

# A novel speed estimation algorithm for induction machines

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## Abstract

In this paper, a novel speed estimation algorithm mathematically derived from current model of an induction motor is presented. The method used here is more advantageous than other techniques due to its simplicity. In this technique, since the speed varies slowly as compared to electrical variables such as currents and fluxes, the speed is assumed to be an unknown constant. Based upon this assumption, a definition of a new speed estimator is reported and its performance is confirmed experimentally.

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## 1. Introduction

In the last two decades, with the advent of powerful and cheap computer processors and the development of advanced control methodologies, induction motors have been adopted for applications that require variable speed and high performance. Such applications including electric propulsion systems have so far relied on DC motors. Interest to the induction motor is increasing due to its lower cost and greater durability compared to the DC motor. In particular, these advantages make it one of the most viable candidates for the propulsion of electric vehicles, which demand high performance, low cost and reliability. These objectives encountered in many applications of the induction motor are one of the challenging subjects in control community.

Sensorless control of induction motors is now attracting wide attention, not only in the field of electrical drive but also in the field of dynamic control. Sensorless control refers to the problem of controlling an induction motor without using a position or speed sensor. The shaft sensor issue is of utmost concern to the electric vehicle industry as it represents a significant cost as well as a reliability issue. However, even if a shaft sensor is used, one can foresee the need for a control algorithm that is capable of tolerating the failure of the sensor. A disadvantage of existing high performance control algorithms for induction motors is that they require a shaft sensor to estimate the rotor fluxes. Achieving

performance despite the unavailability of a shaft sensor constitutes a current research topic. Different methods to solve this problem can be found in Ref. [1]. Most of them are purely based on machine flux model. There are in general two flux based methods, voltage and current model of induction machine. In the literature, generally both voltage and current models of induction machine have been used together for flux estimation and then from those speed has been estimated [1–3]. Both current and voltage models of induction machine are needed to get flux information. Those methods imply the estimation of the time-derivative with subsequent integration. However, implementation of an integrator for motor flux estimation is no easy task. A pure integrator has DC drift and initial value problems. To solve the problems, the pure integrator has replaced by a low-pass filter (LPF). To estimate exactly stator flux in a wide speed range, the LPF should have a very low cutting frequency. However, there still remains the drift problem due to the very large time constant of the LPF. A digital filter has been proposed to solve the drift problem [4] and a programmable-cascaded LPF to solve the drift problem and to estimate exactly stator flux [5,6]. In Refs. [3,5,7], open loop observer structures based on voltage model of the induction motor are proposed and integration problem is attempted to be avoided by using different programmable and/or digital LPF structures. The proposed programmable LPF has phase compensator to estimate exactly stator flux and

solves the DC drift problem associated with a pure integrator and a LPF in a wide speed range. Hu and Wu [8] have proposed three new integration algorithms for motor flux estimation to be used in high performance sensorless AC motor drives. The proposed algorithms solve the problems associated with pure integrators.

Another approach to the sensorless control problem is to consider the speed as an unknown constant parameter and to use the techniques of adaptive control to estimate this parameter [9–11]. The idea here is that the speed changes slowly compared to the electrical variables. This approach has been first formulated by Shauder [12] and with some modification introduced by Peng and Fukao [10]. In Refs. [13–15], the authors have approached the sensorless control problem from a parameter identification point of view. The idea is to consider the speed as an unknown constant parameter and to find out the value of the estimated speed that best fits the measured and calculated data of dynamic equations of the motor. In Refs. [16,17], a method has been proposed to estimate the speed and flux of an induction motor without assuming that the speed is slowly varying compared to the electrical variables. Their approach uses a polar coordinate model of the fluxes rather than the cartesian coordinates model.

Sliding mode control theory, due to its order reduction, disturbance rejection, strong robustness and simple implementation by means of power converter, is one of the prospective control methodologies for electrical machines. The basic concepts and principles of sliding mode control of electrical drives have been demonstrated in Ref. [18] and some aspects of the implementation have been illustrated in Ref. [19]. Furthermore, sliding mode observers [19,21–23] have been proposed for estimating the states of the control system. Sliding mode observers also have the same robust features as the sliding mode controllers. Zaremba [21] has suggested a sliding mode speed observer in d–q coordinate with stability and robustness analysis for the system with constant speed. Benchaib et al. [24] have introduced a control and observation of an induction motor using sliding mode technique. The observer model is a copy of the original system, which has corrector gains with switching terms. Parasiliti et al. [25] have presented an adaptive sliding mode observer for sensorless field oriented control of induction motors. The observer detects the rotor flux components in the stationary reference frame by using motor mechanical equations. An additional relation obtained by a Lyapunov function has identified the motor speed. Zheng et al. [26] have used a singularly perturbed model to design a sliding mode observer. An adaptive flux observer on the sliding surface has been developed using the equivalent switching vector. Lin et al. [27] have introduced a comparative

study of sliding mode and model reference adaptive speed observer for a speed sensorless control of induction motor.

In this paper, a new sliding mode current observer for an induction motor is developed. Sliding mode functions are chosen to determine the rotor speed of an induction motor in which the idea is based on the assumption that the speed is an unknown constant parameter. The algorithm introduced has no integration problem, which has been discussed in detail in the literature. The method presented uses measurements of the stator currents and voltages to estimate the rotor speed. The performance of the proposed method is verified experimentally.

## 2. Observer structure for speed estimation

### 2.1. Dynamical model of induction motor

A dynamic model for an induction motor in rotor flux oriented stationary reference frame, by choosing the stator currents  $i_\alpha$ ,  $i_\beta$  and rotor flux  $\phi_\alpha$ ,  $\phi_\beta$  as state variables, is as follows:

$$\left. \begin{aligned} \frac{di_\alpha}{dt} &= \gamma F_\alpha - k_1 i_\alpha + k_2 v_\alpha \\ \frac{di_\beta}{dt} &= \gamma F_\beta - k_1 i_\beta + k_2 v_\beta \end{aligned} \right\} \quad (1)$$

$$\left. \begin{aligned} \frac{d\phi_\alpha}{dt} &= -F_\alpha + \eta L_m i_\alpha \\ \frac{d\phi_\beta}{dt} &= -F_\beta + \eta L_m i_\beta \end{aligned} \right\} \quad (2)$$

Where

$$F_\alpha = (\eta \phi_\alpha + \omega_r \phi_\beta), \quad F_\beta = (\eta \phi_\beta - \omega_r \phi_\alpha),$$

$$\eta = 1/T_r = R_r/L_r, \quad k_2 = \frac{1}{\sigma L_s},$$

$$k_1 = k_2 \left( R_s + \frac{L_m^2}{L_r T_r} \right), \quad \sigma = 1 - \frac{L_m^2}{L_s L_r}, \quad \gamma = \frac{k_2 L_m}{L_r}$$

$T_r$  is the rotor time constant,  $\omega_r$  is the electrical rotor speed, subscripts  $\alpha$  and  $\beta$  are used for  $\alpha$ -axis and  $\beta$ -axis components. Two-dimensional vectors are rotor fluxes ( $\phi_\alpha$ ,  $\phi_\beta$ ), stator currents ( $i_\alpha$ ,  $i_\beta$ ), and voltages ( $v_\alpha$ ,  $v_\beta$ ) in ( $\alpha$ ,  $\beta$ ) coordinates.  $L_m$ ,  $L_r$ ,  $R_r$ ,  $L_s$  and  $R_s$  are mutual inductance, rotor inductance, rotor resistance, stator inductance and stator resistance, respectively.

### 2.2. Sliding mode observer

A nonlinear observer with discontinuous parameters and stator currents and voltages as inputs is suggested, so that the motor speed can be estimated without measuring of mechanical variables. The sliding mode

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