Modeling and Simulation of Vector Control AC Motor Used by Electric Vehicle

Fengchun Sun [1], Jian Li [2], Liqing Sun [3], Li Zhai [4], and Fen Cguo [5]

[1] *School of Mechanical and Vehicular Engineering, Beijing Institute of Technology, sunfch@bit.edu.cn*
[2] *School of Mechanical and Vehicular Engineering, Beijing Institute of Technology, swordlee2001@163.com*
[3] *School of Mechanical and Vehicular Engineering, Beijing Institute of Technology, sunlq@bit.edu.cn*
[4] *School of Mechanical and Vehicular Engineering, Beijing Institute of Technology*
[5] *School of Mechanical and Vehicular Engineering, Beijing Institute of Technology*

Abstract
According to the principle of coordinates transform in vector control system and the reduced equation law about motor model, a mathematic model of AC motor is introduced in the MT system, and a simulation model is designed using MATLAB/SIMULINK. The simulation example shows that MATLAB/SIMULINK is an effective simulation tool and the validity of the model is verified as well. As a conclusion, a vector control AC motor has an excellent speed-regulation performance, and is very well competent for working as EV driver.

Keywords
AC motor, vector control, mathematics model, simulation, matlab/simulink

1. FOREWORD
The motor and its drive control system are the core of an electric vehicle (EV). EV generally accelerate/decelerate oftentimes, climb hill on occasion and start/stop frequently. As a result, the motors are usually required to transmit high-torque low-speed at hill climbing, low-torque high-speed at cruising, and immense power at turning around, have the characteristic of high energy density, small volume and weight, wide-speed range of operation. [Chen et al., 2002] In view of the above, it is necessary and important to find a way to verify whether the motors have capability to carry out operations of EV. The software, MATLAB/SIMULINK is one of the best choices, which integrate many toolboxes and has great superiority in the simulation of control system. With the help of the simulation platform, MATLAB/SIMULINK, the author design and develop a vector system for alternating current motor based on the fundamental mathematics equations of its. The simulation results show that the vector control system for EV AC motor drive system has better static and dynamic performance, and the rotor flux field-oriented vector control method was practically verified. [Mohan, 1997]

2. THE FUNDAMENTAL MATHEMATICS MODEL
Before we study the fundamental mathematics model of the vector control system of alternating current motor, the following hypothesizes are given. The resistance of three phase is ideal symmetrical, the magnetomotive force varies with sine curve, self-induction and mutual induction are linear with resistance, specific magnetism and most of ullage are ignored, the resistance vary for the change temperature and frequency are overlooked. [Li, 2002]

Built according to the law of generating synchronous magnetomotive force, the mathematics model of AC motor is a system of high-order, non-linear, close coupling. [Wang, 2003] According to some law, the three-phase stator current, i_A, i_B, i_C, can be transformed into two-phase current, i_α, i_β. Basing on the rotor flux field-oriented vector control method, the equivalent direct current in the synchronized reference frame, i_M, i_T, are calculated. In this way, the alternating current motor can be equivalent to a direct current motor, with the input parameters, i_M, i_T and the output one, rotate speed, ω. The principium is shown in Figure 1.

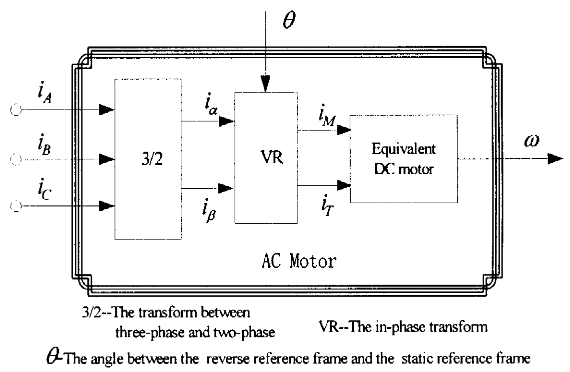

Fig. 1 Frame transform of vector control AC motor

By the above coordinate transformation, (A, B, C), the stationary reference frame in AC motor can be transformed into (M, T), the rotating reference frame in direct current motor, and the magnetic field become adjustable and controllable. In the course of the reverse transformation, the control is done. Just for the reason that the transform parameter is the current space vector, meaning magnetometive force, the system is called the vector control system. The law what we comply with in the course of transform is that, the general power is fixed and the synthetical magnetometive force is invariable. [Hu, 2003; Zhai, 2003]

(a) 3s/2s transformation

3s/2s transformation is the transformation between (A, B, C), the three-phase stationary reference frame and (α, β), the two-phase stationary reference frame. The matrix is represented by

$$C_{3s/2s} = C_{2s/3s}^{-1} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \quad (1)$$

(b) 2s/2r transformation

2s/2r transformation is the transformation between (α, β), the two-phase stationary reference frame and (M, T), the rotating reference frame. The matrix is represented by

$$C_{2s/2r} = C_{2r/2s}^{-1} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \quad (2)$$

where θ is the angle between the reverse reference frame and the static reference frame.

The fundamental mathematics model of the vector control three-phase squirrel-cage AC motor can be described by the following equations, voltage equation, flux equation, torque equation, dynamic equation. [Hu, 2003; Zhai, 2003; Wade et al., 1997; Fu, 2000; Pereira, 1998]

2.1 Voltage equations

$$\begin{bmatrix} u_M \\ u_T \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + L_s p & -\omega_s L_s & L_m p & -\omega_s L_m \\ \omega_s L_s & R_s + L_s p & \omega_s L_m & L_m p \\ L_m p & 0 & R_r + L_r p & 0 \\ \omega_s L_s & 0 & \omega_{s1} L_r & R_r \end{bmatrix} \begin{bmatrix} i_M \\ i_T \\ i_m \\ i_t \end{bmatrix} \quad (3)$$

2.2 Flux equations

$$\begin{bmatrix} \psi_M \\ \psi_T \\ \psi_m \\ \psi_t \end{bmatrix} = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \begin{bmatrix} i_M \\ i_T \\ i_m \\ i_t \end{bmatrix} \quad (4)$$

Here the rotor flux, ψ_r, is align with the axis of M. $\psi_r = \psi_m$, $\psi_t = 0$. We can get the follow equation:

$$\psi_r = \frac{L_m}{1 + T_r p} i_M \quad (5)$$

2.3 Torque equation

$$T_e = p_n L_m (i_T i_m - i_M i_t) \quad (6)$$

2.4 Dynamic equations

$$\begin{cases} T_e = T_L + \frac{J}{p_n}\frac{d\omega_r}{dt} \\ \omega_{s1} = \omega_s - \omega_r \\ \omega = \omega_r / p_n \end{cases} \quad (7)$$

From Eqs.(3), (4), (5), (6), (7),we can get the follow equations:

$$u_M = (R_s + \frac{L_m^2 R_r}{L_r^2}) i_M + L_\sigma p i_M - \omega_s L_\sigma i_T - \frac{L_m R_r}{L_r^2}\psi_r$$

$$u_T = R_s i_T + L_\sigma p i_T + \omega_s L_m \frac{\psi_r}{L_r} + \omega_s L_\sigma i_M$$

(where $L_\sigma = L_s - L_m^2 / L_r$)

$$T_e = \frac{p_n L_m \psi_r i_T}{L_r} \qquad \omega_{s1} = \frac{L_m i_T R_r}{L_r \psi_r} = \frac{L_m i_T}{T_2 \psi_r}$$

(Here $T_2 = L_r / R_r$ is the rotor time constant)

In the above equations, u_M, u_T are the M- and T-axis stator voltages respectively; i_M, i_T are the M- and T-axis stator currents respectively; i_m, i_t are the M- and T-axis rotor current respectively; R_s is the stator resistance per phase, L_s is the stator inductance per phase; R_r is the rotor resistance per phase; L_r is the rotor inductance per phase; L_m is the mutual inductance per phase; ψ_M, ψ_T are the M- and T-axis stator flux respectively; ψ_m, ψ_t are the M- and T-axis rotor flux respectively; T_e, T_L are the rotor torque and load torque respectively; J is the inertia of transmission system; ω_s, ω_r are the synchronous frequency and rotor frequency; ω is the rotor speed; ω_{s1} is the slip frequency, p_n is the number of poles; p is the differential operator.

3. THE MODEL BASED ON MATLAB/SIMULINK

From the above equations, we can construct the simulation model of vector control based on matlab/simulink. It is shown in Figure 2.

The matlab/simulink model of vector control AC motor comprises a series of subsystem. Each subsystem have been encapsulated, the detail of them is shown in what follows.

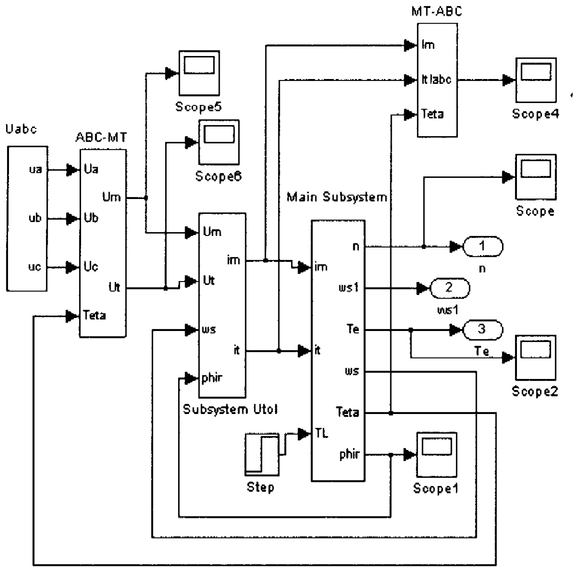

Fig. 2 The matlab/simulink model of vector control AC Motor

3.1 Vector transform of ABC-MT

The detail transformation between the three-phase stationary reference frame, (A,B,C),and the two-phase the rotating reference frame, (M,T), is shown in Figure 3.

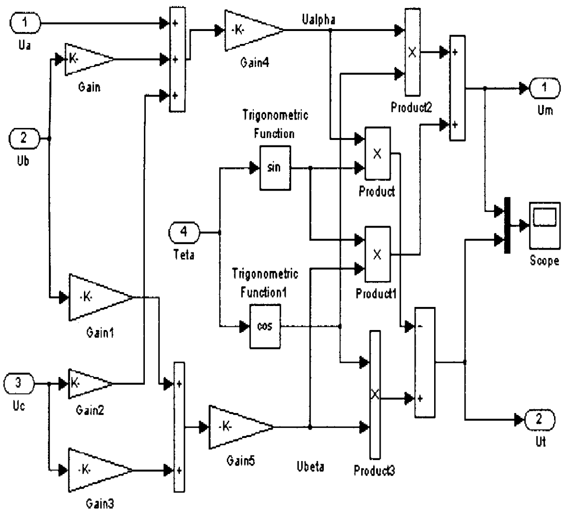

Fig. 3 The simulation model of ABC-MT

3.2 Vector transform of MT-ABC

The detail of transformation between the two-phase the rotating reference frame, (M, T), and three-phase stationary reference frame, (A, B, C), is shown in Figure 4.

3.3 Subsystem UtoI

Subsystem UtoI describes the connection between the voltage and current of the system. The detail of it is shown in Figure 5.

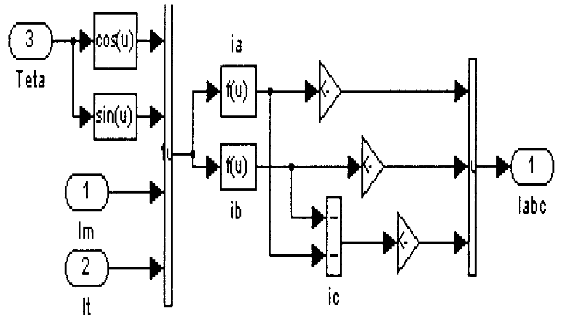

Fig. 4 The simulation model of MT-ABC transform

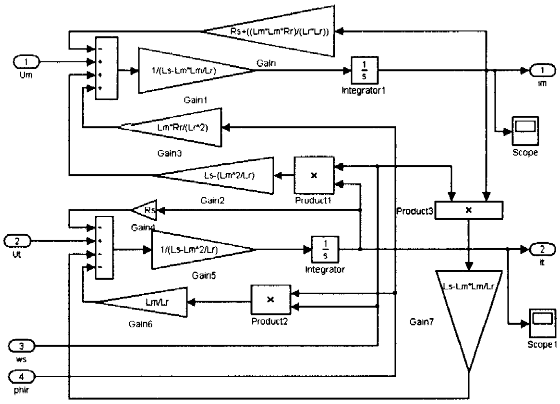

Fig. 5 The simulation model of subsystem UtoI

3.4 Simulation model of main system

The input parameters of Main Subsystem are the currents of M- and T-axis and the load torque. The output parameters shown in Figure 6 narrate the characteristic and performance of the vector control AC motor.

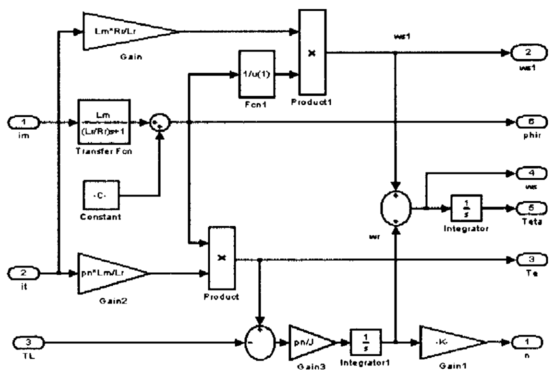

Fig. 6 The simulation model of main system

4. SIMULATION RESULTS

In order to verify the validity of the system, a series of simulation was carried out on an alternating current motor. The motor parameters enumerate in the following text. The rated power is 30KW, the rated speed is 3600r/min, the number of poles is 2, the stator resistance is 0.0110Ω, the stator inductance is 0.001441mH, the rotor resistance is 0.0082 Ω, the rotor inductance is 0.0014697mH,the mutual inductance is 0.00141mH, the inertia of transmission system is 0.379 $kg \cdot m^2$. Figure 7 describes the speed responses of the motor, Figure 8 shows the torque responses of the motor, Figure 9 represents the flux responses of the motor.

It can be see from the above three figures that the speed, the torque, the flux of the motor are not affected by other factors and come into steadying in one second when EV stars. The practical speed is a little higher than the rated speed for no other reasons than that some reasonable ullage. Five second later, the load torque of 100 $N \cdot m$ is given. The speed, torque, flux of the motor respond rapidly and run stability.

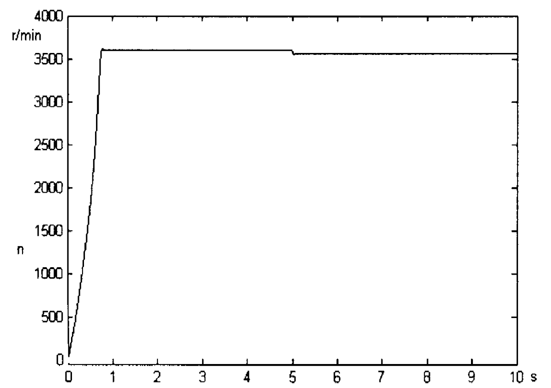

Fig. 7 The speed responses of the motor

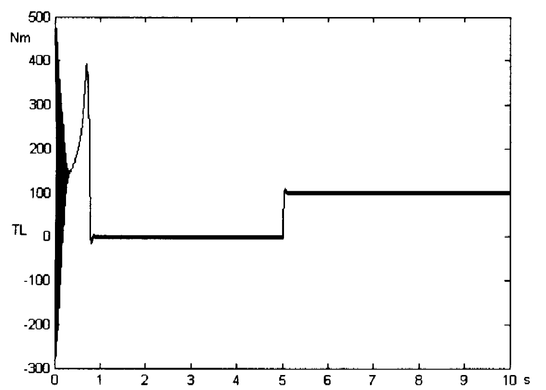

Fig. 8 The torque responses of the motor

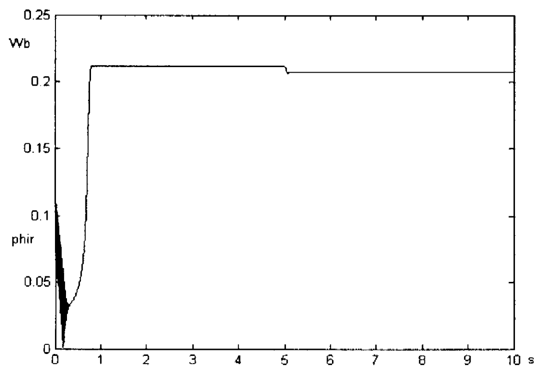

Fig. 9 The flux responses of the motor

5. CONCLUSIONS

From above paragraphs, we can see the stator voltage and current, the flux of stator and rotor are calculated in the model, the rotor torque, the load torque, the speed, the synchronous frequency, the rotor frequency, the slip frequency are computed in this system.

(1) The mathematical model and the simulation model of the vector control AC motor are accurate and credible, and are applicable to EV driver motor and other industrial motor. In the next simulation, what we do is just to change the relative parameter.

(2) These results indicate that the vector control system has better static performance, faster torque, speed and flux response, possess of better dynamic performance for torque variations in a wider speed range. This simulation offers us a reliable, low price, high efficiency way to figure or engineer an EV driver system.

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