Direct Torque Control and Vector Control of Three-phase Asynchronous Motors

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Abstract. When the motor is running at high speed with the vector control, the rotor resistance will change with the load in a larger range, and the magnetic field orientation is not accurate. When the torque control is controlled by the electromagnetic torque and the hysteresis loop, the torque of the motor is inevitably pulsed, which directly affects the stability of the motor at low speed and the range of speed adjustment. Design of a three-phase asynchronous motor vector control and direct torque control system, while at a low speed, to control the motor by vector control system, when the motor speed to high speed, switch to direct torque control system.

The Introduction

Compared with the vector control system, the direct torque control technology only needs to estimate the stator magnetic chain, which greatly reduces the problem that the control performance of vector control is easily affected by the internal parameters of the motor. And direct torque as the control quantity, the control means quickly, the structure is simple, is a kind of high performance ac motor speed regulation method. But the direct torque control is easy to choose the same voltage vector when the torque and magnetic chain error are relatively large, causing the system to be slow [1]. Moreover, the resistance of the stator resistor will change due to temperature change after a period of operation, which will cause the electromagnetic torque to produce a larger pulsation. In this paper, the combination of vector control and direct torque control system has the advantages of two kinds of control mode, makes the flux and torque ripple is reduced, different ways of switch that the motor has good starting and running process.

Direct Torque Control

The electronic torque of the asynchronous motor in the three-phase axis coordinate system is:

\[ T_e = P_0 \frac{L_m}{L_s} |\psi_s| |\psi_r| \sin \delta_{sr}. \]  

(1)

\[ P_0 \] is the polar logarithm, \( L_s \) is the stator transient inductance, and \( L_m \) is the mutual inductance of the rotor, the \( L_r \) is the rotor winding self-induction, \( |\psi_s| \) is the stator magnetic chain mode value, \( |\psi_r| \) is the rotor magnetic chain mode value, \( \delta_{sr} \) is the load Angle. Equation (1) indicates that the electromagnetic torque depends on the amplitude of the rotor flux and the electric Angle of the space, if \( |\psi_s| \) and \( |\psi_r| \) remain unchanged, the electromagnetic torque is only related to the load Angle. By (1) to

\[ \frac{dT_e}{d\delta_{sr}} = P_0 \frac{L_m}{L_s L_r} |\psi_s| |\psi_r| |\cos \delta_{sr}. \]  

(2)

It can be seen from (2) that by adjusting the load Angle \( \delta_{sr} \), the electromagnetic torque can be controlled effectively, which is the basic principle of direct torque control.
**Hysteresis Comparator**

The hysteresis comparison principle of the magnetic chain is shown in FIG. 1 (b)

\[ |\psi_s| \leq |\psi_s^*| - \Delta |\psi_s|, \ \Delta \psi = 1; \]  

\[ |\psi_s| \geq |\psi_s^*| + \Delta |\psi_s|, \ \Delta \psi = -1. \]  

(3) (4)

When \( \Delta \psi = 1 \), the need to increase flux, \( \Delta \psi = 1 \), magnetic chain need to reduce [2].

Torque differential \( \Delta T \) value by three torque replacement comparator output signal to determine, as shown in figure 1 (a), Formula is:

\[ T_e \leq T_e^* - \Delta |T_e|, \ \Delta T = 1; \]  

\[ T_e \geq T_e^*, \ \Delta T = 0; \]  

\[ T_e \geq T_e^* + \Delta |T_e|, \ \Delta T = -1; \]  

\[ T_e \leq T_e^*, \ \Delta T = 0. \]  

(5) (6) (7) (8)

**Selection of Switching Voltage Vector**

I as shown in figure 2, we selected sectors, for example, when the stator flux \( \psi_s \) between sectors, the optional voltage vector is only Us2 billion, Us3, Us5, Us6 and zero voltage vector Us7, Us8. Us1 and Us4 cannot be selected because they will make \( |\psi_s| \) sharp changes, which will be difficult to control in the bandwidth, and the function of speed is very limited.

\[ |\Delta \psi_s| \leq |\Delta \psi_s^*| - \Delta |\psi_s|, \ \Delta \psi = 1; \]  

\[ |\Delta \psi_s| \geq |\Delta \psi_s^*| + \Delta |\psi_s|, \ \Delta \psi = -1. \]  

(9) (10)

(9) (10)

It will be a little bit sector I clear after decomposition, Us2 billion, Us6 can increase the flux linkage, Us3, Us5 can reduce magnetic chain; Meanwhile, Us2, Us3 can increase torque, Us5, Us6 can reduce torque, so the voltage vector selection table is shown in Table 1.  

![Figure 1. Torque and magnetic link comparator.](image1.png)

![Figure 2. Sector judgment.](image2.png)
Table 1. Switch voltage vector selection table.

<table>
<thead>
<tr>
<th>Δψ</th>
<th>Δt</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
</tr>
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<td>1</td>
<td>1</td>
<td>Us2</td>
<td>Us3</td>
<td>Us4</td>
<td>Us5</td>
<td>Us6</td>
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<td>Us8</td>
<td>Us7</td>
<td>Us8</td>
<td>Us8</td>
<td>Us8</td>
<td></td>
</tr>
<tr>
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<td>Us6</td>
<td>Us1</td>
<td>Us2</td>
<td>Us3</td>
<td>Us4</td>
<td>Us5</td>
<td></td>
</tr>
<tr>
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<td>Us3</td>
<td>Us4</td>
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<td>Us6</td>
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<td>Us7</td>
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<tr>
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<td>Us1</td>
<td>Us2</td>
<td>Us3</td>
<td>Us4</td>
<td></td>
</tr>
</tbody>
</table>

Vector Control

The Principle of Vector Control System

The vector control parameters based on the MT axis of the two-phase rotating magnetic field are as follows:

(1) the magnetic chain equation of the rotor

\[
\psi_M = L_s i_M + L_m i_m.
\]  
(9)

\[
\psi_T = L_s i_T + L_m i_t.
\]  
(10)

\[
\psi_m = L_m i_M + L_r i_m.
\]  
(11)

\[
0 = L_m i_T + L_r i_t.
\]  
(12)

(2) the voltage equation of the rotor
The relationship between the angular frequency of the rotor, the rotor flux, the stator current component and the electromagnetic torque is reflected in (19) ~ (21)[2].

**Joint Control System Structure Diagram**

![Joint Control System Structure Diagram](image)

Figure 4. Schematic diagram of joint control.
**Simulation Results of Joint Control**

The simulation parameters are as follows: voltage 380 V, frequency 50 Hz, 0.435 Ω stator resistance and rotor resistance 0.816 Ω, stator inductance 0.02 H, rotor inductance 0.02H, mutual inductance 0.069 H, rated speed 500 rad/s, the stator flux linkage rating 1.5 Wb/turn.

The simulation results are shown below.

**Figure 6. Magnetic chain simulation diagram.**

**Figure 7. Speed simulation chart.**

**Figure 8. Torque simulation diagram.**

**Conclusion**

This article through to the three-phase asynchronous motor direct torque control and vector control simulation of joint control in low-speed segment using the vector control system, high speed period of using direct torque control system, makes the system has good startup performance and running performance.
References
