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Combined vector control and direct torque control method for high performance induction motor drives

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Abstract

A new control method is proposed for three phase high performance induction motor drives. The control system enjoys the advantages of vector control and direct torque control and avoids some of the implementation difficulties of either of the two control methods. In particular, the proposed control system includes a current vector control in connection with a switching table. An extensive comparative performance evaluation of a motor under the proposed control method confirms the effectiveness of the method and its partial superiority over either vector control or direct torque control despite its relative structural simplicity.

Keywords: Induction machine; Motor drive; Vector control; Direct torque control

1. Introduction

Control of high performance AC motor drives has reached a high level of maturity based on two competing methods, i.e. vector control (VC) and direct torque control (DTC), introduced in the early 1970s and mid-1980s, respectively, [1,2]. Both methods include many different schemes now and provide excellent performance characteristics of AC motors in terms of fast dynamics and accurate steady state operation [3,4]. Despite these similarities, VC and DTC differ substantially in the way they are implemented. Also, the details of the motor drive performances, like torque and flux pulsations and inverter switching frequency, are quite different, at least in the original VC and DTC schemes. More importantly, the principles of the two methods are far apart. These differences have mainly been the focus of comparative analysis of the VC and DTC presented in the literature so far [5–9]. The motor characteristics, including torque, speed and current, under the two methods and the influences of stator and rotor resistances variations are compared [5]. The performances of the two methods in a specific application, electric vehicle, are presented [6]. A comparison of the two methods, including the effects of inaccuracy in flux estimation, is provided [7]. The motor characteristics and their pulsations are also investigated [8,9]. The comparisons of VC and DTC are performed mostly by focusing on performance analysis.

This paper, on the other hand, is focused on the comparison of VC and DTC by looking for their principle similarities and searching for a fundamental common basis as the main cause of their performances swiftness and accuracy. From this common basis, a new control method is proposed for three phase high performance induction motor drives. A brief overview of VC and DTC is presented in Section 2 by recalling their operation principles. Then, the common basis of the two control methods is investigated in this section by an in depth analysis. The proposed control system and its basic idea are presented in Section 3. In Section 4, an extensive performance analysis of a typical induction motor under the three methods is presented comparatively by computer simulation. The results confirm the

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partial superiority of the new method over either VC or DTC.

2. Principles of VC and DTC and search for a common basis

2.1. Vector control

Vector control is performed in different schemes [10]. However, in all schemes, the machine torque and flux linkage are controlled through stator current vector control. The current vector is decomposed into a torque and flux producing components in a rotating reference frame, e.g. i_{ds} and i_{qs}, respectively. The former component is along a machine flux linkage vector, and the latter component is perpendicular to the former as depicted in Fig. 1 in a rotor flux reference frame. This decouples the torque control from the flux control as the torque is obtained as

$$T_{\mathrm{e}} = \frac{3}{2} n_{\mathrm{P}} \frac{L_{\mathrm{m}}}{L_{\mathrm{r}}} (\psi_{d\mathrm{r}} i_{qs} - \psi_{q\mathrm{r}} i_{ds}), \tag{1}$$

where n_{p}, L_{m} and L_{r} represent the number of pole pairs, the magnetizing inductance and the rotor inductance. Also, $\psi_{q\mathrm{r}}$ and $\psi_{d\mathrm{r}}$ stand for the quadratic axis and direct axis rotor flux linkage components. Since the d axis flux vanishes, the torque equation is simplified to

$$T_{\mathrm{e}} = \frac{3}{2} n_{\mathrm{P}} \frac{L_{\mathrm{m}}}{L_{\mathrm{r}}} (\psi_{d\mathrm{r}} i_{qs}), \tag{2}$$

where

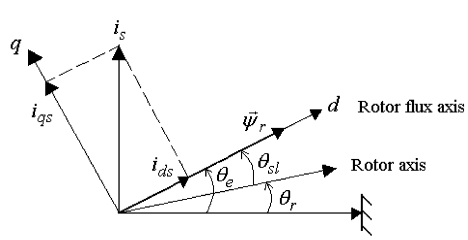

Fig. 1. Principles of vector control.

$$\psi_{d\mathrm{r}} = L_{\mathrm{m}} i_{d\mathrm{s}}. \tag{3}$$

By taking i_{ds} = constant, the torque linearly depends on i_{qs}, providing a torque response as fast as the current (i_{qs}) response. The following stator and rotor voltage and flux linkage equations also hold for an induction machine

$$\vec{V}_{\mathrm{s}} = R_{\mathrm{s}} \vec{i}_{\mathrm{s}} + \frac{\mathrm{d}\vec{\psi}_{\mathrm{s}}}{\mathrm{d}t}, \tag{4}$$

$$0 = R_{\mathrm{r}} \vec{i}_{\mathrm{r}} + \frac{\mathrm{d}\vec{\psi}_{\mathrm{r}}}{\mathrm{d}t} - \mathrm{j}\omega_{\mathrm{m}} \vec{\psi}_{\mathrm{r}}, \tag{5}$$

$$\vec{\psi}_{\mathrm{s}} = L_{\mathrm{s}} \vec{i}_{\mathrm{s}} + L_{\mathrm{m}} \vec{i}_{\mathrm{r}}, \tag{6}$$

$$\vec{\psi}_{\mathrm{r}} = L_{\mathrm{m}} \vec{i}_{\mathrm{s}} + L_{\mathrm{r}} \vec{i}_{\mathrm{r}}. \tag{7}$$

Fig. 2 shows a block diagram of a typical vector controlled induction motor drive.

2.2. Direct torque control

In a DTC motor drive, the machine torque and flux linkage are controlled directly without a current control. The principles of DTC can be explained by looking at the following torque and current equations of an induction machine:

$$T_{\mathrm{e}} = \frac{3}{2} n_{\mathrm{P}} \mathrm{Im}\{\vec{\psi}_{\mathrm{s}}^{*} \vec{i}_{\mathrm{s}}\}, \tag{8}$$

$$\vec{i}_{\mathrm{s}} = \frac{1}{\sigma L_{\mathrm{s}}} \vec{\psi}_{\mathrm{s}} - \frac{L_{\mathrm{m}}}{\sigma L_{\mathrm{s}} L_{\mathrm{r}}} \vec{\psi}_{\mathrm{r}}, \quad \left(\sigma = 1 - \frac{L_{\mathrm{m}^2}}{L_{\mathrm{s}} L_{\mathrm{r}}}\right). \tag{9}$$

Substituting Eq. (9) in Eq. (8) yields

$$T_{\mathrm{e}} = \frac{3}{2} n_{\mathrm{P}} \frac{L_{\mathrm{m}}}{\sigma L_{\mathrm{s}} L_{\mathrm{r}}} |\vec{\psi}_{\mathrm{s}}||\vec{\psi}_{r}| \sin\beta, \tag{10}$$

where β is the angle between the stator and rotor flux linkage vectors [4]. The derivative of Eq. (10) can be represented approximately as

$$\frac{\mathrm{d}T_{\mathrm{e}}}{\mathrm{d}t} = \frac{3}{2} n_{\mathrm{p}} \frac{L_{\mathrm{m}}}{\sigma L_{\mathrm{s}} L_{\mathrm{r}}} |\vec{\psi}_{\mathrm{s}}||\vec{\psi}_{\mathrm{r}}| \frac{\mathrm{d}\beta}{\mathrm{d}t} \cos\beta. \tag{11}$$

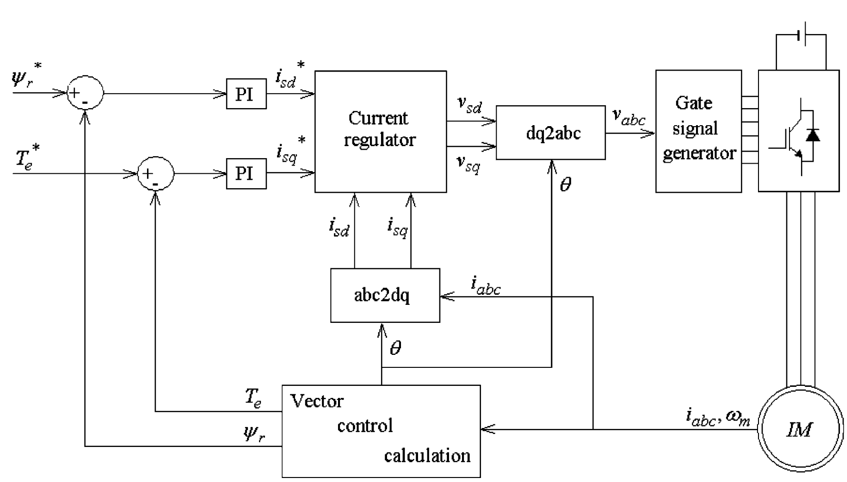

Fig. 2. Block diagram of a vector controlled induction motor drive.