Available online at www.sciencedirect.com
ScienceDirect
Mathematics and Computers in Simulation 115 (2015) 12–23
MATHEMATICS AND COMPUTERS IN SIMULATION
www.elsevier.com/locate/matcom

Original articles

Convergence analysis of back-EMF MRAS observers used in sensorless control of induction motor drives

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Received 5 January 2013; received in revised form 30 December 2014; accepted 7 April 2015
Available online 22 April 2015

Highlights

- The design of two Model Reference Adaptive System speed estimators is presented.
- Dynamic tracking performances of the MRAS based on rotor flux estimation are studied.
- Stability analysis of Back-EMF MRAS estimator is explored to find unstable regions.
- We propose a new adaptation law which allows reducing of unstable zones.
- Simulation results show effectiveness of the estimator with the new adaptation law.

Abstract

This paper seeks to analyse stability and dynamics of back EMF MRAS based approach used in sensorless control of induction motors. Stability analysis is investigated to show unstable zones and it is explored using a state representation. A new rotor speed estimator is designed to achieve the stability in the various operating modes except for the inobservability line.

Keywords: Induction motors; Sensorless control; Model reference adaptive system; Stability analysis

1. Introduction

Three phase induction motors are the most widely used electrical motors, due to their ruggedness and low price. Speed and torque control of an induction motor is usually attained by application of a speed or position sensor. However, speed and position sensors require additional mounting space, reduce the reliability and increase the cost. The recent trend in field oriented control (FOC) is towards the use of sensorless techniques that avoid the use of speed sensor and flux sensor. Adaptive observers introduced by [9,21] were a powerful prolongation of initial sensor based observers [20]. However, some limits of operation of conventional observers were quickly highlighted [2]. Model Reference Adaptive System is one of the most popular adaptive control method used in motor control applications for tracking and observing system parameters and states [6,12]. There are presently several techniques devoted to rotor

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http://dx.doi.org/10.1016/j.matcom.2015.04.002

speed estimation for induction motors each one of them presenting their respective advantages and disadvantages. Model Reference Adaptive System (MRAS) [19], Extended Kalman Filter (EKF) [3,22] or low-pass programmable filter [17] give robust speed and flux estimates but they exhibit a high complexity in implementation. Sliding mode control observers [11,13] have also been employed for estimation of IM variables such as rotor flux, rotor time constant and motor speed. These observers are recognized for their robustness and parameter insensitivity, yet no clear analytical tuning has been reported for these estimators. They require fast execution and theoretically an infinite switching rate. To overcome problems associated with model-based schemes, estimators utilizing saliency and high frequency signal injection have been proposed [4]. They require a high precision measurement and increase the overall complexity of the system. In spite of their particular limitations, all these methods aim for achieving parametric robustness and wider possible range of speed operation. MRAS-based speed estimation schemes have found widespread application in field oriented control induction motor drives for reasons of simplicity and comparatively low computational effort [1,15,18]. The most common MRAS structure is that based on the rotor flux error vector [6], which provides the advantage of producing rotor flux angle estimate for field orientation scheme. Other MRAS structures have also been proposed recently that use back EMF, stator current and reactive power as error vectors estimators [8,10,14,16].

Regardless of the sensorless method used, a critical zone exists around zero speed. The convergence of estimators cannot be guaranteed and the stability of the control scheme may fail. The aim of this paper is to study convergence of MRAS based estimator. Analysis of unstable regions is traditionally led using transfer function and Routh criteria which will be very complicated if applied to MIMO systems. In this paper, stability problem is explored using a state representation and a new interpretation of the stability is proposed by plotting a cartography of unstable eigenvalues in the torque/speed plan.

2. Machine modelling

Basic equations of induction motor in a general reference frame in terms of complex space vector quantities are:

$$\underline{u}_s = R_s \underline{i}_s + \frac{d}{dt}\underline{\psi}_s + j\omega_s \underline{\psi}_s, \tag{1a}$$

$$0 = R_r \underline{i}_r + \frac{d}{dt}\underline{\psi}_r + j(\omega_s - \omega_m)\underline{\psi}_r \tag{1b}$$

where:

$\underline{u}_s = u_{sd} + ju_{sq}$	: stator voltage vector,
$\underline{i}_s = i_{sd} + ji_{sq}$	: stator current vector,
$\underline{i}_r = i_{rd} + ji_{rq}$	: rotor current vector,
$\underline{\psi}_s = \psi_{sd} + j\psi_{sq}$	: stator flux vector,
$\underline{\psi}_r = \psi_{rd} + j\psi_{rq}$	: rotor flux vector,
R_s, R_r	: stator and rotor resistances,
$\sigma = 1 - \frac{L_m^2}{L_s L_r}$	: leakage coefficient

ω_s and ω_m are angular speed of reference frame and of the rotor respectively.

Stator and rotor flux linkages are:

$$\underline{\psi}_s = L_s \underline{i}_s + L_m \underline{i}_r, \tag{2a}$$

$$\underline{\psi}_r = L_m \underline{i}_s + L_r \underline{i}_r \tag{2b}$$

where L_m, L_s, L_r are magnetizing inductance, stator inductance, and the rotor inductance respectively.

Under rotor flux orientation conditions (FOC), rotor flux is aligned on the d-axis. The electromagnetic torque equation is:

$$T_{em} = \frac{3}{2} p \frac{L_m}{L_r} \psi_r I_{sq}. \tag{3}$$

Bloc diagram of sensorless indirect field oriented control induction motor drive is shown in Fig. 1.