Study of Direct Torque Control Scheme for 3-phase Induction Motor

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Abstract: This paper provides a study of direct torque control scheme of 3-phase induction motor. Mathematical modelling of induction motor and direct torque control scheme has been discussed in this paper. Using direct torque control speed and torque of the motor can be controlled.

Keywords:3-phase induction motor, direct torque control, flux, speed

Introduction

Induction motor direct torque control is a decoupled control mechanism which decouples and control the flux and torque of the motor independently. Adjustable speed drive with induction motor and direct torque control are a very challenging area of research.In [1], authors provided direct torque control (DTC) scheme with space vector modulation (SVM). A exhaustive survey of different control techniques of AC motor has been discussed in [2]. Direct torque control provides improved flux and torque response in induction motor [3]. Apart from direct torque control, induction motor can also be controlled using model predictive control and indirect field oriented control [4-6]. Induction motor is applied in various applications. Electrical vehicle is one such application where induction motor is used [7].

This paper provides a simulation analysis of direct torque control scheme for 3-phase induction motor. Simulation and mathematical analysis has been provided in this paper.

Induction Motor: Preliminary

Figure 1 illustrates the schematic diagram of 3-phase induction motor and per-phase electrical equivalent circuit of induction motor.

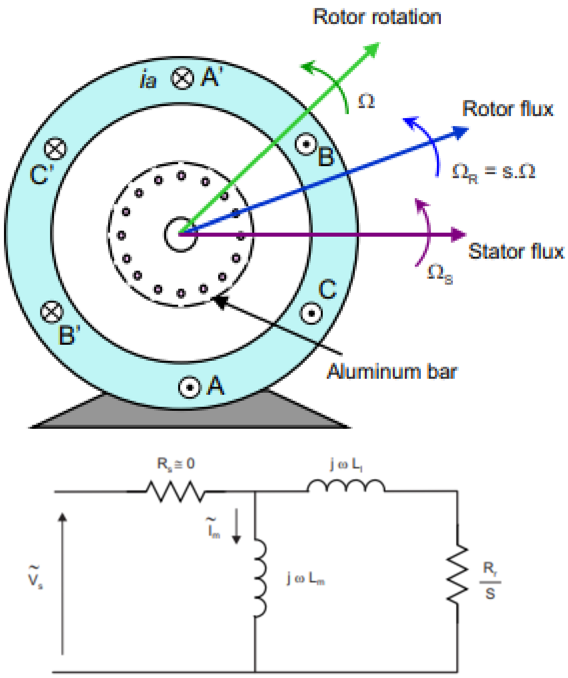


Figure 1: Schematic diagram and per-phase equivalent circuit of 3-phase induction motor

The phase voltage of stator for 3-phase induction motor can be represented as

$$U_{sa} = R_{sa} i_{sa} + \frac{d\Psi_{sa}}{dt}$$
$$U_{sb} = R_{sb} i_{sb} + \frac{d\Psi_{sb}}{dt} \quad (1)$$
$$U_{sc} = R_{sc} i_{sc} + \frac{d\Psi_{sc}}{dt}$$

The phase voltage of rotor for 3-phase induction motor can be represented as

$$U_{ra} = R_{ra} i_{ra} + \frac{d\Psi_{ra}}{dt}$$
$$U_{rb} = R_{rb} i_{rb} + \frac{d\Psi_{rb}}{dt} \quad (2)$$
$$U_{rc} = R_{rc} i_{rc} + \frac{d\Psi_{rc}}{dt}$$

Where Ψ_s is the flux linkage of stator, Ψ_r is the flux linkage of rotor, R_r is the rotor resistance, R_s is the stator resistance, U_s and U_r are stator and rotor voltage respectively. i_s and i_r are stator and rotor current respectively.

$$\Psi_{sa} = L_s i_{sa} + l_{sr}\left[i_{ra}\cos(x) + i_{rb}\cos\left(x+\frac{2\pi}{3}\right) + i_{rc}\cos\left(x+\frac{2\pi}{3}\right)\right]$$
$$\Psi_{sb} = L_s i_{sb} + l_{sr}\left[i_{ra}\cos\left(x+\frac{4\pi}{3}\right) + i_{rb}\cos(x) + i_{rc}\cos\left(x+\frac{2\pi}{3}\right)\right] \quad (3)$$
$$\Psi_{sc} = L_s i_{sc} + l_{sr}\left[i_{ra}\cos\left(x+\frac{2\pi}{3}\right) + i_{rb}\cos\left(x+\frac{4\pi}{3}\right) + i_{rc}\cos(x)\right]$$

$$\Psi_{ra} = L_r i_{ra} + l_{sr}\left[i_{sa}\cos(x) + i_{sb}\cos\left(-x+\frac{2\pi}{3}\right) + i_{sc}\cos\left(-x+\frac{4\pi}{3}\right)\right]$$
$$\Psi_{rb} = L_r i_{rb} + l_{sr}\left[i_{sa}\cos\left(-x+\frac{4\pi}{3}\right) + i_{sb}\cos(x) + i_{sc}\cos\left(-x+\frac{2\pi}{3}\right)\right] \quad (4)$$
$$\Psi_{rc} = L_r i_{rc} + l_{sr}\left[i_{sa}\cos\left(x+\frac{2\pi}{3}\right) + i_{sb}\cos\left(x+\frac{4\pi}{3}\right) + i_{sc}\cos(x)\right]$$

Here $l_{sr} = \frac{2}{3}L_m$

L_m is the mutual inductance $L_r = L_{1r} + L_m$ $J\frac{d\omega_m}{dt} = T_e - f\,\omega_m - T_m$

$$U_q = \frac{2}{3}\left[U_a\cos\theta + U_b\cos\left(\theta-\frac{2\pi}{3}\right) + U_c\cos\left(\theta+\frac{2\pi}{3}\right)\right]$$
$$U_d = \frac{2}{3}\left[U_a\sin\theta + U_b\sin\left(\theta-\frac{2\pi}{3}\right) + U_c\sin\left(\theta+\frac{2\pi}{3}\right)\right] \quad (5)$$

Different Control Schemes of Induction Motor Control

Figure 2 illustrates different types of variable frequency control. Variable frequency control can be subdivided as scalar control or vector control. Vector control can be classified as field oriented control, direct torque control, passivity based control or feedback linearization based control. Direct torque control have Space vector modulation scheme for switching.

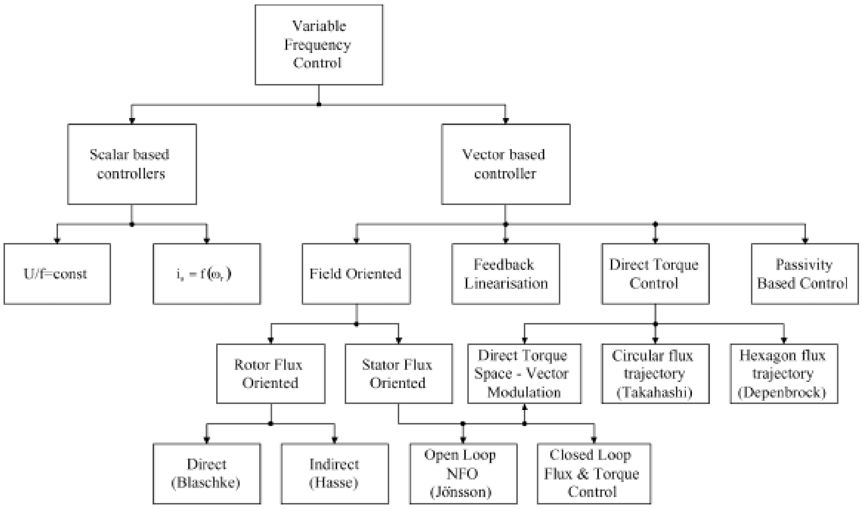


Figure 2: Classification of control scheme of induction motor

Figure 3 illustrates the block diagram of diret torque control of 3-phase induction motor. Speed sensor is used to measure the speed and speed regulator is used for regulation of speed. Direct torque control is used for speed controller. A more detailed block diagram of direct torque control is shown in Figure 4 where torque estimator and flux estimator is used.

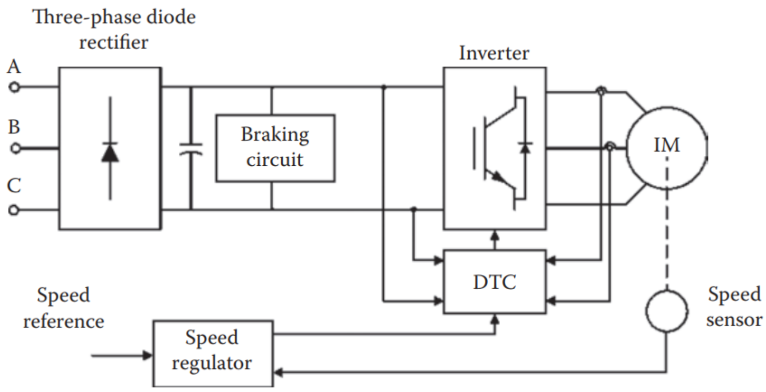


Figure 3: 3-phase inverter fed induction motor with direct torque control

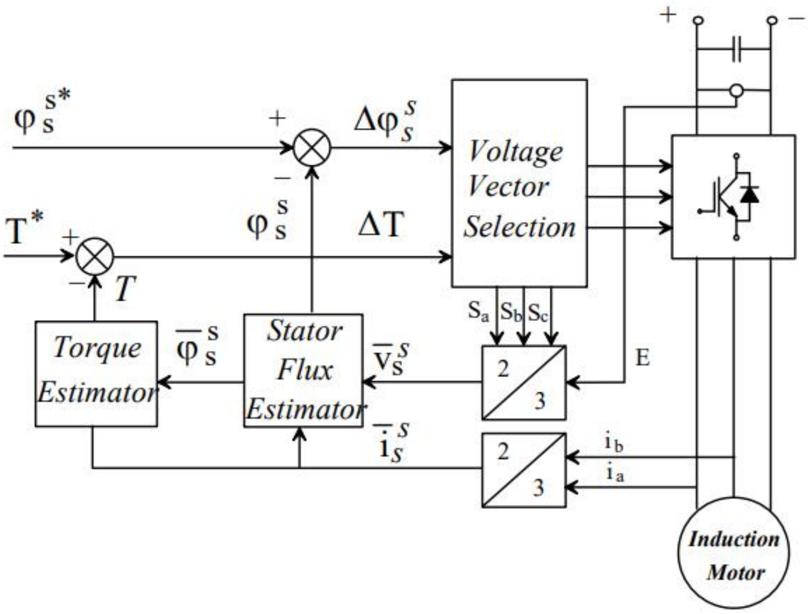


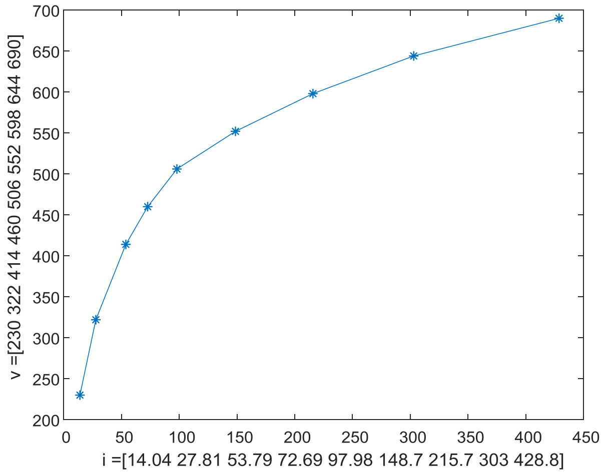
Figure 4: Direct torque control with torque and flux estimator

Simulation Results

Table 1 provides the simulation parameters for 3-phase induction motor

Table 1: Simulation parameters

Parameter	Values
Rotor type	Squirrel cage
Nominal power	1.485×10^4 W
Line to line voltage	220 V
Frequency	50 Hz
Stator resistance	0.5968 ohm
Stator inductance	0.0003495 H
Rotor resistance	0.6258 ohm
Rotor inductance	0.005473 H
Mutual inductance	0.03554
Inertia	0.05
Friction factor	0.005879
Pole pairs	2
Mechanical power	1.492×10^6



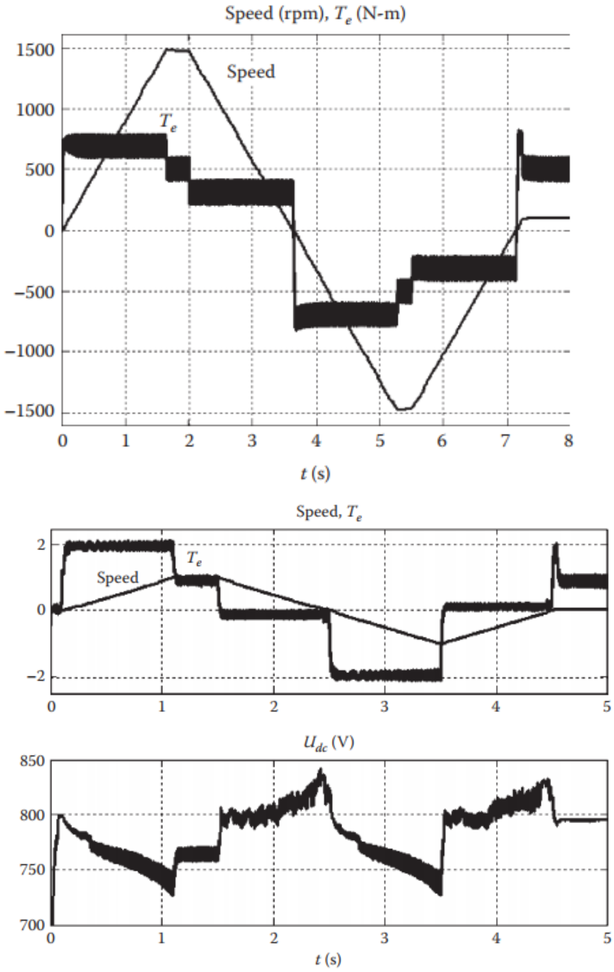


Figure 5: Speed of induction motor with varying load under DTC

Figure 5 illustartes the speed of induction motor under varying load condition and speed profile while controlled using direct torque control scheme

Conclusion

This paper provides a mathematical modelling and simulation analysis of direct torque control of 3-phase induction motor. Detailed analysis has been provided with an illustrative example. Direct torque control maintains suitable speed and flux for 3-phase induction motor.

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