Modeling and Simulation of Asynchronous Motor in $\alpha\beta$ Coordinate System Based on Matlab

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***Abstract*—Asynchronous motor has simple structure, low cost, comparable to DC motor control performance when using the vector control technology. This paper focuses on the three-phase asynchronous motor which account for most of the proportion of the AC machines. Firstly, this paper builds the vector control system of asynchronous motor, then deduces the mathematical models of asynchronous motor based on $\alpha\beta$ coordinate system. At last the paper builds the simulation model of asynchronous motor based on $\alpha\beta$ coordinate system in Matlab/Simulink, and the paper gives and analyzes the simulation results. The simulation results verify the correctness of the theory of asynchronous motor based on $\alpha\beta$ coordinate system.**

Keywords- asynchronous motor；mathematical model；$\alpha\beta$ coordinate system；simulation;

I. INTRODUCTION

After entering the 21st century, the energy supply is increasingly tense, so it is very important to conserve electricity. Asynchronous motor has the advantages of simple structure, and is easy to maintain, so it occupies a significant market. At the same time, with the development of power electronics, micro-processor of motor control and the new theory of motor control, the control technology of asynchronous motor is highly promoted. Asynchronous motor has simple structure, low cost, comparable to DC motor control performance when using the vector control technology. Moreover, vector control of asynchronous motor has higher precision, wider speed-regulating range and faster response[1][2]. So it is necessary to study asynchronous motor and the paper builds the mathematical math of asynchronous motor in $\alpha\beta$ coordinate system based on Matlab/Simulink.

II. THE BASIC THEORY OF VECTOR CONTROL SYSTEM FOR ASYNCHRONOUS MOTOR

The core idea of vector control AC motor by coordinate transformation is equivalent to the DC motor. It is learned from the reference[1] that the three-phase stator currents of i_A, i_B and i_C become two-phase AC currents of i_α and i_β. by 3/2 transformation. Then AC currents of i_α and i_β become DC currents of i_d and i_q by 2s/2r transform, and then AC motor is equivalent to DC motor . The rotor flux of AC motor is Φ_r, and it is equivalent to the magnetic flux of DC motor. If the d-axis is oriented in the direction of Φ_r, and at this time the dq coordinate system is also called MT coordinates. M represents the magnetization, T represents the torque.

According to the above idea asynchronous motor model is equivalently converted to DC motor model, and imitates control strategy of DC motor, then gets the corresponding control amount, and then through the corresponding coordinate inverse transform, it can get the corresponding control amount of asynchronous motor, so that it can realize the control of asynchronous. For the 2s/2r coordinate transformation, the current is seen as representative of the space vector of the magnetomotive force. The control system achieved through the coordinate transformation is referred as the vector control system (VC system) through the above process,. The principle schematic of VC system is shown in Figure1.

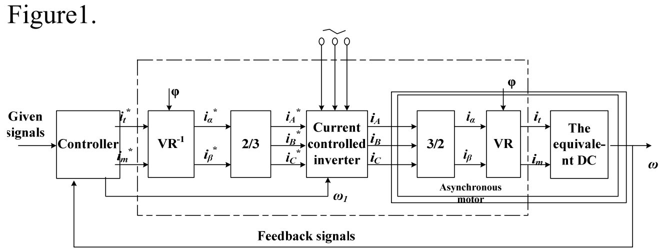

Figure1. The block diagram of VC system

The given signal shown as Figure1 generates the control signals to control the inverter through transform, and the VC system gets the input signals of the input signal of i_A, i_B and i_C for the asynchronous motor. It is required to run at a specified input of the asynchronous motor. The VC system offsets the rotation and anti-rotation transformation of dotted, and the VC system is consistent with the speed-adjusting control process of DC motor, so the control performance of the vector control system can be comparable to the DC speed control system.

The figure is expounded the basic ideas of vector control system, and the actual electromagnetic calorimeter of asynchronous motor is very complex, at last the asynchronous motor only uses the dynamic mathematical model to analyze itself. The rotor flux oriented vector control system (FOC, Field Orientation Control System) is the successful application of the control scheme, and it is next to analysis the realization of FOC implementation.

The model of FOC is built in the MT coordinate system. In the MT coordinate system, the direction of d-axis is consistent with the direction of rotor flux linkage vector because the coordinate system of two-phase synchronous rotating is based on the rotor flux orientation[3][4].

$$\psi_{rd} = \psi_{rm} = \psi_r \,,\quad \psi_{rq} = \psi_{rt} = 0 \qquad (1)$$

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It can get the state equation of MT coordinate system based on the theory of rotating coordinate system for asynchronous motor .

$$T_e = \frac{n_p L_m}{L_r} i_{st} \psi_r \quad (2)$$

$$\frac{d\omega}{dt} = \frac{n_p^2 L_m}{J L_r} i_{st} \psi_r - \frac{n_p}{J} T_L \quad (3)$$

$$\frac{d\psi_r}{dt} = -\frac{1}{T_r}\psi_r + \frac{L_m}{T_r} i_{sm} \quad (4)$$

$$0 = -(\omega_1 - \omega)\psi_r + \frac{L_m}{T_r} i_{st} \quad (5)$$

$$\frac{di_{sm}}{dt} = -\frac{L_m}{\sigma L_s L_r T_r}\psi_r - \frac{R_s L_r^2 + R_r L_m^2}{\sigma L_s L_r^2} i_{sm} + \omega_1 i_{st} + \frac{u_{sm}}{\sigma L_s} \quad (6)$$

$$\frac{di_{st}}{dt} = -\frac{L_m}{\sigma L_s L_r}\omega\psi_r - \frac{R_s L_r^2 + R_r L_m^2}{\sigma L_s L_r^2} i_{st} - \omega_1 i_{sm} + \frac{u_{st}}{\sigma L_s} \quad (7)$$

The type(5) can be turned into type(8) for $\psi_{rt}=0$.

$$\omega_1 - \omega = \omega_s = \frac{L_m i_{st}}{T_r \psi_r} \quad (8)$$

$$T_r p \psi_r + \psi_r = L_m i_{sm} \quad (9)$$

$$\psi_r = \frac{L_m}{T_r p + 1} i_{sm} \quad (10)$$

$$i_{sm} = \frac{T_r p + 1}{L_m}\psi_r \quad (11)$$

The type(11) shows that the rotor flux generated by the stator current excitation component only, nothing to do with the torque component, From this point of view, the excitation component and torque component of the stator current is decoupled. The basic equation for the vector control is type(1), (8), (10). It can get the mathematical model of vector transform for asynchronous motor according to the above equations, and the .model is shown as the figure2.

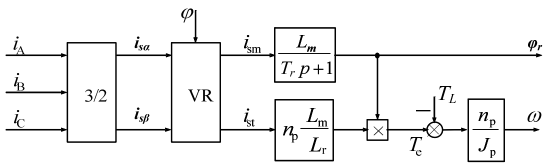

Figure2. The vector transformation and current decoupling mathematical model of asynchronous motor

From the type(1) it can learn that the excitation component and torque component is coupled because T_e is affected by the i_{st} and ψ_r. , On the other hand, ψ_r is affected by the i_{sm}, and T_e is affected by the i_{sm} too. In order to realize complete decoupling, T_e needs to eliminate the affection of ψ_r in addition to the vector transformation. It can get the completely decoupled system shown in Figure3 for setting the divider.

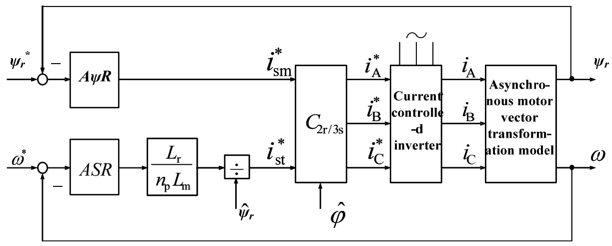

Figure3. The decoupled vector control system with division links

III. THE SPEED-ADJUSTING THEORY OF VOLTAGE FREQUENCY RATIO CONTROL FOR ASYNCHRONOUS MOTOR

Scalar control system is to control magnetmomotive force amplitude and rotating speed in chart3, and do not control the angle between them. The reason is that the amplitude and speed of rotation are scalar, hence the scalar control system of voltage to frequency ration control(*V/f*) is base on the steady state relationship between the control of open-loop system, and has no torque control loop, so the system dynamic performance isn't good. But this kind of control mode of the inverter has the advantages of simple structure, low cost, reliable operation, convenient speed regulation, and it is widely applied to the dynamic performance requirements of high speed, small occasions, wind machine, water pump. The premise of motor speed-adjusting control is to make full use of iron core and the wire of the motor, and remains the core flux density and the current density of wires stable. The effective value of phase electromotive force for three-phase asynchronous motor is shown as type(8).

$$E_s = \sqrt{2}\pi f_1 N_s k_{Ns} \Phi_m \quad (8)$$

If make flux keep rated value unchanged, the electromotive force and frequency ratio should be kept unchanged.

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$$\frac{E_s}{f_1} = const = \frac{E_{sN}}{f_{1N}} \tag{9}$$

The rated value of flux is rated magnetomotive force, and the constant value is $\frac{E_{sN}}{f_{1N}}$. It is known as constant voltage frequency ratio control method because the magnetomotive force magnetic force and frequency ration is constant value. *V/f* can be discussed by steady-state equivalent circuit because *V/f* is the control mode of steady-state relationship[5].

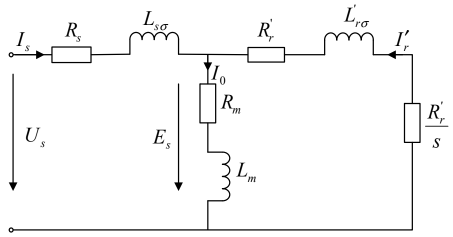

Figure4. The steady-state equivalent circuit of asynchronous motor

It can be got the type (10) from the formula of electromagnetic moment.

$$T_e = \frac{P_{em}}{\Omega_1} = \frac{3n_p}{\omega_1} I_r'^2 \frac{R_r'}{s} = \frac{3n_p}{2\pi}\left(\frac{E_s}{f_1}\right)^2 \frac{s f_1 R_r'}{(R_r')^2 + s^2\omega_1^2 L_{r\sigma}'^2} \tag{10}$$

The type(10) is strictly constant flux control equation of the mechanical characteristic. If order $dT_s / ds = 0$, it can get the maximum torque equation as follow as type(11).

$$T_{e\max} = \frac{3n_p}{8\pi^2}\left(\frac{E_s}{f_1}\right)^2 \frac{1}{L_{r\sigma}'} \tag{11}$$

It is easy to know that the maximum torque is constant when $\frac{E_s}{f_1} = const$, and it can show the output capacity of motor torque is constant. It can achieve constant flux control when $\frac{E_s}{f_1} = const$, but the actual input of motor is stator phase voltage *Us*, and the stator winding EMF is difficult to measure directly, so to achieve precise control is not easy. However, it can get type(12) from the formula(11)[6].

$$T_e = \frac{P_{em}}{\Omega_1} = \frac{3n_p}{\omega_1} I_r'^2 \frac{R_r'}{s} = \frac{3n_p U_s^2 R_r' / s}{\omega_1\left[\left(R_s + \frac{R_r'}{s}\right)^2 + \omega_1^2\left(L_{s\sigma} + L_{r\sigma}'\right)^2\right]} \tag{12}$$

$$= \frac{3n_p}{2\pi}\left(\frac{U_s}{f_1}\right)^2 \frac{s f_1 R_r'}{\left(sR_s + R_r'\right)^2 + s^2\left(L_{s\sigma} + L_{r\sigma}'\right)^2}$$

When the motor operates in the steady state, the speed is close to synchronous speed, and *s* is very small. So it can be neglected, and the type(13)can be got.

$$T_e = \frac{3n_p}{2\pi}\left(\frac{U_s}{f_1}\right)^2 \frac{s f_1}{R_r'} \tag{13}$$

From the type(13) it can be seen that the mechanical properties is parallel to descend when we change frequency for the same torque *Te*. It also can achieve very good speed regulator. On the other hand, it can ignore the stator winding and magnetic flux leakage impedance drop when the electromotive force is high from the motor voltage balance equation, so it can be thought $U_s \approx E_s$.

When the speed is low, the stator resistance *Rs* can't be ignored, *Us* and *Es* are very small with low frequency, and the stator impedance drop ratio increases, the stator power supply voltage by the partial pressure of *Rs* for generating magnetic flux of induction electromotive force *Es* will become smaller, thereby causing the air gap flux weakening the maximum torque Te_{max} decreases, with a load capacity is reduced. Therefore, in order to improve the low speed performance in low speed on the voltage *Us* compensation[6][7].

So it can get the *U/f* curve from the above theory, then get the principle block diagram of constant voltage frequency ratio control system according to the operating frequency and the frequency converter theory to get the block diagram as follow as Figure5.

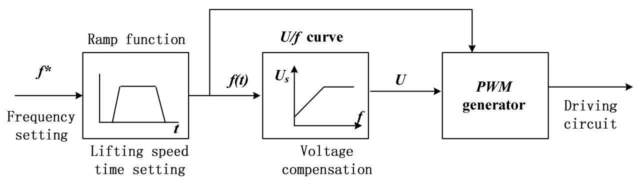

Figure5. The block diagram of variable frequency speed control system

IV. MODELING AND SIMULATION OF ASYNCHRONOUS MOTOR FOR VOLTAGE FREQUENCY RATIO CONTROL SYSTEM BASED ON MATLB

A. *The simulation parameters settings of asynchronous motor*

The motor parameters are as follows: stator winding phase resistance: $R = 0.435\Omega$; rotor winding phase resistance: $R = 0.816\Omega$; phase inductance: $L = 0.002H$; the rotational inertia of the stator and rotor: $J_s = J_r = 1.99Kgm^2$; motor pole pairs: $P = 2$; rated voltage:380V.

B. *The simulation models of asynchronous motor in coordinate system based on Matlab/Simulink*

It can get the equations of motor according to the mathematical model in $\alpha\beta$ coordinate system shown as type(5) to type(9), and the subscript " 1 " represents the stator, and the subscript " 2 " represents the rotor in the following type.

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$$\psi_{\alpha 1} = \frac{1}{p}(u_{\alpha 1} - r_1 i_{\alpha 1})$$
$$\psi_{\beta 1} = \frac{1}{p}(u_{\beta 1} - r_1 i_{\beta 1}) \quad (14)$$

$$\psi_{\alpha 2} = \frac{1}{p}(u_{\alpha 2} - r_2 i_{\alpha 2} - \psi_{\beta 2}\omega_r)$$
$$\psi_{\beta 2} = \frac{1}{p}(u_{\beta 2} - r_2 i_{\beta 2} - \psi_{\alpha 2}\omega_r) \quad (15)$$

$$i_{\alpha 1} = \frac{1}{L_m}(\psi_{\alpha 2} - L_r i_{\alpha 2})$$
$$i_{\alpha 2} = \frac{1}{L_m}(\psi_{\alpha 1} - L_s i_{\alpha 1}) \quad (16)$$

$$T_e = T_L + \frac{J}{n_p}\frac{d\omega}{dt} \quad (17)$$

It may build the simulation model of the three-phase asynchronous motor in the $\alpha\beta$ coordinate system shown as the Figure6[8].

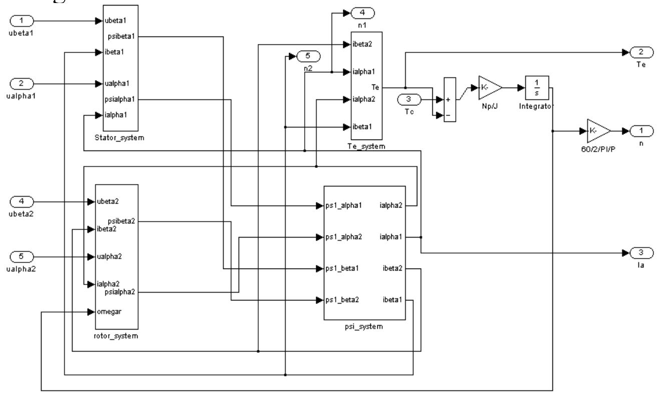

Figure6. The simulation model of asynchronous motor in the $\alpha\beta$ coordinate system

C. The simulation results and analysis

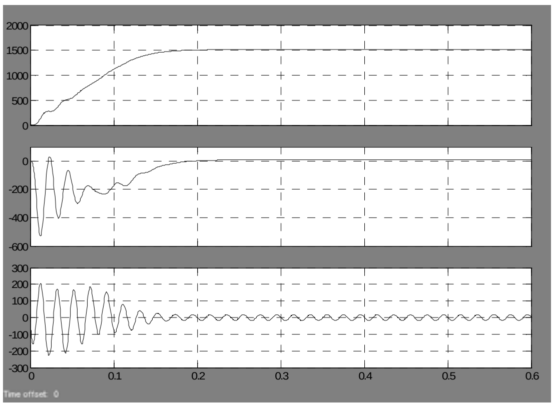

Figure7. The simulation waveforms of motor speed torque and current for asynchronous motor

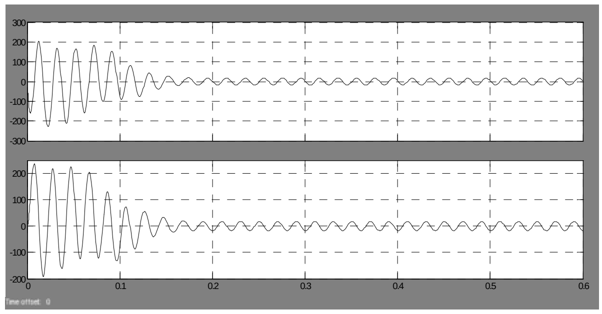

Figure8. The simulation waveforms of α current and β current

From the Figure7 and Figure8, it is easy to see the frequency of modulated wave is 50Hz and amplitude modulation wave is 380 of the rated value when the work frequency is 50Hz from the Figure10. At the same time, the frequency of modulated wave is 40Hz and amplitude modulation wave is 300 of the rated value when the work frequency is 40Hz from the Figure11. Thus changing the input frequency can change the inverter output voltage amplitude and frequency, and it is to say that it can change the input of asynchronous motor. So it has been validated by changing the frequency to control asynchronous motor through above principle.

V. CONCLUSION

According to working principle of the asynchronous motor, the paper builds the mathematical model based on $\alpha\beta$ coordinate system, and then builds the simulation model *in the* Matlab/Simulink. At last the paper gives and analyzes the simulation results. The simulation results demonstrate the validity of the theoretical analysis, which provides a theoretical basis for the development for asynchronous motor.

REFERENCES

[1] Hu Chongyue. Modern AC Speed Regulation Technology[M]. Beijing : Machinery Industry Press,2001 (In Chinese)

[2] Chen Boshi. Electric drive control system - motion control systems. 3rd ed. Beijing: China Machine Press, 2003 (In Chinese)

[3] Malinowski M, Gopakumar K, Rodriguez J, et al. A survey on cascaded multilevel inverters[J]. IEEE Transactions on Industrial Electronics, 2010, 57(7): 2197−2206.

[4] REN Yi-feng, LIU Gang, ZHAO Min. Application of active disturbance rejection control in direct torque control of induction motor[J]. Electric Drive, 2009, 39(6): 15−18.

[5] Tae-Hyung Kim, Byung-Kuk Lee, Ehsani, M., Sensorless control of the BLDC motors from near zero to high speed, Applied Power Electronics Conference and Exposition[J], 2003. APEC , 03. Eighteenth Annual IEEE , Volume: 1 , 9-13 Feb. 2003, Pages:306-312 vol.1

[6] Depenbrock M. Direct Self Control(DSC) of Inverter-fed Induction Machines[J].IEEE Trans.PE,1988,3(4):420-429.

[7] Du Yonghong, Li Zhefeng, Liu Zhigang. Indirect Field Orientation Double Close Loop System of Induction Motors[J]. Transactions of China Electrotechnical Society,2009,24(5):24-28.

[8] Hong Naigang. The MATLAB Simulation of power electronics and electric drive control system. Beijing: China Machine Press, 2006 (In Chinese)

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