment dynamic performance based on internal current model control is correspondingly worse (the quadrature axis current dynamic course in diagram 9). While, it can still supply good steady torque decoupled effect, which can be analyzed from feedback control theory. Taking the d axis current decouple in diagram 4 as an example, the decoupled signal is from current i_{sq} single closed-loop route way. Considering the lower part structure of diagram 4, set $C(s)=\alpha\dfrac{\hat{R}_s'+\hat{L}_\sigma}{s}$,

$$P(s)=\frac{1}{\hat{R}_s'+\hat{L}_\sigma s},\quad W_1(s)=\frac{\alpha\omega_1\hat{L}_\sigma}{s},\quad W_2(s)=\omega_1\hat{L}_\sigma$$

From here, we can get the decoupled pressure of d axis.

$\Delta V_{qd}(s)=W_2(s)I_{sq}(s)-[I^{\bullet}_{sq}(s)-I_{sq}(s)]W_1(s)$, then we can get

$$\frac{\Delta V_{qd}(s)}{I^{\bullet}_{sq}(s)}=\frac{C(s)P(s)W_2(s)-W_1(s)}{1+C(s)P(s)}=\frac{\alpha\omega_1(L_\sigma-\hat{L}_\sigma)}{s[1+C(s)P(s)]}$$

Shown from the above formula, the decoupled pressure, caused by parameters estimation error because of magnetic saturation, with the denominator of $1+C(s)P(s)$, is controlled by minus feedback and then achieve good decoupled effect.

5 Conclusions

Considering that the machine parameters in real system will bring magnetic saturation to cause nonlinear change because of load change, while the asynchronous machine model in MATLAB/SIMULINK didn't consider magnetic saturation effect, the writer composed the asynchronous inductive machine dynamic model which considers machine magnetic saturation. The magnetic test-type asynchronous inductive machine vector control simulation system based on the internal current model control adjustor and rotor magnetism-orientation brought by itself can supply good torque dynamic and static characteristics and decoupled effect on condition of the model mismatch caused by machine model match and field saturation effect. Moreover, the internal current model adjustor can only confirm the control parameters of quadrature and direct axis according to the needed current band width and estimated model parameters.

Appendix: Asynchronous machine parameters

P_N □ 37300W□p □ 2□

n_N□ 1420 r□min□U_N=460V (line-line)

R_1 □0.087 Ω□ R_2 □0.226Ω□

L_m □ 34.7 mH□ L_1 □ 35.5 mH□

L_2 □ 35.5 mH□J □ 0.0067 kgm^2

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