Direct Torque Control of Induction Motor

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Abstract

Induction motors are the most widely used motor drives in industries because of their simple construction and other advantages such as reliable operation, low initial cost, easy operation and simple maintenance, high efficiency and having simple control gear for starting and speed control. This usefulness of the induction motor has resulted into a lot of research including the transient behavior of the machine. This paper presents a MATLAB/ SIMULINK model depicting the implementation of direct torque control strategy with an induction motor.

Keywords: *Direct torque control, self control, induction motor drives*

1. Introduction

In the mid- 1980s, an advanced scalar control technique, known as direct torque and flux control [DTFC or DTC] or direct self control (DSC), was introduced for voltage- fed PWM inverter drives. The technique was claimed to have nearly comparable performance with vector- controlled drives. The scheme, as the name indicates, is the direct control of torque and stator- flux of a drive by inverter voltage space vector selection through a lookup table [1].

The basic principle of DTC is to directly select stator voltage vectors according to the differences between the reference and actual torque and stator- flux linkage. The DTC possesses advantages such as lesser parameter dependence [stator resistance, only for PMSM] and fast torque response when compared with the torque control via PWM current control [2].

Direct torque control (DTC) is one method used in electric- drives to control the torque (and thus finally the speed) of the three- phase AC electric motors. This involves calculating an estimate of the motor's magnetic flux and torque based on the measured voltage and current of the motor.

The model makes use of an induction motor in arbitrary reference frame referred to stationary reference frame which acts as an advantage to the strategy at large.

The torque and stator flux of the induction motor are compared and digitized in order to feed the voltage to the induction motor.

Using DTC or DSC it is possible to obtain a good dynamic control of the torque without any mechanical transducers on the machine shaft. Thus, DTC and DSC can be considered as "sensor less type" control techniques [3].

The basic scheme of DSC is preferable in the high power range applications, where a lower inverter switching frequency can justify higher current distortion. In this paper, the attention will be mainly focused on the basic DTC- scheme, which is more suitable in the small and medium power range applications [3].

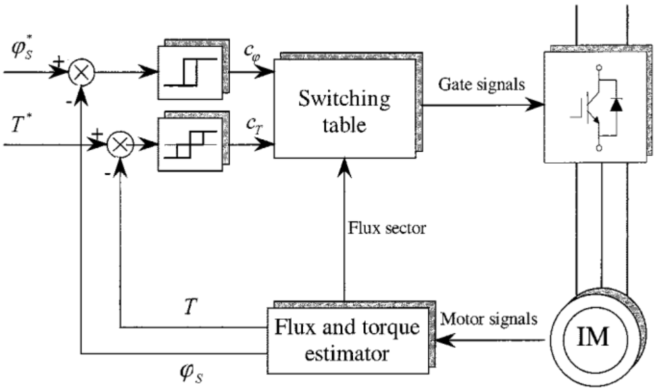

Figure 1: Basic DTC scheme

The name direct torque control is derived by the fact that, on the basis of the errors between the reference and the estimated values of torque and flux, it is possible to directly control the inverter states in order to reduce the torque and flux errors within the prefixed band limits [3].

Unlike FOC, DTC doesn't require any current regulator, co-ordinate transformation and PWM signals generator. In spite of its simplicity, DTC allows a good torque control in steady-state and transient operating conditions to be obtained [3].

2. Dynamic Equations of Induction Motor

The induction motor in arbitrary reference frame can be represented by the following equations [1]:-

$$V_s = R_s i_s + \frac{1}{\omega_0}\frac{df_s}{dt} + \omega_k M f_s \quad (1)$$

$$V_r = R_r i_r + \frac{1}{\omega_0}\frac{df_r}{dt} + (\omega_k - \omega_m) M f_r \quad (2)$$

Where the variables i, v & f are two- dimensional space- vectors.
ω_k: Arbitrary reference frame speed
ω_m : Rotor speed
$M = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$

3. Basic DTC Principle

The basic principle for the direct torque control of induction motor is shown in figure 1 [3].

The error between the estimated torque and the reference torque is the input of a three level hysteresis comparator, whereas the error between the estimated stator flux magnitude and the reference stator flux magnitude is the input of a two level hysteresis comparator.

Figures 2 and 3 illustrate the torque and flux comparators, respectively [3].

The selection of the appropriate voltage vector is based on the switching table given in Table I [1].The input quantities are the stator flux sector and the outputs of the two hysteresis comparators.

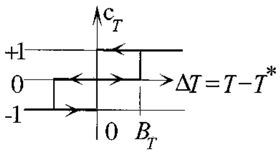

Figure 2: Torque hysteresis comparator

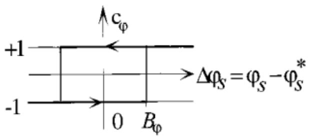

Figure 3: Flux hysteresis comparator

This simple approach allows a quick torque response to be achieved, but the steady-state performance is characterized by undesired ripple in current and torque [1, 3].

The flux- estimator is obtained from the relation between flux and motor currents as [1]:

$$f_{(d,q)s} = L_s i_{(d,q)s} + L_m i_{(d,q)r} \tag{3}$$

$$f_{(d,q)r} = L_r i_{(d,q)r} + L_m i_{(d,q)s} \tag{4}$$

where $L_s = L_m + L_{sl}$
$L_r = L_m + L_{rl}$
L_{rl}: *Leakage Inductance*

The electromagnetic torque of the motor is obtained as [1]:

$$\begin{aligned} T_e &= f_s \times i_s && (5)\\ &= |\vec{f_s}||\vec{i_s}| && (6)\\ &= f_s \cdot i_s \cdot M && (7)\\ &= \left(\frac{3}{2}\right)\frac{P}{2} \times \left(f_{ds} i_{qs} - f_{qs} i_{ds}\right) && (8)\\ &= 0.75\, P\, |f_s \cdot i_s|\, M && (9) \end{aligned}$$

The mechanical system is represented as [1]:

$$\omega_m = \frac{1}{J}\int (T_e - T_l - B\omega_m)dt \tag{10}$$

The sector is selected as:

$$\theta_s = \begin{cases} \tan^{-1}\frac{f_{qs}}{f_{ds}} & >0 \\ 2\pi + \tan^{-1}\frac{f_{qs}}{f_{ds}} & <0 \end{cases} \tag{11}$$

4. Simulation Results

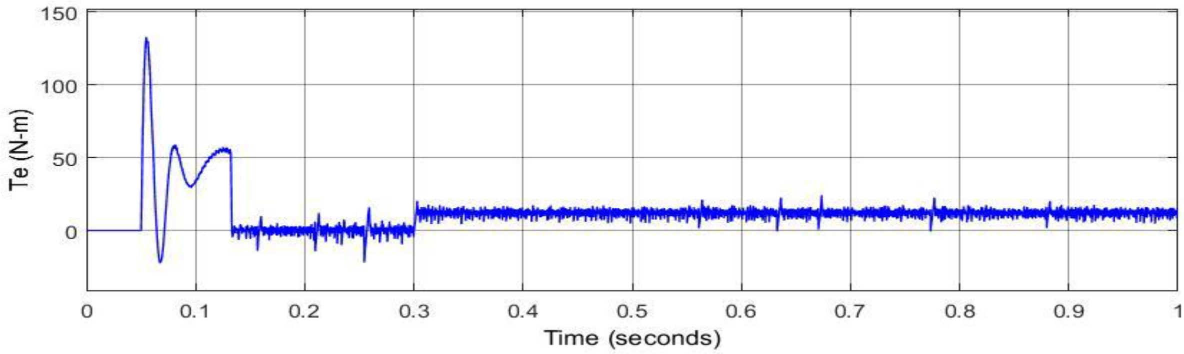

Figure 4: Electromagnetic Torque of Induction Motor

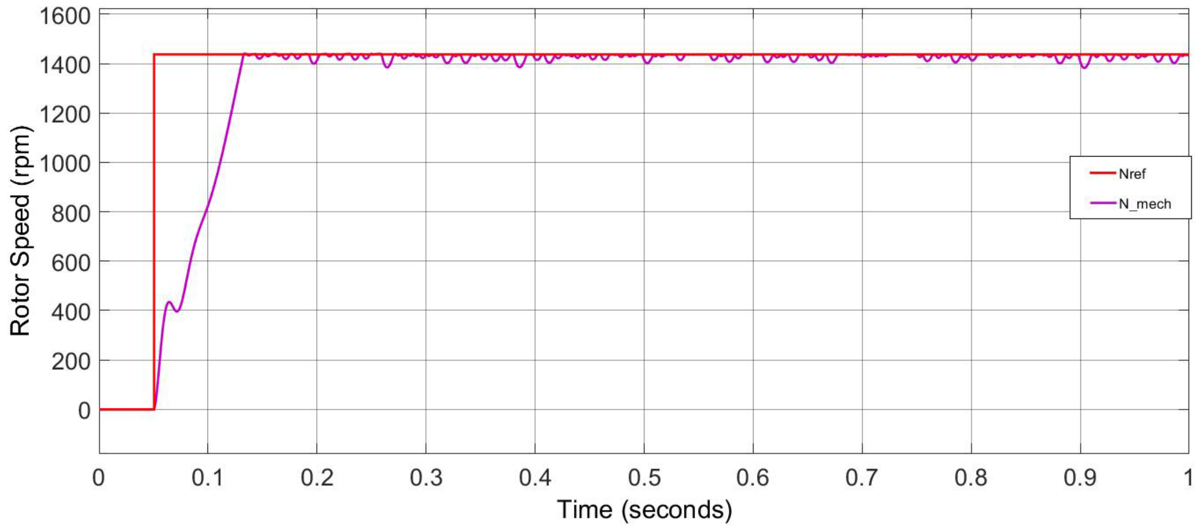

Figure 5: Reference and Rotor Speeds of Induction Motor

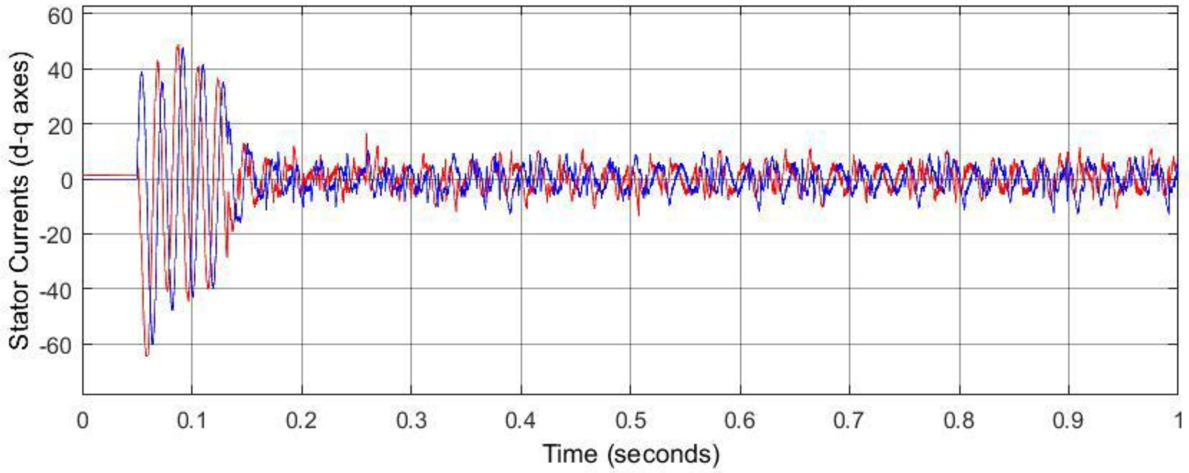

Figure 6: Stator Currents (d and q axes) of Induction Motor

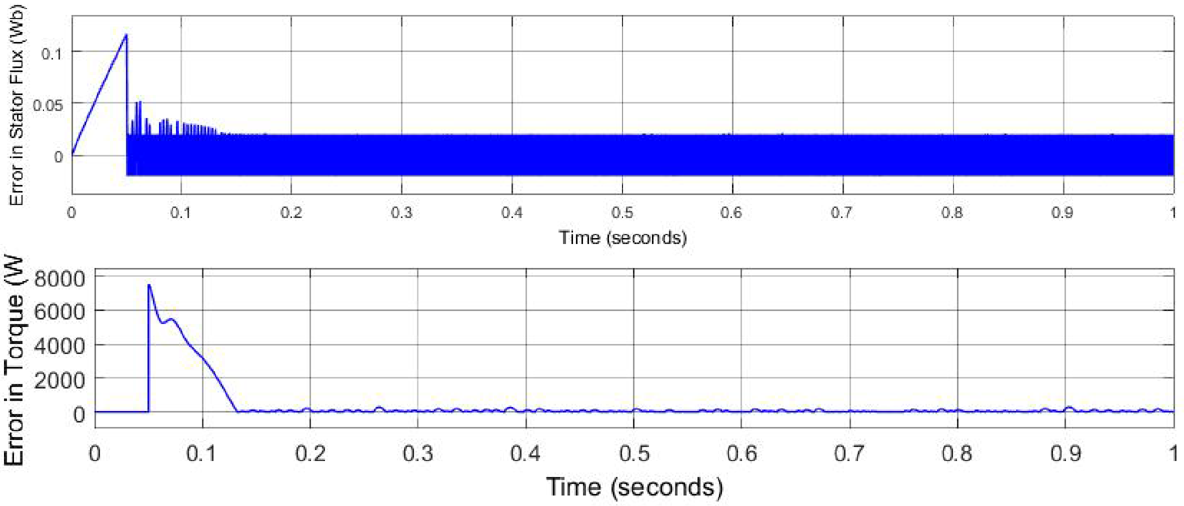

Figure 7: Flux and Torque Errors

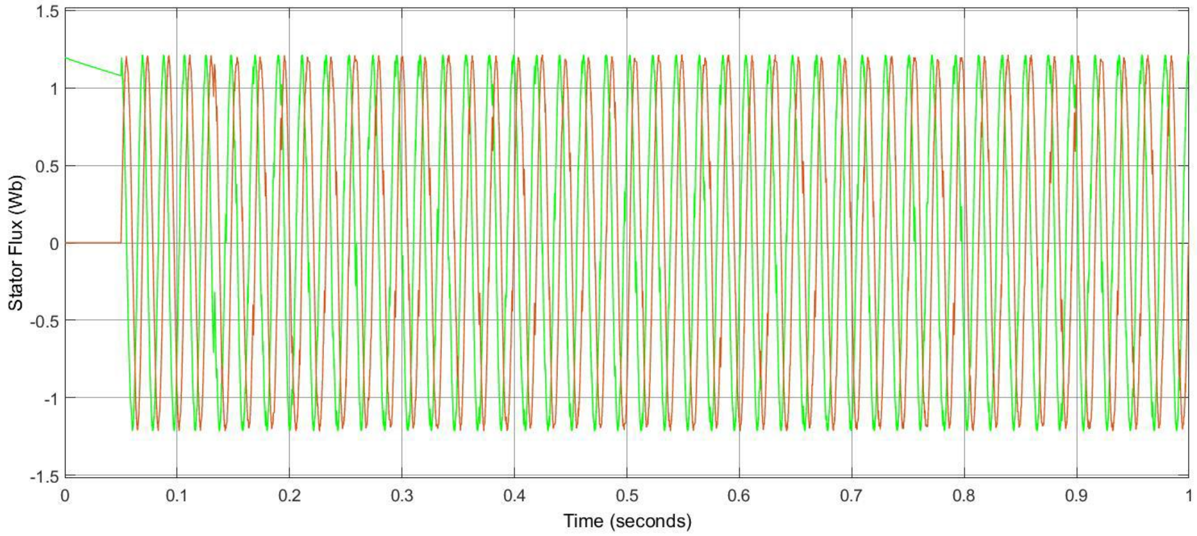

Figure 8: Stator flux (Wb) of Induction Motor

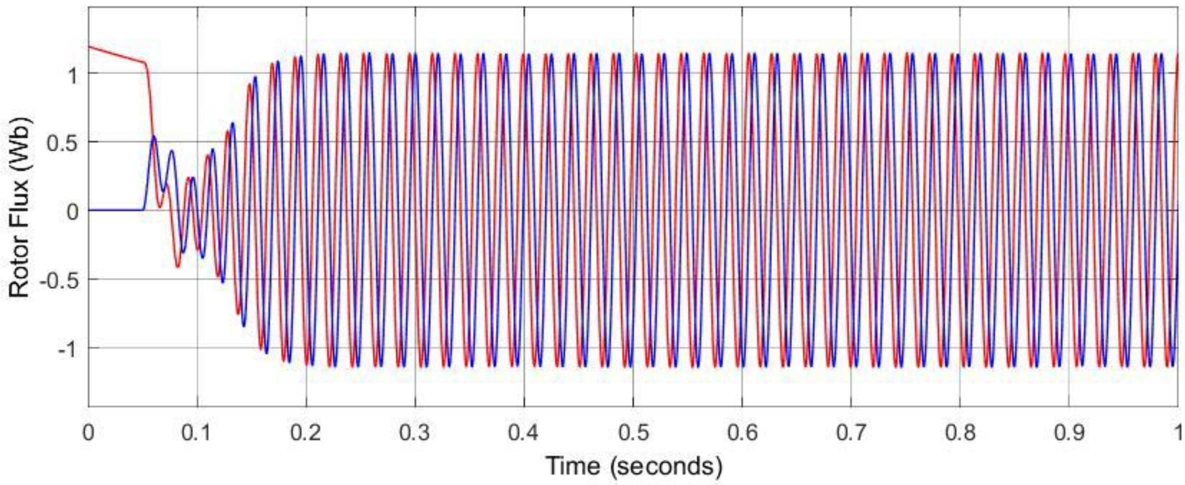

Figure 9: Rotor flux (Wb) of Induction Motor

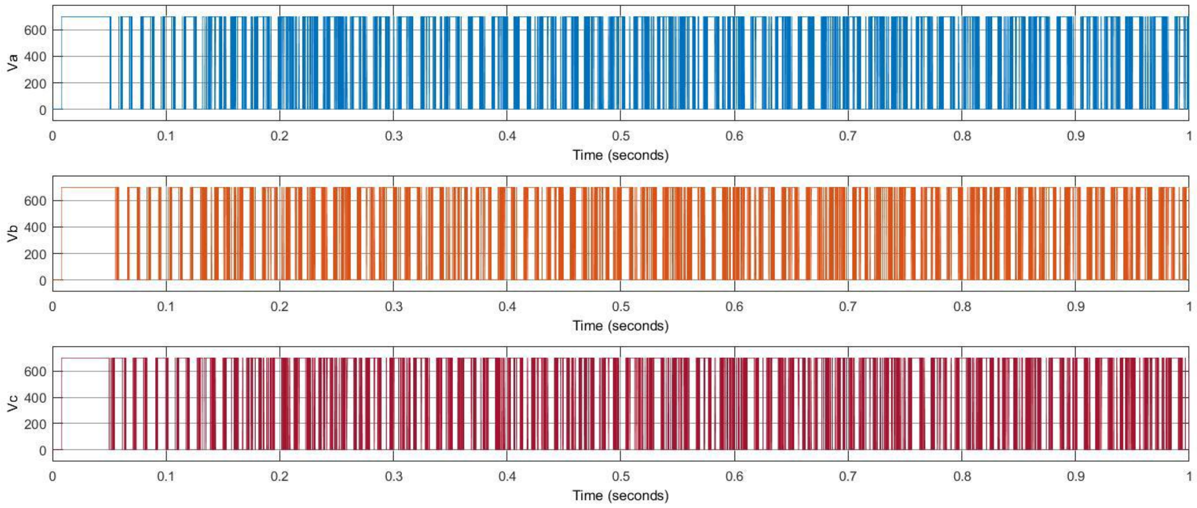

Figure 10: Stator Voltages (a, b and c) of Induction Motor

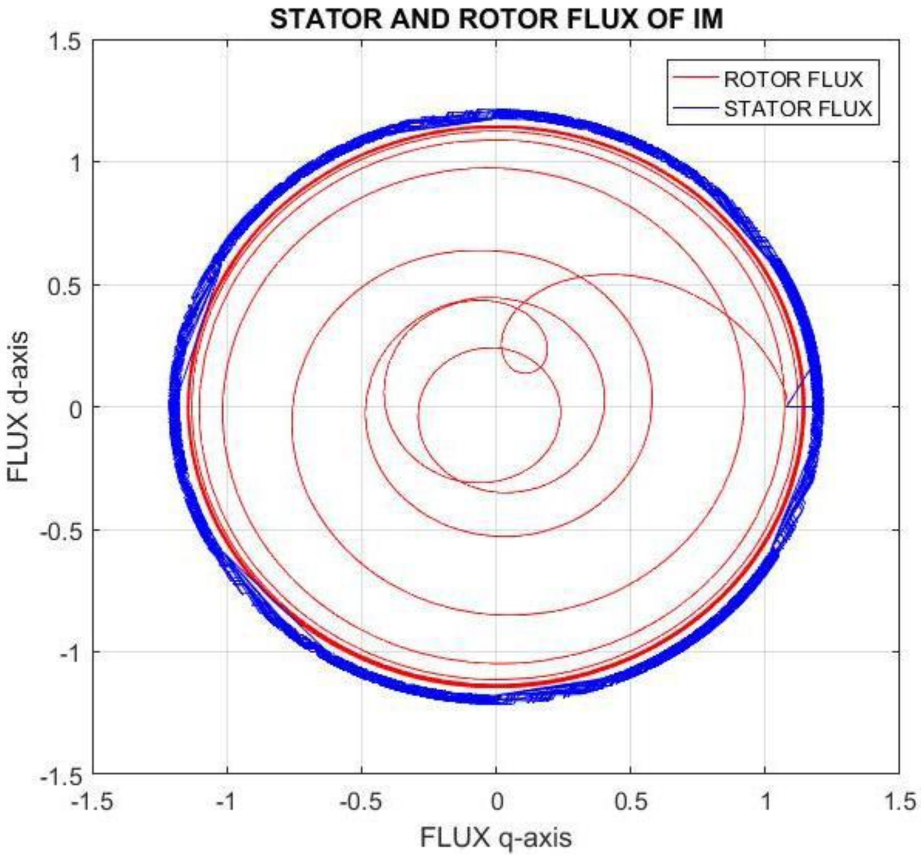

Figure 11: Stator and Rotor fluxes of Induction Motor

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