Vector control system design for asynchronous motors

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Abstract. In order to decouple the excitation and torque components of the stator current so that the asynchronous motor speed control system approximates a DC speed control system. Firstly, the asynchronous motor model is transformed in coordinates, and then the vector control idea is proposed to construct a vector control system for the asynchronous motor. At the same time, a simulation model of the vector control system of an asynchronous motor was created on the Matlab platform and the speed waveform was recorded. The analysis of the experimental data showed that the speed response of the vector control system was fast and smooth, which improved the performance of the asynchronous motor speed control system.

1. Introduction

Today's society is developing at a rapid pace and the electric motor is becoming an indispensable factor in working life. Due to their relatively smooth speed and ease of control, DC motors are frequently used in industry. However, due to their constructional characteristics, the use of DC motors is limited to low and medium speeds and small capacities. In order to meet the social status quo, the asynchronous motor gradually occupies a dominant position, but the mathematical model of the asynchronous motor has non-linear, strongly coupled, multi-variable qualities[1]. To obtain high dynamic speed regulation performance, it is necessary to start from the dynamic model, analyse the torque and magnetic chain control law of the asynchronous motor, obtain the equivalent DC motor model, and then imitate the DC motor control strategy to design the speed regulation system[2]. Vector control systems can optimise the parameters of the PID controller and provide a significant improvement in the robustness, static and dynamic characteristics of the speed control system[3]. Asynchronous motor vector control systems can make asynchronous motors converge to DC motors, enabling them to have faster response times, higher control accuracy, more energy efficiency, etc. and enhanced control of the motor[4].

2. Mathematical models

2.1. Coordinate transformation

The purpose of the coordinate transformation is to equate an AC motor to a DC motor, transforming the more complex three-phase stationary parameters into simpler and easier to control two-phase rotational parameters, thus simplifying the control methods and processes[5].

(1) Three phase - two phase conversion
The transformation between the three-phase windings A, B and C and the two-phase windings, is called the transformation between the three-phase and two-phase coordinate systems, or the 3/2 transformation for short. The transformation process is shown in Figure 1, where, is composed of a two-phase coordinate system, A, B, C is composed of a three-phase coordinate system, N3 indicates the number of effective turns of three phases, N2 is the number of effective turns of two phases[6].

Figure 1. Physical model of the 3/2 coordinate transformation

Since their total magnetic momentum is equal, transformed into matrix form:

\[
\begin{bmatrix}
    i_a \\
    i_b
\end{bmatrix} = \frac{N_3}{N_2} \begin{bmatrix}
    1 & -\frac{1}{2} & -\frac{1}{2} \\
    \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} & 0
\end{bmatrix} \begin{bmatrix}
    i_A \\
    i_B \\
    i_C
\end{bmatrix}
\]

(1)

(2) Stationary two phase - rotating orthogonal transformation

The transformation from a stationary two-phase coordinate system, m, t, to a rotating orthogonal coordinate system, M, T, is called the stationary two-phase-rotating orthogonal transformation, or the 2s/2r transformation for short[7]. The transformation process is shown in Figure 2, where the M-axis T-axis is rotating at speed \(\omega_1\), and since, the coordinate system is stationary and unchanging, the M-axis keeps changing around the axis, and the angle between them is used for representation, summarising the relationship that exists between \(i_\alpha\), \(i_\beta\) and \(i_m\), it in the figure above.

Figure 2. Physical model of the 2s/2r coordinate transformation

Transformed into matrix form:

\[
\begin{bmatrix}
    i_a \\
    i_b
\end{bmatrix} = \begin{bmatrix}
    \cos \varphi & -\sin \varphi \\
    \sin \varphi & \cos \varphi
\end{bmatrix} \begin{bmatrix}
    i_m \\
    i_t
\end{bmatrix} = C_{2s/2r} \begin{bmatrix}
    i_m \\
    i_t
\end{bmatrix}
\]

(2)
2.2. Mathematical model of the asynchronous motor
The original model of the three-phase asynchronous motor is quite complex, and the coordinate transformation can simplify the mathematical model and facilitate the analysis and calculation, by which the three-phase asynchronous motor can be approximated as a DC motor. The mathematical model of the asynchronous motor can be obtained after the transformation as shown below.

1 Voltage equation:
\[
\begin{bmatrix}
u_{sd} \\
u_{sq} \\
u_{rd} \\
u_{rq}
\end{bmatrix} =
\begin{bmatrix}
R_s & 0 & 0 & 0 \\
0 & R_s & 0 & 0 \\
0 & 0 & R_r & 0 \\
0 & 0 & 0 & R_r
\end{bmatrix}
\begin{bmatrix}
i_{sd} \\
i_{sq} \\
i_{rd} \\
i_{rq}
\end{bmatrix} +
\frac{d}{dt}\begin{bmatrix}
\psi_{sd} \\
\psi_{sq} \\
\psi_{rd} \\
\psi_{rq}
\end{bmatrix} +
\begin{bmatrix}
-\omega\psi_{sq} \\
\omega\psi_{rd} \\
-\omega_i\psi_{sq} \\
(\omega_i - \omega)\psi_{rq}
\end{bmatrix}
\]

2 Magnetic chain equation:
\[
\begin{bmatrix}
\psi_{sd} \\
\psi_{sq} \\
\psi_{rd} \\
\psi_{rq}
\end{bmatrix} =
\begin{bmatrix}
L_s & 0 & L_m & 0 \\
0 & L_s & 0 & L_m \\
L_m & 0 & L_r & 0 \\
0 & L_m & 0 & L_r
\end{bmatrix}
\begin{bmatrix}
i_{sd} \\
i_{sq} \\
i_{rd} \\
i_{rq}
\end{bmatrix}
\]

3 Torque equation:
\[
T_e = n_p L_m (i_{sq} i_{rd} - i_{sd} i_{rq})
\]

3. Vector control system for asynchronous motors

3.1. Vector control system design for asynchronous motors
Based on the same rotating magnetic potential, the three-phase alternating current is first converted into a two-phase alternating current by means of a 3/2 transformation, and then into dc currents \(i_m\) and \(i_t\) by means of a rotational transformation, which results in a dc motor.

Figure 3. Coordinate transformation diagram of an asynchronous motor
The equivalent DC motor model is obtained by transformation, and then the electromagnetic torque and magnetic chain are controlled by imitating the control method of the DC motor, and then the control quantities in the rotor magnetic chain oriented coordinate system are inverted to obtain the corresponding quantities in the three-phase coordinate system, in order to implement control, thus obtaining the principle structure diagram of the vector control system.
3.2 Asynchronous motor vector control system simulation

A model of the vector control system of an asynchronous motor is built on the Matlab platform as shown in Figure 6.

No-load start of the speed control system, rated speed set at 1400r/min, loaded with 55N-m load at 0.6s, in the starting phase, the magnetic field is established in a relatively smooth process, the magnetic chain increases in a spiral, while the motor torque rises continuously, the motor speed rises smoothly, drops slightly after loading but then recovers; while the traditional PID speed control system after loading, it will drop slightly and then recover, there will be overshoot, its overshoot is 2.76%, and the motor speed rises slowly, and no vector control system speed response is fast and smooth, the waveforms are shown below (horizontal coordinates are in s and vertical coordinates are in r/min).
4. Summary

From the experimental results, it can be seen that the performance index of vector control system is obviously better than the traditional PID control system, and the stator current excitation component and torque component are decoupled according to the rotor magnetic chain orientation, but the accuracy of the rotor magnetic chain calculation is easily affected by the rotor resistance accuracy is not high, and the vector control structure is complex and the calculation volume is large.

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