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A novel sliding-mode control of induction motor using space vector modulation technique

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Abstract

This paper presents a novel sliding-mode control method for torque control of induction motors. The control principle is based on sliding-mode control combined with space vector modulation technique. The sliding-mode control contributes to the robustness of induction motor drives, and the space vector modulation improves the torque, flux, and current steady-state performance by reducing the ripple. The Lyapunov direct method is used to ensure the reaching and sustaining of sliding mode and stability of the control system. The performance of the proposed system is compared with those of conventional sliding-mode controller and classical PI controller. Finally, computer simulation results show that the proposed control scheme provides robust dynamic characteristics with low torque ripple. © 2005 ISA—The Instrumentation, Systems, and Automation Society.

Keywords: Sliding-mode control; Induction motor; Space vector modulation

1. Introduction

The induction motor is widely used in industry, mainly due to its rigidness, maintenance-free operation, and relatively low cost. In contrast to the commutation dc motor, it can be used in aggressive or volatile environments since there are no risks of corrosion or sparks. However, induction motors constitute a theoretically challenging control problem since the dynamical system is nonlinear, the electric rotor variables are not measurable, and the physical parameters are most often imprecisely known. The control of the induction motor has attracted much attention in the past few decades; especially the speed sensorless control of induction motors has been a popular area due to its low cost and strong robustness [1].

Classical PI controller is a simple method used in control of induction motor drives. However, the main drawbacks of PI controller are the sensitivity of performance to the system-parameter variations and inadequate rejection of external disturbances and load changes [2,3]. Sliding-mode control (SMC) is a robust control since the high gain feedback control input suppresses the influence of the disturbances and uncertainties [4]. Due to its order reduction, good disturbance rejection, strong robustness, and simple hardware/software implementation by means of power inverter, SMC has attracted much attention in the electric drive industry, and becomes one of the prospective control methodologies for induction motor drives [5]. The applications of SMC to electric motors have been previously investigated by Utkin in Refs. [4,5], where the author gives the basic concepts, mathematics, and design aspects of variable structure systems, as well as sliding mode as a principle operation mode.

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Various SMC techniques for induction motors have been proposed in many literatures. The linearization SMC techniques were suggested in Refs. [2,6,7]. Linear reference models or input-output linearization techniques were used in the control of the nonlinear systems. A fuzzy SMC method was developed in Ref. [3]. SMC acts in a transient state to enhance the stability, while fuzzy technique functions in the steady state to reduce chattering. In Refs. [8–10], the Lyapunov direct method is used to ensure the reaching and sustaining of the sliding mode. These SMC methods result in a good transient performance, sound disturbance rejection, and strong robustness in a control system. However, the chattering is a problem in SMC and causes the torque, flux, and current ripple in the systems. In Ref. [9], sliding-mode concepts were used to implement pulse width modulation (PWM). This implementation method is simple and efficient by means of power inverter since both implementation of SMC and PWM imply high-frequency switching. However, this method causes severe ripple in the torque signal due to the irregular logic control signals for inverter. To overcome this problem, an rms torque-ripple equation was developed in Ref. [11] to minimize torque ripple. In Ref. [12], a direct torque control (DTC) is combined with space vector modulation (SVM) techniques to improve the torque, flux, and current steady-state wave forms through ripple reduction.

With the development of microprocessors, the SVM technique has become one of the most important PWM methods for voltage source inverter (VSI). It uses the space vector concept to compute the duty cycle of the switches. It simplifies the digital implementation of PWM modulations. An aptitude for easy digital implementation and wide linear modulation range for output line-to-line voltages are the notable features of SVM [13,14]. Thus SVM becomes a potential technique to reduce the ripple in the torque signal.

This paper presents a new sliding-mode controller for torque regulation of induction motors. This novel control method integrates the speed sensorless SMC with the SVM technique. It replaces the PWM component in the conventional SMC with the SVM so that the torque ripple of induction motors is effectively reduced while the robustness is ensured at the same time.

The paper is organized as follows. The dynamic model of induction motor is given in Section 2 and SVM techniques in induction motor drives are discussed in Section 3. Details of sliding-mode controller design are given in Section 4, while the simulation results are presented in Section 5. Finally, some concluding remarks are given in Section 6.

2. Dynamic model of induction motor

A three-phase induction motor with squirrel-cage rotor is considered in the paper. Assuming that three-phase ac voltages are balanced and stator windings are uniformly distributed and based on the well-known two-phase equivalent motor representation, the nonsaturated symmetrical induction motor can be described in the fixed coordinate system (α,β) by a set of fifth-order nonlinear differential equations with respect to rotor velocity ω, the components of rotor magnetic flux ψ_α, ψ_β, and of stator current i_α, i_β [4]:

$$\frac{d\psi_\alpha}{dt} = -\frac{R_r}{L_r}\psi_\alpha - \omega\psi_\beta + R_r\frac{L_m}{L_r}i_\alpha,$$

$$\frac{d\psi_\beta}{dt} = -\frac{R_r}{L_r}\psi_\beta + \omega\psi_\alpha + R_r\frac{L_m}{L_r}i_\beta,$$

$$\frac{di_\alpha}{dt} = \frac{L_r}{L_sL_r - L_m^2}\left(-\frac{L_m}{L_r}\frac{d\psi_\alpha}{dt} - R_si_\alpha + u_\alpha\right),$$

$$\frac{di_\beta}{dt} = \frac{L_r}{L_sL_r - L_m^2}\left(-\frac{L_m}{L_r}\frac{d\psi_\beta}{dt} - R_si_\beta + u_\beta\right),$$

$$\frac{d\omega}{dt} = \frac{P}{J}(T - T_L),$$

$$T = \frac{3P}{2}\frac{L_m}{L_r}(i_\beta\psi_\alpha - i_\alpha\psi_\beta), \tag{1}$$

where ω is the electrical rotor angle velocity; $\psi = [\psi_\alpha\psi_\beta]^T$, $i=[i_\alpha i_\beta]^T$, and $u=[u_\alpha u_\beta]^T$ are rotor flux, stator current, and stator voltage in (α,β) coordinate, respectively; T and T_L are the torque of motor and load torque; J is the inertia of the rotor; P is the number of pole pairs. R_r and R_s are rotor and stator resistances, L_r and L_s are rotor and stator inductances, and L_m is the mutual inductance.