DEVELOPMENT OF DIRECT TORQUE CONTROL MODELWITH USING SVI FOR THREE PHASE INDUCTION MOTOR

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Abstract:
Direct torque control method is one of the best control strategies which allow a torque control in steady state and transient operation of induction motor. The main aim of direct torque control strategies is to effectively control the torque and flux of induction motor. Direct torque control method made the motor more accurate and fast torque control, high dynamic speed response and simple to control. This paper present the principle of the direct torque control for voltage source inverter fed induction motor drive, and switching table, amplitude selection of the hysterics band of torque and flux. And also this method based on space vector modulation and it's considered as an alternative to field oriented control technique. Direct torque control methods are the first technology to control the 'real' motor control variable of torque and flux. And it has also more advantage such as it not required a feedback device and also not need external excitation. The performance of direct torque control method has been demonstrated by simulation using a simulation package in matlab.

Keywords: direct torque control; space vector modulation; induction motor.

1. Introduction

Direct torque control method was introduced by takahashi in japan (1984) and also by depenbrock in germany (1985). From many years induction machine is one of the most common form of electromechanical drive which is used for industrial, commercial and domestic application due to low cost, simple mechanical construction, more reliable, and low maintenance. The induction motor is high order non linear system of considerable complexity. With the use of power electronics which allow making it possible to vary the frequency of voltage or current relatively easy using various control method and extended it to use of induction motor in variable speed drive application. For high performance applications there are two types of control method of induction motor is used such as. Scalar control and vector control, in scalar controller it's based on relation which is valid in steady state, i.e. only magnitude and frequency (angular speed) of voltage, current, and flux space vectors are controlled. Thus during the transient position of space vector the scalar control does not act. While in vector controller it's based on relation which is valid for dynamic states, i.e. not only magnitude and frequency (angular speed) but also instantaneous positions of voltage, current, and flux space vectors are controlled. Thus, the vector control is acts on the positions of the space vectors and provides correct orientation for both in steady state and transient's state. In the vector control the motor equation transformed in the coordinate system that rotates in synchronism with the rotor flux vector. And torque and flux component are identifies and controlled independently to produce the batter dynamic response of induction motor. However there it is necessary to transform the variable in synchronously rotating reference frame to the stator reference frame to control the actual currents and voltage. the block diagram of direct toque control system for induction machine is consists component such as torque and flux hysteresis controller, torque and flux estimator and a switching table etc. as shown in Fig. 1.

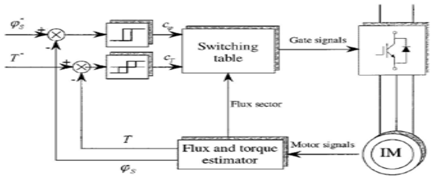

Fig. 1. Block diagram of direct torque control technique

2. Basic concept of direct torque control

In direct torque control method the stator flux and stator torque directly controlled by selecting the appropriate inverter switching state. And stator current and voltage are indirectly controlled hence no current feedback loop are required. As shown in block diagram of direct torque control scheme it's including two hysteresis controllers. In the stator flux controller that imposes the time duration of active voltage vectors, which rotates the stator flux along with the reference trajectory and in the stator torque controller that determine the time duration of zero voltage vector which keep the motor torque in the predefine hysteresis tolerance band. At each sampling time the voltage vector selection block choose the inverter switching state (S_a,S_b,S_c) which reduces the flux and torque errors. Hence the inverter fed induction machine develop torque is carried out by hysteresis controller that select one of the six non-zero and two zero inverter voltage vector as shown in Fig 2. and this selection are made in order to maintain the torque and flux error inside the hysteresis band in which the error is indicate by ΔTe and $\Delta\Psi_{s.}$ as given

$$\Delta T_e = T_{eref} - T_e \quad (1)$$

$$\Delta\psi^s_s = \overline{\psi}^s_{sref} - \overline{\psi}^s_s \quad (2)$$

The six different state of $\overline{V}^s_s$ considering $\overline{V}_i$(i=1-6) noted as S_a,S_b,S_c as the switches status of inverter are shown in Fig. 2.

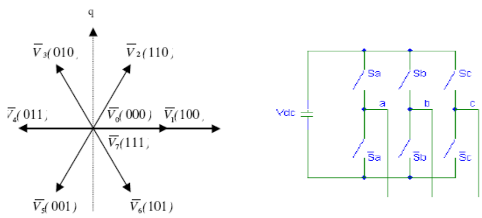

Fig.2. PWM VSI inverter eight switching states and corresponding switching space vectors

The upper switching states can be defined as the equation given below.

$$V_{as} = \frac{2S_a - S_b - S_c}{3} V_{dc} \quad (3)$$

$$V_{bs} = \frac{S_a + 2S_b - S_c}{3} V_{dc} \quad (4)$$

$$V_{cs} = \frac{-S_a - S_b + S_c}{3} V_{dc} \quad (5)$$

Hence, the space vector is

$$\overline{V}^s_s = \frac{2}{3} V_{dc} (S_a + S_b^{ej2\pi/3} + S_c^{ej4\pi/3}) \quad (6)$$

3. Torque control

The electromagnetic torque of induction machine is as cross product of the stator and rotor flux vector or stator current and flux as given by Eq.(7) is a sinusoidal function of γ and the angle between $\overline{\Psi}^s_s$ and $\overline{\Psi}^r_r$ are shown in Fig. 3.

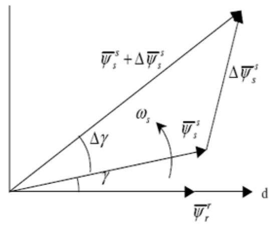

Fig.3. Stator and rotor flux space vector

$$T_e = \frac{3}{2} P\, \overline{I_s} * j\, \overline{\Psi_s} \qquad (7)$$

The magnitude of electromagnetic torque is written as

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_s}\, \overline{\Psi^s}_s\, \overline{\Psi^r}_r \sin\gamma \qquad (8)$$

Hence by selecting appropriate inverter voltage vectors V_i to obtain strong rotation speed of W_s a good dynamic performance can be achieved. The actual stator flux can be estimated from the equivalent circuit of the motor as follows:

$$\overline{\Psi^s}_s = \int (\overline{V^s}_s - R_S.\overline{i^s}_s)\, \partial t \qquad (9)$$

Where $\overline{V^s}_s$ and $\overline{i^s}_s$, are stator voltage and current respectively

The Electromagnetic torque of the motor is calculated by the equation.

$$T_e = \frac{3}{2} P\, (\Psi^s_{ds}\, i^s_{qs} - \Psi^s_{qs}\, i^s_{ds}) \qquad (10)$$

4. Stator control

For control the stator flux, selecting the appropriate inverter output voltage $\overline{V_i}$(i=1-6), the stator flux $\overline{\Psi^s}_s$ rotates at the desired frequency W_s inside the specified band. If stator ohmic drops are neglected, the stator voltage impressed directly the stator flux in accordance with the equation.

$$V^s_s = \frac{d\, \overline{\Psi^s}_s}{dt} \qquad (11)$$

Or

$$d\overline{\Psi^s}_s = \overline{V^s}_s\, dt \qquad (12)$$

Therefore during the time interval of Δt, the variation of the stator flux space vector due to the application of stator voltage vector V_s can be approximated as in equation

$$\Delta\overline{\Psi^s}_s = \overline{V^s}_s \Delta t. \qquad (13)$$

5. Modeling of induction motor

One of the major differences between FOC and DTC control is the modeling of the motor. In FOC the motor is modeled in synchronously reference frame i.e. $\omega = \omega_e$, while in DTC it is in stationary reference frame i.e. $\omega = 0$. The basic mathematical model of the induction machine is derived from the Fig. 4 and is rewritten as below:

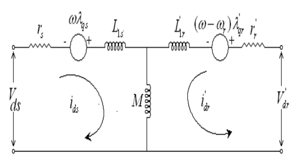

FIG. 4: Equivalent Induction Machine circuit at dq reference frame.

$$V_{qs} = R_S\; i_{qs} + \omega.\lambda_{ds} + \partial\lambda_{qs}/\partial t \qquad (14)$$

$$V_{qr} = R_r i_{qr} + (\omega - \omega_r)\lambda_{dr} + \partial\lambda_{qr}/\partial t \qquad (15)$$

$$V_{ds} = R_S i_{qs} - \omega\, \lambda_{qs} + \partial\lambda_{ds}/\partial t \qquad (16)$$

$$V_{qr} = R_r i_{dr} - (\omega - \omega_r)\lambda_{qr} + \partial\lambda_{dr}/\partial t \qquad (17)$$

$$Te = 1.5*(P/2)*(i_{ds} * \lambda_{qs} - i_{qs} * \lambda_{ds} \qquad (18)$$

6. Basic Switching Table and Selection of Voltage Vectors

The basic working principle of switching table of direct torque control concept is shown in Fig. 1. The reference stator flux Ψ_{sref} , and torque T_{eref} are compared with the actual value of Ψ_s, and Te in hysteresis flux and torque controller respectively. The hysteresis flux controller is a two-level comparator while the hysteresis torque controller is a three-level comparator.

The output signal of hysteresis flux controller is define as given below

$$\Psi_{serr} = 1, \text{ for } \Psi_s < \Psi_{sref} - H_\Psi \quad (19)$$

$$\Psi_{serr} = -1, \text{ for } \Psi_s < \Psi_{sref} + H_\Psi \quad (20)$$

And output signal of hysteresis torque controller are define as given below

$$T_{eer} = 1, \text{ for } T_e < T_{eref} - H_m \quad (21)$$

$$T_{eerr} = 0, \text{ for } T_e = T_{eref} \quad (22)$$

$$T_{eerr} = -1, \text{ for } T_e < T_{eref} + H_m \quad (23)$$

Where $2H_\Psi$ is the flux tolerance band and $2\,H_m$ is the torque tolerance band.

On the basis of the torque and flux hysteresis status and stator flux switching sector which is indicated by

$$\alpha = \angle\Psi^s_{s.} = \tan\text{-}1(\Psi^s_{qs} \;/\; \Psi^s_{ds}) \quad (24)$$

Switching table output is a setting of switching devices of the inverter; hence direct torque control technique selects the inverter voltage vector to apply the induction machine from table1.

Fig.5. show the relationship between the inverter voltage vector and stator flux switching sector in which six active switching vectors are:

V_1=(1,0,0), V_2=(1,1,0), V_3=(0,1,0), V_4=(0,1,1), V_5=(0,0,1), V_6=(1,0,1)

And two zero switching vectors are: V_0=(0,0,0), V_7=(1,1,1)

And also

$-30^o<\alpha(1)<30^o$

$30^o<\alpha(2)<90^o$

$90^o<\alpha(3)<150^o$

$150^o<\alpha(4)<210^o$

$210^o<\alpha(5)<270^o$

$270^o<\alpha(6)<330^o$

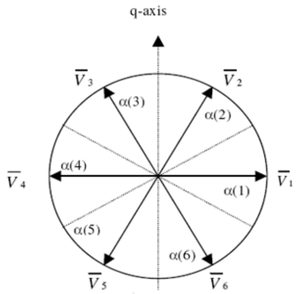

Fig. 5. Stator and rotor flux space vector

Table 1. Switching table of inverter voltage vectors

dψ	*dTe*	α *(1)*	α *(2)*	α *(3)*	α *(4)*	α *(5)*	α *(6)*
1	1	110	010	011	001	101	100
	0	000	111	000	111	000	111
	–1	101	100	110	010	011	001
–1	1	010	011	001	101	100	110
	0	111	000	111	000	111	000
	–1	001	101	100	110	010	011

7. Simulation Implementation and result

The direct torque control principle has been simulated using Matlab/Simulink . The simulink model of the direct torque control scheme fed from IGBT PWM voltage source inverter for the three phase induction motor rated 10Hp (7.5KW) 400v , 50hz and 1440 rpm are shown in Fig. 6. The dynamics performance of load torque produce by direct torque control model is evaluated by applying a variable load torque commend on the torque reference points maintained to amplitude of 25 Nm after 0.04ms. And the mechanical dynamics torque commends is maintained to 1 Nm. And speed reference is also applied to speed reference command point. The simulation time used in this simulation is adjusted to 0.1ms.

The main features of direct torque control can be summarized as follows:

- DTC is completely a motion-sensor less control method.
- DTC is not sensitive for rotor parameters because its need only stator flux and torque estimator.
- DTC is operate without current controller, but with closed torque and flux loop

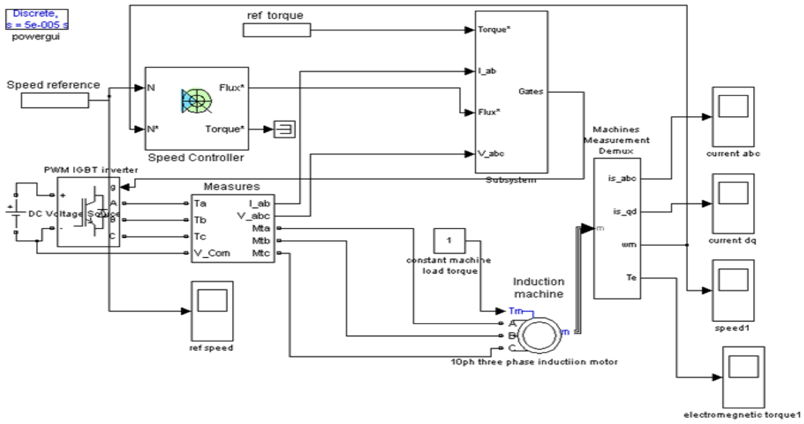

Fig. 6. matlab simulink model for direct torque control

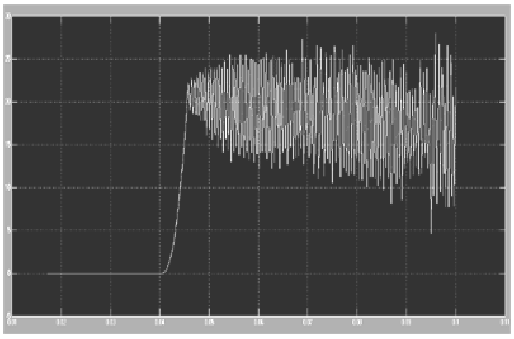

Fig. 7. Electromagnetic torque response

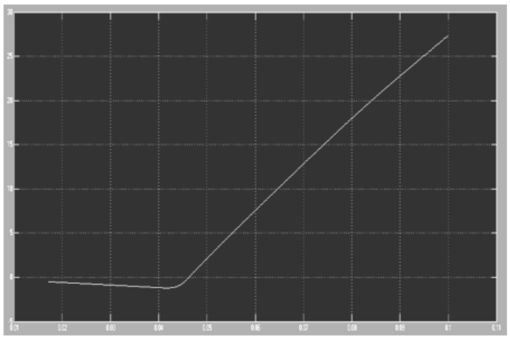

Fig. 8. Speed responce

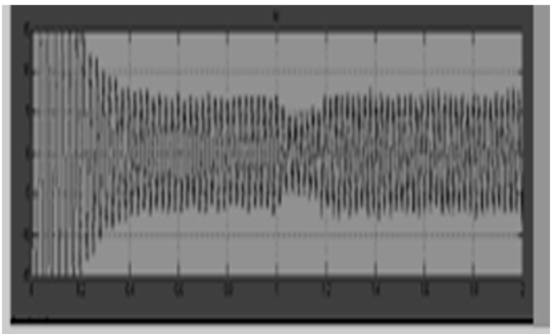

Fig. 9. Stator phase current response

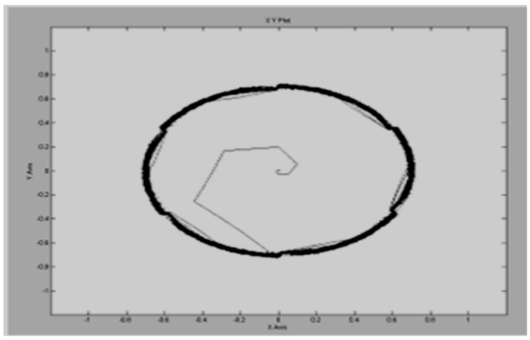

Fig. 10. Stator phase trajectory

8. Discussion and conclusion

The complete simulation of direct torque control & flux control has been demonstrated in this paper. The simulation results agree with the basic principle of the direct torque technique. From this simulation it is clearly seen that the loci of the stator flux is within the boundary created b six active vectors. When there is a change in flux, the space vector switching are such chosen that the flux error remain within the band of the controller. From the torque response its clear torque attend the required torque after the 0.04 ms and then speed also start to increases rapidly.

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Appendix

The test machine is a three phase and 50hz induction machine having the following parameter.

R_S = 0.7384 ohm.
R_r = 0.7402 ohm.
L_S = 0.003045 Henry.
L_r = 0.003045 Henry.
Lm = 0.1241 Henry.
P = Number of Poles = 2.
J = Moment of Inertia = 0.14.
B = Friction Coefficient = 0.0.