The Analysis of vector-frequency control System of Induction Motor

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Abstract. The thesis have introduced the operating principle of frequency control, analyzed mechanical character, under and above basic frequency proportion of constant voltage-frequency control character, adapted vector control method to frequency control system design, the simulation model of the motor is given, the simulation results confirm the validity of the theory.

Introduction

With the rapid development of variable frequency control technique, speed control system of three-phase asynchronous motor have excellent energy efficiency performance[1] [2]. The range of frequency control is larger, the gliding property is higher, when variable frequency according to in different stress condition, speed control with constant torque or speed control with constant power can be realized, to orientate request of different load, and this method is the most promising future in the speed control system of asynchronous motor. It becomes more and more popular in the industrial production as well as in our daily life[3]. So, three-phase asynchronous motor frequency control of motor speed features research has aroused people more and more attention.

Variable frequency speed regulation principle

When the speed is controlled by frequency, it wants to keep magnetic flux Φ · By the following formula:

$$U_1 \approx E_1 = 4.44 f_1 N_1 k_{w1} \Phi_m \tag{1}$$

we can know U_1/f_1 should be a fixed value.

For constant torque speed control, if the frequency conversion device can guarantee that U_1 with f_1 is proportional to the change, then it can be asured in the process of frequency change motor will have the same overloading capacity, the ratio of the rated torque around the characteristic frequency is as follows:

$$\frac{T_N'}{T_N} \approx \left(\frac{U_1'}{U_1}\right)^2 \left(\frac{f_1}{f_1'}\right)^2 \frac{K_T}{K_T'} \tag{2}$$

To make the motor have the same ability of overloading around the characteristic frequency, that is $K_T' = K_T$, we should adjust the stator voltage according to the following rules:

$$\frac{U_1'}{U_1} = \frac{f_1'}{f_1}\sqrt{\frac{T_N'}{T_N}} \tag{3}$$

For the constant torque load, $T_N' = T_N$ by the formula mentioned above can be obtained, $U_1'/f_1' = U_1/f_1$, so when the constant torque speed in control, if you can keep U_1/f_1 a fixed value, it can guarantee the motor has the same ability of overload in the process of speed control, at the same time it can meet the requirements of flux Φ keeps invariant.

The constant power speed regulation woks like this, because of $P_{TN} = T_N' \Omega_N' = T_N \Omega_S$, so

$T_N' / T_N = f_1 / f_1'$, in this time we should adjust the stator voltage according to the following rules $U_1' / \sqrt{f_1'} = U_1 / \sqrt{f_1}$, so in the constant power speed regulation theory, if you keep $U_1 / \sqrt{f_1}$ a fixed value , what can be guaranteed is the motor has the same ability of overload in the process of speed control too[4] [5]. But if flux will change, the graph of variable frequency speed regulation principle as follows:

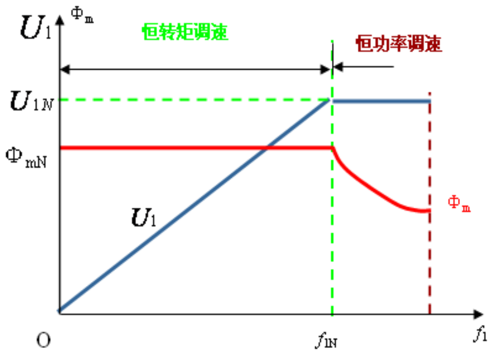

Fig.1. constant voltage frequency ratio frequency control of motor speed characteristics

Variable-frequency motor starting characteristic analysis

The main parameters of Asynchronous motor starting characteristic are starting torque and starting current, when the asynchronous motor starting *n=0, s=1* ,the relationship between voltage and frequency is as follows:

$$I_{st} = \frac{U_\phi}{\sqrt{\left(\frac{R_2'}{s}+R_1\right)^2+\left(X_1+X_2'\right)^2}} = \frac{U_\phi / f}{\sqrt{\left(\frac{R_2'+R_1}{f}\right)+4\pi^2\left(L1+L'2\right)^2}} \tag{4}$$

$$Tst = \frac{m_1}{\Omega_s}\frac{U_\phi^2\frac{R_2'}{s}}{\left(R_1+\frac{R_2'}{s}\right)^2+\left(X_1+X_2'\right)^2} = \frac{\left(U\phi / f\right)^2}{\left[\left(\frac{R_1+R'}{f}\right)^2+4\pi^2\left(L1+L'2\right)^2\right]} \tag{5}$$

From the top, when the lower voltage with the the frequency reduction, keep the ratio of *U/f* constant, starting current is reduced. And the change of the starting torque T_{st} is more complex, when the frequency is very low, because of the proportion of stator and rotor resistance in the resistance is increase obviously, T_{st} will be decreased with lower f obviously, but when the frequency is higher, in a certain frequency range, may be T_{st} will slightly higher with lower *f*, variable frequency speed regulation imposed by frequency motor *f*, voltage *U*, the power of the motor, stator reactance and in the process of starting the skin effect of rotor resistance are changing.

The vector control mathematical model of asynchronous motor

In order to achieve high dynamic performance of vector control speed regulation system, must be based on the dynamic mathematical model of asynchronous motor to design the system, mathematical modeling method is generally three-phase coordinate transformation into two phase coordinates, in α-β state equation of induction motor with the static coordinate system has nothing to do with the angle of stator and rotor, you can easily find out each state variable asynchronous motor[6] [7]. For the cage type asynchronous motor, the side of the rotor voltage is zero, according to the literature can derive the asynchronous motor in the *d*, *q* system mathematical model of the voltage equation is as follows:

$$U_{sd} = R_s i_{sd} + p\Psi_{sd} - \omega_s \Psi_{sq} \tag{6}$$

$$U_{sq} = R_s i_{sq} + p\Psi_{sq} - \omega_s \Psi_{sq} \tag{7}$$

$$0 = R_r i_{rd} + p\Psi_{rd} \tag{8}$$

$$0 = R_r i_{rq} + p\Psi_{rq} \tag{9}$$

Where U_{sd}, U_{sq}as component of the stator voltage synchronous coordinate system, R_s, R_r as the stator and rotor resistance, Ψ_{sd} , Ψ_{sq} for the rotor flux in the synchronous coordinate system components, ω_s , ω_{sl} were synchronized angular velocity and angular velocity slip, p is the differential operator.

Flux equation is as follows:

$$\Psi_{sd} = L_s i_{st} + L_m i_{rd} , \Psi_{sq} = L_s i_{sq} + L_m i_{rq} , \Psi_{rd} = L_m i_{sd} + L_r i_{rd} , \quad 0 = L_m i_{sq} + L_r i_{rq} \tag{10}$$

Where, L_s ,L_r,L_m respectively as stator inductance, rotor inductance and mutual inductance i_{sd}, i_{sq} are the stator current in the synchronous coordinate system components， i_{rq} is the rotor current component in the synchronous coordinate system.

Torque equation is as follows:

$$T_e = p\frac{L_m}{L_r} i_{st} \Psi_{rd} \tag{11}$$

In the type:Te is the electromagnetic torque of the motor, p is as logarithm for the motor.

According to the above equation, the following relation can be obtained.

$$U_{sd} = R_s i_{sd} + \sigma L_s p i_{sd} + \frac{L_m}{L_r} p\Psi_{rd} - \omega_s \sigma L_s i_{sq} \tag{12}$$

$$U_{sq} = R_s i_{sq} + \sigma L_s p i_{sd} + \omega_s (\sigma L_s i_{sd} \Psi_{sd} \frac{L_m}{L_r} \Psi_{rd}) \tag{13}$$

$$\Psi_{rd} = \frac{L_m}{1 + T_r p} i_{sd} \tag{14}$$

$$\omega_{sl} = \frac{L_m}{T_r} \frac{i_{sd}}{\Psi_{rd}} \tag{15}$$

$$i_{rq} = -\frac{L_m}{L_r} i_{sq} \tag{16}$$

$$i_{rd} = \frac{\Psi_{rd} - L_m i_{sd}}{L_r} \tag{17}$$

$$T_e = \frac{p}{R_r} \Psi^2{}_{rd} \omega_{sl} \tag{18}$$

$$\sigma = 1 - \frac{L^2{}_m}{L_s L_r} \tag{19}$$

$$T_r = \frac{L_r}{R_r} \tag{20}$$

When the fotor flux is constant, q-axis stator current torque component. Electromagnetic torque and stator current is proportional to q-axis component, q-axis component of the stator current control can control the electromagnetic torque. D-axis voltage equation by controlling the fotor flux component to achieve decoupling control of flux and torque.

Vector control simulation model is established

Modeling and simulation results based on the above principle is as follows:

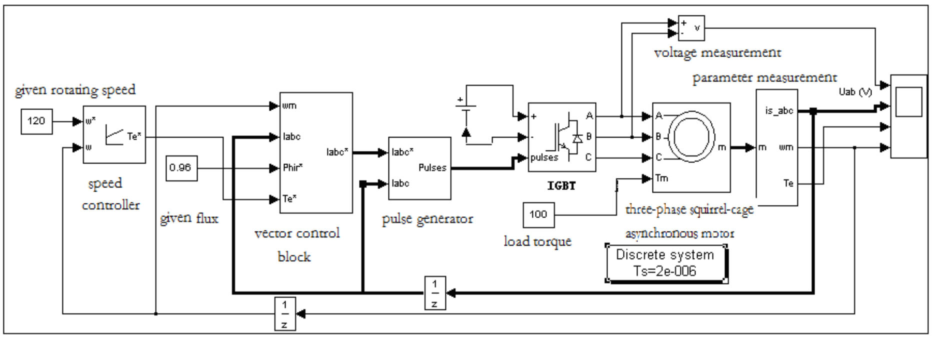

Fig.2. Asynchronous motor vector control simulation model

Given speed to 120 rad/s, the load is set to 100, frequency 50 hz, the system output speed and torque curve as shown in the figure below:

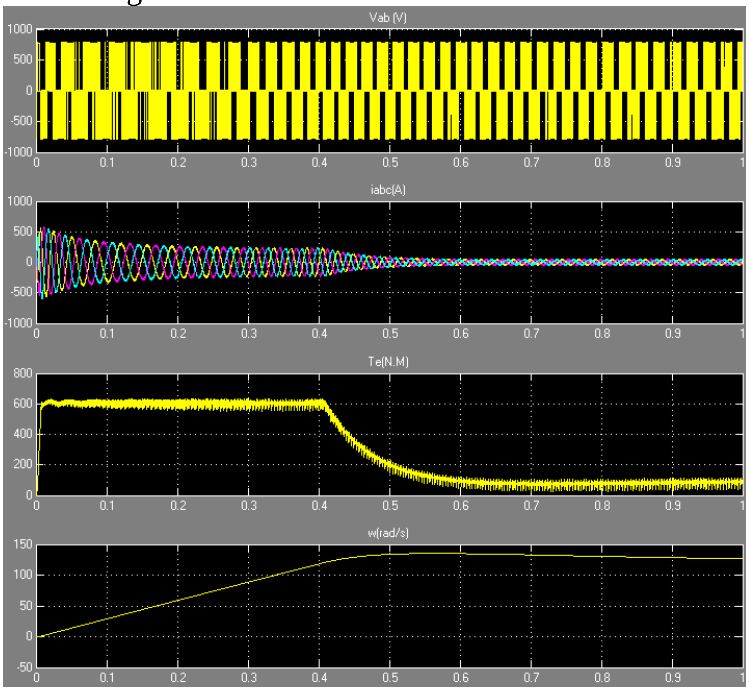

Fig.3. The results of motor parameters change over time

Conclusion

From the above simulation we can see that, this model adopts frequency conversion vector control mode, the whole process of starting operation is stable, fast, and the accuracy is improved also. Under the fundamental frequency for constant torque speed control, the fundamental frequency above for constant power speed regulation, the maximum torque of the motor speed constant torque 600NM, constant power speed regulation after 0.4s, Starting the first dynamic process is relatively complex, volatility is larger, and then gradually into the stable. Voltage, frequency gradually increases, the speed also will increase, Torque is also gradually reduced by a constant torque load torque eventually stabilize and eventually stabilize at the desired speed speed 120rad/s， the simulation results are consistent with the basic theory as a whole.

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