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ScienceDirect
Energy Conversion and Management 49 (2008) 687–697
ENERGY CONVERSION & MANAGEMENT
www.elsevier.com/locate/enconman

Digital simulation and hardware implementation of a simple scheme for direct torque control of induction motor

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Received 28 April 2006; received in revised form 16 December 2006; accepted 31 July 2007
Available online 14 September 2007

Abstract

A simple scheme that allows fast control of induction motor torque has been presented. It is different from the conventional direct torque control (DTC) scheme in the sense that it does not use the popular DTC switching table. Also, it does not require use of any online fast computing device like a microprocessor, personal computer (PC) or digital signal processor (DSP). The proposed scheme uses only commonly used discrete hardware components for its implementation. The experimental results obtained from the hardware realization of the proposed scheme are found to be in close agreement with the simulation results.

Keywords: Electric drive; Induction motor drive; Inverter control; Direct torque control; Electric machines; Digital simulation; Hardware realization

1. Introduction

High performance variable speed drives have become indispensable for modern age industry where the product quality and productivity are of utmost importance. Earlier, dc motors were used to meet the high performance requirements because they offered faster control over torque production and drive speed than their ac counterparts. Because of the many drawbacks of these dc drives, recent research attention has been focused on ac drives, mainly induction motor drives. AC drives have evolved over the years with improved transient torque output response that closely matches the response obtained from dc drives [1]. A significant milestone was achieved during the early 1970s when Blaschke [2] presented an innovative method of torque and speed control for induction motors called 'field-oriented control' (FOC). Another milestone came towards the end of the 1980s when Takahashi and Noguchi [3] proposed 'direct torque control', or DTC, of the induction motor. Around the same time, Depenbrock [4] proposed a similar technique called 'direct self control', or DSC. The DSC and DTC schemes are essentially identical, the finer difference lying only in their implementation algorithm. Unlike the FOC scheme, the DTC and DSC schemes are easy to implement because complex co-ordinate transformations and rotor position sensors are not required [5]. Moreover, the DTC and DSC schemes do not depend on machine parameter variations except for the minor variation in stator resistance [6]. Because of this implementation simplicity, the DTC (or, for that matter, DSC) scheme for induction motors has drawn the attention of researchers worldwide [7,8].

All these DTC related works [9] use relatively costly digital signal processors with fast interfacing units like analog to digital (A/D) converters, etc. Although the advantages of digitally controlled drives in terms of flexibility and user friendliness are quite significant, their increased cost may limit their use to high end drives where the controller cost may be only a small fraction of the overall drive cost. Another factor coming in the way of these digitally controlled drives is the delay in inputting the analog values

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0196-8904/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enconman.2007.08.001

of the motor currents and the inverter dc link voltage during the PC (or, for that matter, DSP) based DTC implementation. For example, the typical value of this delay in a DSP based implementation [10] is around 100 μs. This delay is partly due to the inherent delay in the A/D conversion process and partly due to the serial manner in which data is input through a single A/D converter by multiplexing the input line. The overall delay in program execution time severely limits the achievable PWM (pulse width modulation) frequency of the inverter, and thus, the ripple in motor flux, current and torque may not be reduced below certain limits. To achieve higher PWM switching frequency, one may be forced to use higher speed digital processors with multiple A/D converters of faster capability that increases the cost further.

The work presented in this paper investigates a hardware alternative to reduce the overall cost as well as to achieve higher PWM switching frequency. The entire control scheme is implemented using low cost, commonly available, discrete electronic components. The developed hardware is expected to find application in numerous low and medium power induction motor drives in small scale industries (e.g. packaging industries) where consideration of controller cost may be a significant factor in choosing the drive. In the hardware based control scheme described here for fast control of induction motor torque, the popular DTC switching table [11,12] has been discarded. The frequency, magnitude and shape of the stator linked flux are directly controlled. The flux shape is kept sinusoidal, and its magnitude is kept equal to the rated flux magnitude for operation below base speed. The torque controller, realized using discrete hardware components, decides the dynamic frequency of the stator linked flux without using any digital computing device like a PC or DSP.

The controller in this scheme generates quadrature (q) and direct (d) axes components of the stator reference flux vector in the stationary frame of reference. The magnitude of the stator reference flux vector is kept constant for operation below base speed. For increased torque demand, the spatial flux speed needs to be accelerated, while it needs to be retarded to get less torque. The spatial speed will remain unchanged if the torque error is within the defined error band. For constant magnitude of the stator flux rotating at constant speed, the 'd' and 'q' components of flux will be sinusoidal and in phase quadrature. The proposed torque controller is able to effect the change in the spatial position of the stator flux vector fast in comparison to the rotor flux space vector and, thus, achieves dynamic control over the motor torque. The novelty of the controller lies in its simplicity as well as in the elimination of the need for the sector calculator and switching table formulation as required in a conventional DTC scheme. Here, no software based control is necessary. The simulation and experimental results of the proposed scheme are found to be in close agreement, thereby indicating the feasibility of the proposed scheme in giving fast control over induction motor torque.

2. The proposed torque control scheme

The new scheme proposed in this paper has been shown in block diagram form in Fig. 1. The motor terminal voltages and line currents are measured with the help of voltage and current sensors. The three phase terminal voltages v_{ab}, v_{bc}, v_{ca} and stator currents i_{as}, i_{bs}, i_{cs} are transformed to two phase (stationary d, q) voltages v_{qs}, v_{ds} and currents i_{qs}, i_{ds} using the principle of amplitude invariant transformation [13] as shown in Eqs. (1)–(4) below.

$$v_{qs} = v_{an} = \frac{2}{3}v_{ab} + \frac{1}{3}v_{bc} \tag{1}$$

$$v_{ds} = \frac{1}{\sqrt{3}}(-v_{bc}) \tag{2}$$

$$i_{qs} = i_{as} \tag{3}$$

$$i_{ds} = \frac{1}{\sqrt{3}} \cdot (i_{cs} - i_{bs}) \tag{4}$$

The stator resistance drops along the dq axes are then subtracted from the corresponding two phase dq terminal voltages, and the resultant quantities are integrated [14,15] to get the resultant flux linkage components ψ_{qs}, ψ_{ds} along the two phase stationary d and q axes as per the following Eqs. (5) and (6).

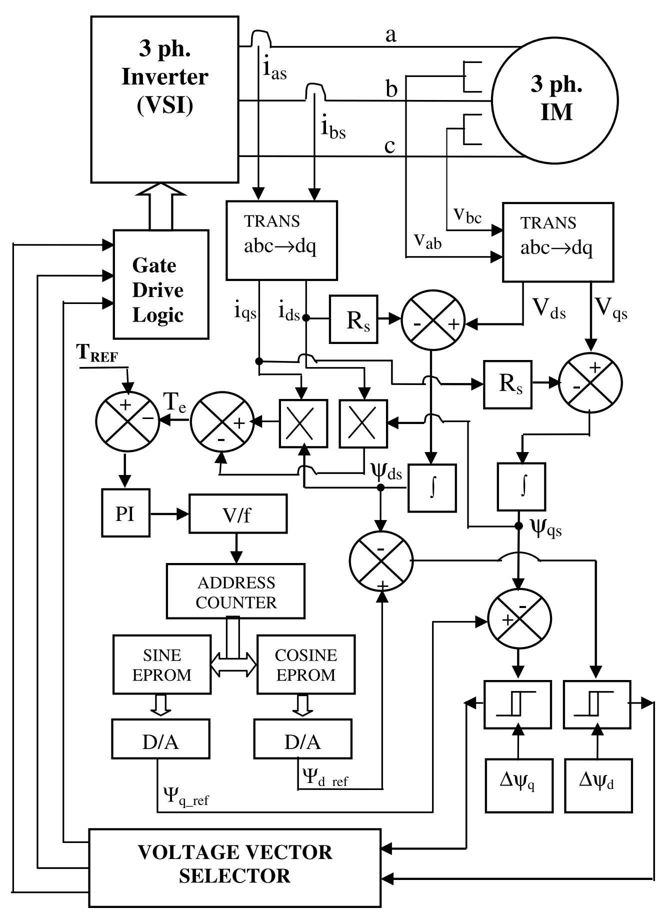

Fig. 1. Block diagram of the proposed scheme.