Neurocomputing 118 (2013) 87–100

Contents lists available at SciVerse ScienceDirect

Neurocomputing

journal homepage: www.elsevier.com/locate/neucom

A review of parameter estimators and controllers for induction motors based on artificial neural networks

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ARTICLE INFO

Article history:
Received 28 July 2012
Received in revised form
27 January 2013
Accepted 2 February 2013
Communicated by M.-J. Er
Available online 29 April 2013

Keywords:
Neural networks
Adjustable speed driver
Parameter estimation
Rotor-flux oriented
Adaptive observer
Real-time identification

ABSTRACT

Induction motors (IMs) are the most used electromechanic machines in industrial applications. Their control has become the subject of many studies since the 70 s, and there have been several approaches to achieve high-performance adjustable speed drivers (ASDs). The review presented in this article can support the state of some related researches, since it deals with current state-of-the-art of Artificial Neural Networks (ANNs) oriented to experiments that perform motion control with induction motors. It summarizes many previous works focused on IM and can help the reader to have a starting point to begin their own research on choosing a correct type of Neural Network (NN). The paper provides a list of ANNs used to improve the ASD-control, extending the IM-driver life and achieving proper motor operation, their size and performance. A good match between IM parameter values and the data that the controller needs for the induction machine is imperative. Artificial Intelligence (AI) is a helpful tool to achieve this. The summary will also present an overview of different ANN-based drive approaches.

1. Introduction

The current industrial field has increased its use of induction motors in most of its high-performance processes because of their advantages. For IM motor control, it is imperative to know the induction machine parameter like magnetic flux, rotor time constant and mainly rotor resistance value, besides speed and torque. These parameters can adversely affect the model that represents the induction machine; they are strongly dependent on working condition such as temperature, operating frequency and saturation. This paper presents a review focused on IM parameter estimation based on ANN. There have been other reviews previously published, like Ref. [1], but they are focused on many methods without going deep and providing a general scene, while this work is devoted to ANN approaches and gives the researchers a point to start their own research. A list of different schemes and their results are reported here as well. Improvements for IM motion control are also shown in Ref. [27], but just a few shames are compered. The problem of estimation induction motor parameters using ANNs is summarized within this survey paper which can help the community readers.

Regarding IMs, there has been an enormous improvement in terms of field-oriented control (FOC) especially in parameter estimation. Generally speaking, there are two kinds of field-oriented control. The first is called Direct Field Oriented Control (DFOC), the second Indirect Field Oriented Control (IFOC). AI has been used as part of several applications, including broken bars detection, fault diagnosis, and Sensorless IM-control. It has proven to be good approximations for complicated non-linear dynamic systems using multilayers, and ANNs have been implemented to reduce total harmonic distortion (THD) in current-controlled voltage source inverters. In power converters, NNs have been a useful implement for power factor correction (PFC), harmonic cancelation and the control of pulse-width modulation (PWM) source inverters [2]. Therefore, in this paper, it is presented a state of the art review of parameter estimation and controllers based on ANNs. The rest of this work is divided in the following sections. Section 2 introduces to the different methods to estimate the electrical parameters of an induction motor. Section 3 presents some neural network architectures to understand how they consist, which are used in next Section 4 as part of the schemes to estimate parameters. Section 5 gives certain examples of proposed approaches to control IM motion using its estimated parameters. Finally, to conclude, remarks are shown in Section 6.

2. Parameter estimation

In recent years there has been an unexpected improvement in micro-electronic and power devices, which has led to a trend of

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http://dx.doi.org/10.1016/j.neucom.2013.02.018

Nomenclature

R_s	stator resistance per phase
L_s	stator magnetizing inductance per phase
R_r	rotor resistance per phase
L_r	rotor magnetizing inductance per phase referred to stator
L_m	magnetizing inductance per phase
P	number of poles
σ	total leakage coefficient
ω_e	electrical angular speed
ω_r	slip angular speed
v_{ds}	d-axis stator voltage
v_{qs}	q-axis stator voltage
i_{ds}	d-axis stator current
i_{qs}	q-axis stator current

reliable, robust and high-performance drives for high-precision processes. These applications, such as machine tools, robots and ASDs whose control over speed, torque and position is essential, need a good control scheme. The features of IFOC have made it the top control strategy used for IMs [3]. The main disadvantage of IFOC is that it is difficult to determine the values of the currents and voltages fed to the machine in the orthogonal vector variable system. Thus, the direct and indirect transformation of the primitive coordinates and the field-oriented coordinates depends on the existing position of the magnetizing current space vector [4]. Another problem to be eliminated is the complexity of a direct or indirect measurement of that angle. The direct measurement needs special sensors insertion into the induction machine, which is both costly and difficult. The indirect measurement needs to integrate the set of system-modeling differential equations in real-time. At any given time, the q^e electrical axis is at angular position θ_e with respect to the q^s axis. The angle θ_e is given by the sum of rotor angular position θ_r and the slip angular position θ_{sl} and the rotor flux $\hat{\psi}_r$ is aligned with the d^e axis [5]. Fig. 1 shows an illustration of how rotor flux-oriented reference frames must operate in an IFOC. The main objective for new control approaches is to be less dependent on constant values and sensors, in order to reduce cost and complexity, and to be able to improve robustness and accuracy.

The stated equations that model an IM in the rotating reference frame fixed to the stator are written as follows. The electric torque is T_e [6]:

$$\frac{d}{dt}\begin{bmatrix} i_{ds} \\ i_{qs} \\ \hat{\psi}_{dr} \\ \hat{\psi}_{qr} \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{\sigma L_s}-\frac{R_r(1-\sigma)}{\sigma L_r} & \omega_e & \frac{L_m R_r}{\sigma L_s L_r^2} & \frac{P\omega_r L_m}{2\sigma L_s L_r^2} \\ \omega_e & -\frac{R_s}{\sigma L_s}-\frac{R_r(1-\sigma)}{\sigma L_r} & \frac{-P\omega_r L_m}{2\sigma L_s L_r^2} & \frac{L_m R_r}{\sigma L_s L_r^2} \\ \frac{L_m R_r}{L_r} & 0 & -\frac{R_r}{L_r} & (\omega_e-\frac{P}{2}\omega_r) \\ 0 & \frac{L_m R_r}{L_r} & -(\omega_e-\frac{P}{2}\omega_r) & -\frac{R_r}{L_r} \end{bmatrix} \times \begin{bmatrix} i_{ds} \\ i_{qs} \\ \hat{\psi}_{dr} \\ \hat{\psi}_{qr} \end{bmatrix} + \frac{1}{\sigma L_r}\begin{bmatrix} v_{ds} \\ v_{qs} \\ 0 \\ 0 \end{bmatrix} \quad (1)$$

$$T_e = \frac{3P}{4}\frac{L_m}{L_r}(i_{qs}\hat{\psi}_{dr}-i_{ds}\hat{\psi}_{qr}) \quad (2)$$

2.1. On-line and off-line estimation

Several estimators have been proposed in reported literature. Those solutions which allow for *in system* identification of the IM are of main interest to some industrial applications. This means that the estimation process can be applied while the IM is connected to a mechanical load, using commercial equipment and considering a few modifications. When performing parameter estimation, identification techniques for the IM are mainly divided into two kinds: off-line and on-line methods [7].

The off-line process is completed while the motor is at a standstill, and no torque is applied from the mechanical load. This action is usually done when the initialization of the motion control is taking place [8].

The on-line process, on the other hand, is accomplished while the electric drive is operating normally. It is carried out while the motion control is being executed.

The second method offers a very important advantage over the first; on-line parameter estimation has the capability of tracking low IM parameter variations during operation conditions. The working frequency, heating and saturation have a big effect on both stator and rotor winding resistance values; this feature allow for the self-tuning of the ASD-control over the electric machine [9].

2.2. Driver for IMs

The motor is fed by means of a PWM-inverter, and its command signals are generated through a controller that uses the induction machine information, which is either impossible or very difficult to obtain from the motor directly. Fig. 2 shows the basic IM-control scheme. The block diagram is based on the *Model References Adaptive System* (MRAS), which offers accuracy control and requires less computational effort. More importantly, it lacks a speed sensor. Various MRAS observers have been listed [10–13]; they depend on the rotor flux, the finite element method or the reactive power. They all suffer from stator resistance variations and integration problems, which may produce dc drift and initial condition problems [14]. These problems can limit the driver

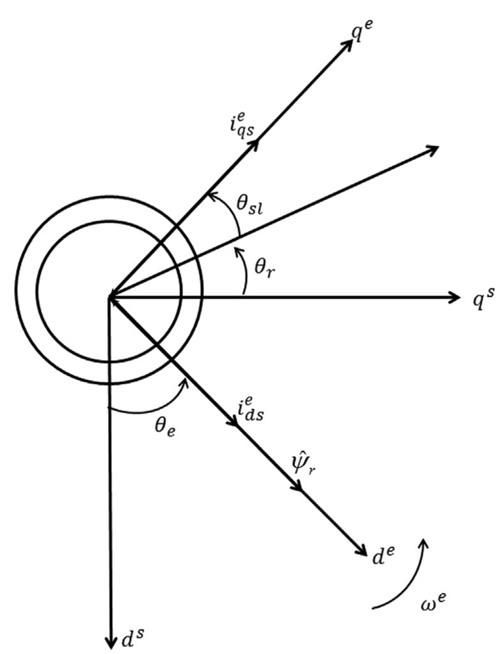

Fig. 1. Illustration of the rotor flux reference frame for IFOC.