Research on the Voltage Space Vector Selection of Direct Torque Control

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Abstract. In this paper, for direct controlling to stator flux and electromagnetic torque of asynchronous motor, we have made an in-depth study on the voltage space vector selection of direct torque control. We used the method of calculating complex angle of flux linkage to determine the flux linkage position about the sector signals. About the voltage space vector selection and inverter switch state controlling, an effective manner was adopted. Moreover, flux linkage torque observer model, sector judgment model and voltage space vector selection model were established and associated simulation was made. The simulation results confirm the correctness of the model, the feasibility of this approach.

Keywords: Direct torque control, voltage space vector selection, modeling, simulation.

1 Introduction

The approach of direct torque control using space vector is calculating the motor torque and flux linkage through detecting stator current and voltage on the stator coordinates directly, then making direct control to flux linkage and torque according to different value between the setting value and calculation value. Direct torque control uses stator magnetic-field orientation and select stator flux linkage as the controlled flux linkage, so its control performance can not be affected by rotor parameters. Through the rapidly changing instantaneous slip speed of stator magnetic field on the motor rotor, asynchronous motor torque and torque growth are directly controlled Direct torque control takes out the complexity transformation vector and needs not consider how to decouple the stator current into component of excitation current and torque current , but simply by following to flux linkage and torque directly and selecting the optimal state of inverter switch, it is to say that by through choosing voltage space vector imposed on the motor. The establishment of the system model and the simulation of system running state are conducive to the optimization of voltage space vector selection and to the performance improvement of direct torque control system.

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2 The Relationship of Stator Flux Linkage Space Vector and Voltage Space Vector

Use Park vector transformation, then convert three stator winding voltage scalar u_a, u_b, u_c to one vector, voltage space vector $\mathbf{u}_s(t)$. This means that all kinds of states of inverter three-phase output voltage of inverter can be expressed by voltage vector space. Setting a axis in three-phase stator coordinates and real axis α in Park vector complex plane coincidence. When inverter switch states are respectively 011-001-101-100-110-010, the corresponding voltage space vectors $\mathbf{u}_s(t)$ is depicted $\mathbf{u}_1$(011)-$\mathbf{u}_2$(001)-$\mathbf{u}_3$(101)-$\mathbf{u}_4$(100)-$\mathbf{u}_5$(110)-$\mathbf{u}_6$(010), as shown in Fig. 1. The angle-interval between two adjacent voltage space vectors is 60°. The peaks of 6 voltage space vector constitute the 6 peaks of regular hexagon. According to the voltage vector space, the flux linkage space is divided into 6 sectors S1-S6.

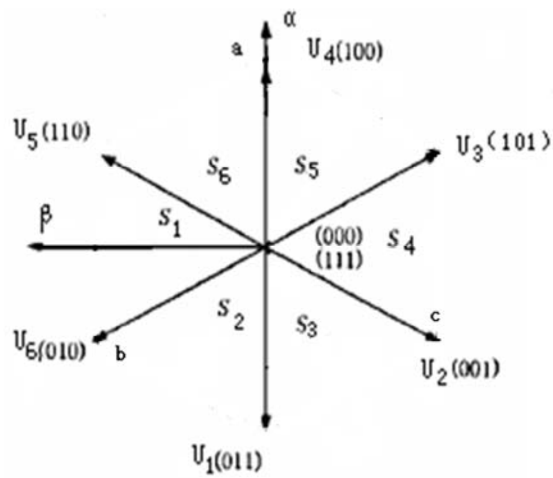

Fig. 1. Sector and voltage vector

Based on the integral relationship between the stator flux linkage space vector and stator voltage space vector as following formula (1), stator flux linkage space vector vertex movement direction and trajectory can be obtained. Corresponding to the voltage space vector's action direction, trajectory of $\psi_\mu(t)$ parallels to the direction of $\mathbf{u}_s(t)$. When the stator flux linkage is a constant, and appropriate control is adopted, according to different needs of different sectors, selecting a suitable voltage space vector among $\mathbf{u}_1$(011)--$\mathbf{u}_6$(010), the stator flux linkage trajectory is similar to a circle.

$$\psi_\mu(t) = \int [u_s(t) - i_s(t) R_s] dt \tag{1}$$

From the torque formula:

$$T_d = \frac{1}{L_\sigma}\frac{3}{2}\left(\psi_{\mu\beta}\psi_{r\alpha} - \psi_{\mu\alpha}\psi_{r\beta}\right) \tag{2}$$

We can know that the torque is related to stator flux linkage $\psi_\mu(t)$, rotor flux linkage $\psi_r(t)$ and the angle between them. The rotor flux linkage amplitude is decided by the load. The torque is actually adjusted by changing rotates speed of the stator flux linkage to adjust the angle between stator flux linkage and rotor flux linkage under maintaining the stator flux linkage unchanged. Therefore, according to increase or decrease of torque, we can selecting the voltage space vector in the different sectors which can increase or decrease the angle between them to achieve torque control.

3 The Constitute of Direct Torque Control System

In the direct torque control, inverter switch state determines the choice of voltage space vector. Because we should get inverter switching state signal, so we need to know the flux linkage signal, torque signal and the sector signal, the former two can be obtained by through magnetic torque observer. Sector signal should be obtained in accordance with the position of stator flux linkage space vector.

The control part of direct torque control system consists of flux linkage torque observer model, speed regulator, flux linkage regulator, torque regulator, flux linkage sector judgment model, and switch state signal selection model corresponding to voltage space vector. The block diagram of direct torque control system is shown in Fig. 2.

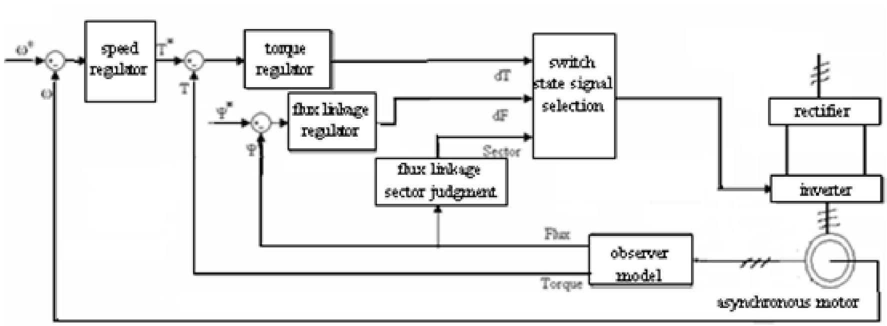

Fig. 2. Block diagram of direct torque control system

Flux linkage torque observer model uses u-i model. The theory base of torque observer is torque formula (3).

$$T_d = \frac{3}{2}(\psi_{\mu\alpha} i_{s\beta} - \psi_{\mu\beta} i_{s\alpha}) \tag{3}$$

The structure of flux linkage regulator is actually a Schmitt trigger, which can achieve two-point regulation to the flux linkage amplitude. Schmitt trigger tolerance width can be set to a very small value of ε, which represents the permitted width fluctuations of stator flux linkage amplitude for a given value. Flux linkage regulator input signal is the difference between given value of flux linkage and feedback value of flux linkage and its output value is flux linkage switch signal dF. Torque regulation uses a three-point regulator, the input signal is the difference between the given torque value and the torque feedback value. Output is the torque switching signal dT. Sector judgment unit is used to determine the sector where the current flux linkage is, and its output is depicted in sector. According to dT, dF and Sector signals, The switch state signal selection unit selectively output switch state signal to control the state of the inverter switch after a comprehensive judging, so that the inverter output of the corresponding three-phase voltage (the voltage state is the voltage space vector) to achieve direct torque control of asynchronous motor.

4 The Establishment of Flux Linkage Torque Observer Model and Sector Judgment Simulation Model

4.1 Flux Linkage Torque Observer Simulation Model

The three-phase voltage U_{abc} and the three-phase current I_{abc} are measured, 3/2 transformation of voltage and 3/2 transformation of current are finished respectively, and two stator flux linkage component $\psi_{\mu\alpha}$ and $\psi_{\mu\beta}$ can be obtained according to formula (1). From formula (3), motor electromagnetic torque can be obtained. Fig. 3 shows the flux linkage and torque observer simulation model. In this figure, the subsystem and subsystem1 are 3/2 transformation module of current and 3/2 transformation module of voltage which are packed.

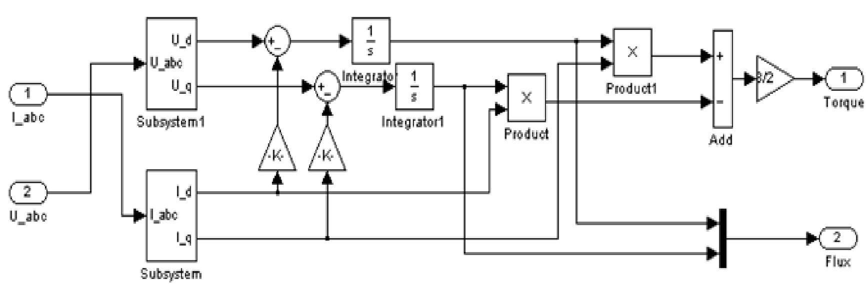

Fig. 3. Flux torque observer simulation model

4.2 Sector Judgment Simulation Model

Which sector the current flux linkage is in can be judged by complex angle of flux linkage. The flux linkage which observed by flux observer is a rotating vector, so it inevitably exist a complex angle θ. we can use this angle θ which using α-axis as 0° position to determine the sector. A comparison is conducted in every 60° range. After comparison, output signals from the way which meet the condition is brought. Each way has a different gain (gain from 1 to 6, corresponding sector S1-S6), then which sector the flux linkage vector is in. can be gotten. Fig. 4 is the sector judgment simulation model.

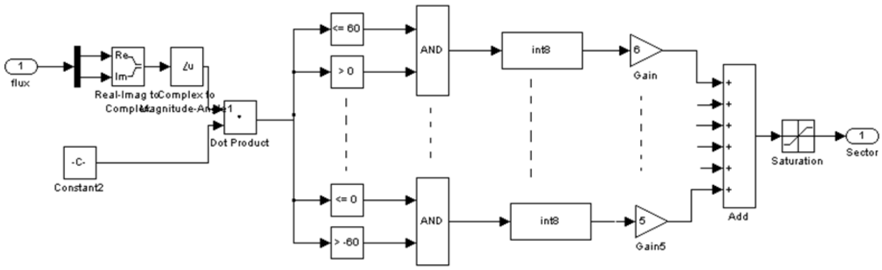

Fig. 4. Sector judgement simulation model

5 Voltage Space Vector Selection and the Establishment of Model

Voltage space vector selection is achieved by through the selection of inverter switching state signals. The inverter switch state signal is gotten from the switch state ID.

5.1 The Selection of Switch State ID

The inputs of switch state ID selection unit are torque switch signal dT, flux linkage switch signal dF and sector judgment signal Sector. This module outputs a switch state ID (0-7) according to dT, dF and Sector.

Because there are three input signals, switch signal dF from the flux linkage regulator as the first state signal in order to convenience. Using multi-switch in line with the other two signals, a two-dimensional table is adopted to achieve the selection of switch state ID. If need to increase the stator flux linkage, record as

Table 1. Switch state ID selection list

dF	dT	S1	S2	S3	S4	S5	S6
	-1	3	4	5	6	1	2
-1	0	0	7	0	7	0	7
	1	2	3	4	5	6	1
	-1	5	6	1	2	3	4
1	0	0	7	0	7	0	7
	1	6	1	2	3	4	5

dF =1. On the other hand, record as dF = -1. In like manner, if need to increase electromagnetism torque, record as dT=1. If need to decrease electromagnetism torque, record as dT=-1. If need not to increase or decrease electromagnetism torque, record as dT=0. According to the above principles, the optimal switch state ID which controlling are needed as shown in Table1 can be obtained. In this table, all the outputs below lines of S1-S6 are numbers of 0-7, which represent the voltage space vectors $\mathbf{u}_0$—$\mathbf{u}_7$. Switch state ID selection model is shown in Fig. 5.

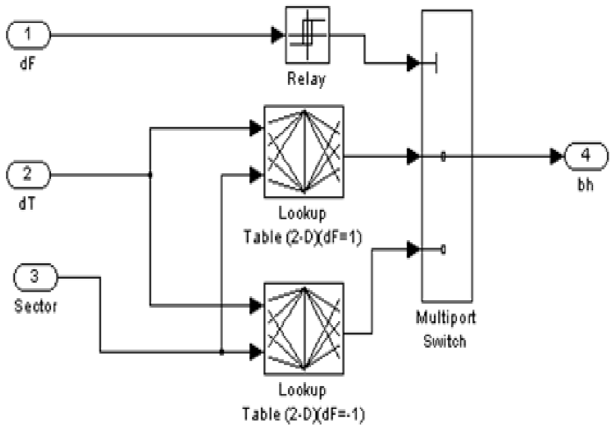

Fig. 5. Switch state ID selection simulation model

5.2 Switch State ID Changed into the Corresponding Inverter Switch State Signal with Space Voltage Vector

The output of switch state ID selection model is one number from 0 to 7. This output is changed by multi-switch in Figure #6 to the switch state signal (001, 010, etc.) which the inverter needs, and then can be used to control the operation condition of IGBT and make the inverter bring corresponding output voltage, that is different voltage space vectors. The output of switch state ID selection model is used as the first state of multi-switch. Because input value of the first state of multi-switch has the least amount of 1, so the input number is plus 1, that is to say enter numbers 1-8 are respectively corresponding to $\mathbf{u}_0$—$\mathbf{u}_7$.

So this switch can be used to achieve the number conversion. Selecting three 8-bit multi-switch, previously put high-low level on different bit of three 8-bit multi-switch according to the law. Output signals we want can be obtained due to the first state of switch input. The simulation model is shown in Fig. 6. The outputs of three 8-bit multi-switch are switch state signals of inverter ($S_aS_bS_c$). Each phase of an inverter needs two opposite switch control signals. There will be a total of six switch control signals which six IGBT inverter needed, which are respectively (S_a, $\overline{S}_a$, S_b, $\overline{S}_b$, S_c, $\overline{S}_c$). The inverter output voltage is the selected voltage

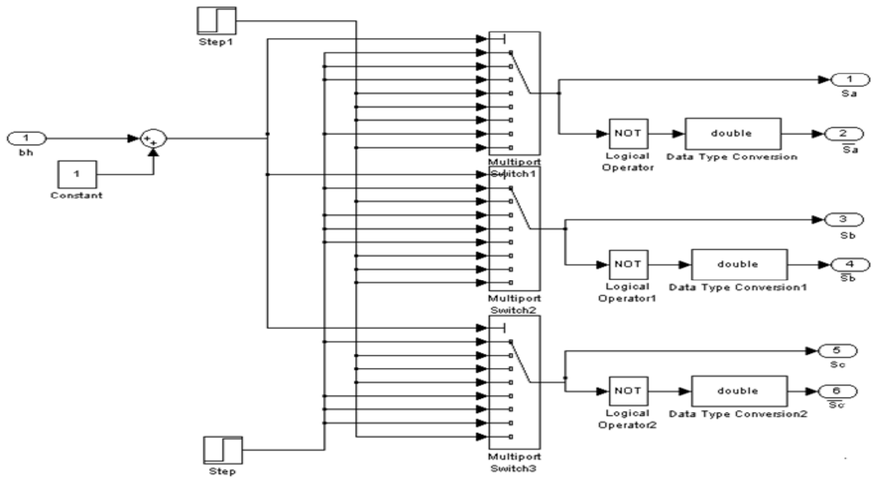

Fig. 6. The corresponding switch state signal selection with space voltage vector selection simulation model

space vector after switch control signal role in the inverter. In this way, according to different switch state ID, deciding the different switch state of inverter and then achieving the selection of voltage space vector.

6 Voltage Space Vector Selection and the Establishment of Model

The simulation model of this system consists of flux linkage torque observer, speed regulator, torque regulator, flux linkage regulator, sector judgment model, switch state signal selection model corresponding to voltage space vector , direct current supply, an IGBT inverter and motor simulation model.

The data of motor that we selected are p_N =7.5KW, U_N =400V, n_N =1440rpm=153rad/s. The simulation algorithm is ode23tb. From the sector judgment simulation waveform graph, we know that flux linkage vector appeared circulatory in 1-6 sectors. The stator flux linkage trace waveform of system simulation is shown as Fig. 7. It shows obviously that stator flux linkage trace is a circle. When the starting and loading of system simulation increased suddenly from 20Nm to 40Nm, the rotational speed and torque signal waveform is shown as Fig. 8. From the rotational speed and torque signal waveform when the direct torque control system started, this system can complete starting transition in very short time. From the rotational speed and torque signal waveform when the loading is increased suddenly, we know that this system has fast response and high anti-interference feature. It shows that this system has high torque control capability, and the selection of voltage space vector is right.

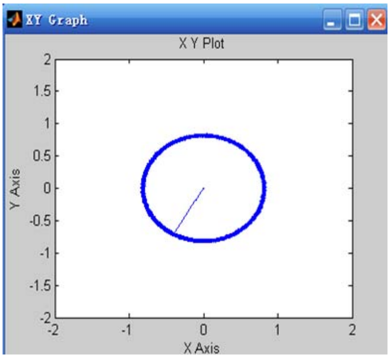

Fig. 7. Stator flux trajectory

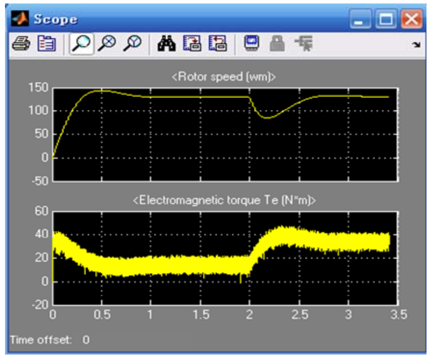

Fig. 8. Speed, torque of system when start and load increase

7 Conclusions

In this paper, we focus on the control to the asynchronous motor stator flux linkage and electromagnetic torque motor and we take an effective measures on sectors identified, voltage space vector selection, inverter switch state control. In the simulation model, the different combinations of flux linkage regulator, the torque regulator, the sector signals judgment was used to choose a different switch state ID, and converted to the corresponding inverter switch state signal. The switch of inverter is controlled to achieve voltage space vector selection. In order to facilitate the implementation, 2 two-dimensional tables are used for three signals. On the design of torque regulator, we used three-point control, not the traditional two-point control.

On judgment sector, calculation complex angle of flux linkage is used in order to determine the location of flux linkage. The system simulation achieves a circular flux linkage control and rapid torque response. The results show that the method of voltage space vector is a good. Moreover, the establishment of simulation model can effectively be used to do further study on direct torque control system.

References

1. Zuquan, Y., Xuliang, Y., Xiaofang, S.: Research on Simulation of Asynchronous Motor Direct Torque Control System. Electric Machines and Control 4, 329–332 (2004)
2. Su, L.: Direct torque control system of asynchronous motor. Machinery Industry Press (1998)
3. Jingli, M., Zenghuan, L., Wenhui, M.: Realization of the switch state selection based on MATLAB in the direct torque control. Electric Drive 6, 20–21, 51 (2005)
4. Dingyu, X., Yangquan, C.: System simulation technique and application based on MATLAB/SIMULINK. Tsinghua University Press (2002)
5. Duo, W., Jingao, H.: Simulation research of direct torque control system for induction motor based on MATLAB. Electromechanical Engineering Technology 1, 47–50 (2006)