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Rotor-resistance estimation for induction machines with indirect-field orientation

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Abstract

This paper presents a detailed study of a method of rotor-resistance estimation for indirect-field-oriented control of induction machines based on the reactive-power reference model. It will show how the estimation procedure can be carried out independently of the stator frequency and the load torque. The stability of the estimation procedure will also be demonstrated. Simulation and experimental results will be presented to validate the main contributions of this work. Finally, the sensitivity of the algorithm to errors in other machine parameters will be investigated.

Keywords: Field-oriented control; Induction machines; Model reference adaptive control

1. Introduction

Induction machines have several advantages with respect to d.c. machines: their low cost, robustness and reliability. Although, d.c. machines have traditionally been used in high-performance variable-speed applications, the development of power electronics has contributed to the use of advanced control techniques that have made it possible to extend the use of induction machines in those applications (Mohan, Undeland, & Robbins, 1995). One of these techniques is the well known field-oriented control.

Power–electronic control of induction machines have made it possible, for example, for them to be used for variable-speed wind energy conversion. Squirrel-cage induction machines with a power–electronic interface are used for low- and medium-power applications. Doubly fed (wound-rotor) machines with a power–electronic converter in the rotor are used for medium- and high-power applications (up to a couple of MWs). More recently, doubly fed machines with a control winding in the stator are being proposed for the latter application (Burton, Sharpe, Jenkins, & Bossanyi, 2001). In all these cases the field-oriented control is a popular alternative.

Traditionally, there have been two conventional methods by which to achieve field-oriented control: direct-field-oriented control (DFOC) and indirect-field-oriented control (IFOC). DFOC includes a closed-loop rotor-flux controller and requires the calculation of rotor-flux–vector modulus and position. This is the standard solution for high-performance drives but requires complicated algorithms. IFOC does not have a closed-loop rotor-flux controller and only requires the angular position of the rotor-flux vector which is calculated by integrating the vector angular speed (Murphy & Turnbull, 1988). This can be computed using the rotor speed and the stator-current measurement. IFOC is a very simple solution worth considering in many applications. Among these applications this paper considers squirrel-cage machines for wind energy conversion. Unfortunately, the calculation of the angular speed of the rotor flux is very sensitive to errors in rotor resistance which undergoes large variations with temperature. Furthermore, the magnetising inductance may cause errors in this calculation due to saturation.

A great effort has been made in the development of rotor-resistance estimation methods. A detailed description

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of these methods can be found in Toliyat, Levi, and Raina (2003) with the following classification:

1. Spectral analysis techniques: These estimation methods are based on the measured response to a specific injected signal or a characteristic harmonic in the voltage or current spectrum. The rotor resistance can be obtained from the spectral analysis of the stator current or stator voltage measurements. A disturbance signal must be used because under non-load conditions of the induction machine the slip frequency is zero and the rotor resistance cannot be calculated. An example of the use of these techniques applied to the sensorless control of induction machines can be found in Baghli, Al-Rouh, and Rezzoug (2006).
2. Observer-based techniques: Several proposed methods using extended Kalman filters or extended Luenberger observers have been developed to estimate the rotor resistance in induction machines (see, for example, Du, Vas, & Stronach, 1995; Zai, DeMarco, & Lipo, 1992). Another work which uses a Kalman filter to estimate the rotor resistance can be found in Duval, Glerc, and Le Gorrec (2006). The main drawbacks of these methods are the computational cost and the fact that the inductances are considered constant.
3. Model reference adaptive system-based techniques: Very often, model reference adaptive control (MRAC) methods have been used to estimate the rotor resistance due to their simple implementation. Some of the best known are:

    (a) The Torque Reference Model uses the torque equation to estimate the rotor resistance (Lorenz & Lawson, 1990). This estimation can be used even under transient torque conditions. However, there is a need to know the stator resistance (also variable with temperature), the magnetising inductance and the rotor inductance. Although the implementation of this method is analysed in Lorenz and Lawson (1990), the convergence is not studied in detail.
    (b) The Reactive-Power Reference Model uses the reactive-power equation to estimate the rotor resistance (Garcés, 1980). This method uses stator inductance, rotor inductance and magnetising inductance, but there is no need to know the stator resistance. A thorough analysis of the convergence of the resistance estimate to its actual value shows a strong dependency on the operating point (supply frequency and load torque). This issue needs further investigation and is one of the contributions of this paper.
    (c) The D-Axis and Q-Axis Voltage Reference Models use the *d*-axis voltage equation and the *q*-axis voltage equation, respectively, to estimate the rotor resistance. Both approaches use stator resistance, stator and rotor inductances and magnetising inductance. The error between the estimated voltage and the real value is analysed in steady state in Rowan, Kerkman, and Leggate (1991). This error is used to drive the adaptive mechanism which provides estimation of the rotor resistance. It is demonstrated that the load torque and the supply frequency also affect the algorithm convergence in this case.

    The MRAC methods are strongly dependent on the accuracy of the machine model and estimation is usually based on the steady-state machine model. Furthermore, in most cases, the adaptation process does not work at zero rotor speed and at zero load torque. Some methods based on MRAC take changes in the magnetising inductance and the operation at light load torques into account (see Vukosavic & Stojic, 1993).
4. Other methods: There are other methods which are not based on the previous techniques such as those based on artificial intelligence, for example, neural networks or fuzzy logic schemes.

In recent years, new algorithms to control induction machines to estimate rotor resistance have been developed using nonlinear control theory, power electronics technology development and the wide use of DSPs. In Behal, Feemster, and Dawson (2003) the global exponential rotor velocity/rotor flux tracking is studied by modifying the standard IFOC controller. However, the problem of the rotor-resistance estimation is not analysed. Marino et al. have developed high-performance nonlinear algorithms for the control of induction machines with rotor-resistance estimation: in Marino, Peresada, and Tomei (1995, 1996) rotor-resistance estimation algorithms are designed providing a proof of the stability in both cases. The algorithms operate at zero rotor speed, but they are influenced by stator-resistance variations. This problem is overcome in Marino, Peresada, and Tomei (2000) where rotor resistance and stator resistance are simultaneously estimated. This work also demonstrates the estimation stability taking several assumptions into account. In Lee, Fu, Tsai, and Lin (2001) a nonlinear adaptive controller for the rotor speed and the torque is designed assuming that all the parameters of the induction machine except the rotor resistance are known. The controller uses measurements of the stator current and rotor speed and the stability of the closed-loop system is analysed using the Lyapunov theory. Following this trend, an adaptive sensorless controller for the rotor speed is developed in Lee, Fu, and Huang (2002) to achieve rotor speed tracking with maximum power transfer to the rotor. In this work, the authors design the controller using adaptive observers for the rotor speed and the rotor flux, and estimate the rotor resistance using only stator variables. A stability proof is provided based on the Lyapunov theory. In Castaldi, Geri, Montanari, and Tilli (2005) a novel adaptation method, based on a non-minimal representation of the induction machine, is used to estimate