Diagnosis of Induction Machines' Rotor Faults in Time-Varying Conditions

Andrea Stefani, Alberto Bellini, *Member, IEEE*, and Fiorenzo Filippetti, *Member, IEEE*

***Abstract*—Motor current signature analysis is the reference method for the diagnosis of induction machines' rotor faults; however, in time-varying conditions, it fails as slip and speed vary, and, thus, sideband components are spread in a bandwidth that is proportional to the variation. Variable speed drive applications are common in the aerospace, appliance, railway, and automotive industries and also in electric generators for wind turbines. In this paper, a simple and effective method is presented that allows the diagnosis of rotor faults for induction machine drives in time-varying conditions. It is tailored to direct rotor flux field-oriented controlled drives, where the control system provides suitable signals that are exploited for the demodulation to a constant frequency of time-varying signatures related to the rotor faults. Simulations and experiments are reported to validate the proposed method on a critical speed transient.**

***Index Terms*—Fault diagnosis, induction motor drives, time-varying systems.**

I. Introduction

INDUCTION motors are widely used in industrial applications for their intrinsic ruggedness and reduced cost. Recently, the use of adjustable speed drives has spread in many applications. Online diagnosis and the early detection of faults in induction machines have focused the attention of researchers since they allow the reduction of maintenance costs and downtime.

In some applications, where continuous operation is a key item, such as railway applications and wind generators, the need for a preventive fault diagnosis is an extremely important point. As an example, the case of railway applications is investigated in [1] and [2] to design a traction drive oriented to maximum fault tolerance. In [3], the use of the Vienna monitoring method (VMM) is investigated for a traction drive application, where rotor fault detection was successfully verified in transient and steady-state conditions.

In this paper, fault detection and the prognosis of rotor faults are critical for industrial applications, although rotor faults share only about 20% of the overall induction machine faults [4]. In fact, the breakage of a bar leads to high current in adjacent bars, thus leading to potential further breakage and stator faults as well.

Manuscript received March 1, 2008; revised February 18, 2009. First published March 16, 2009; current version published October 9, 2009.

A. Stefani and F. Filippetti are with the Department of Electrical Engineering, University of Bologna, 40136 Bologna, Italy.

A. Bellini is with the Department of Engineering Sciences and Methods, University of Modena and Reggio Emilia, 42100 Reggio Emilia, Italy (e-mail: alberto.bellini@unimore.it).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TIE.2009.2016517

Motor current signature analysis (MCSA) was extensively used to detect broken rotor bars and end-ring faults in induction motors [5]–[8]. In steady-state conditions, a quite robust diagnostic index is the sum of the amplitudes of the left and right sideband components of the stator current that is independent of inertia and proportional to the number of adjacent broken bars. The main shortcoming of the MCSA is its dependence on machine slip s, speed, and load, although the dependence on the load torque variations can be compensated for [9]. Moreover, the MCSA fails for current-controlled drives, as the control loop masks the oscillation of the stator current. If an ideal control loop is considered, the controlled variable is desensitized, and anomalous lines appear in the manipulated variables. In actual conditions, depending on the bandwidth, either the manipulated (voltage) or the controlled (current) variable spectrum is more sensitive to the fault. Hence, new diagnostic indexes can be used that are based on control variables [10]–[12].

Other techniques have been investigated for rotor faults beyond the MCSA or its variants. Several demodulation methods were presented to extract fault information from the current. In [13], envelope analysis, Hilbert transformation, and Park transformation were used to perform amplitude demodulation of rotor faults. Other methods were based on multiple electrical signals such as torque and leakage flux. The VMM [14] relies on voltage, current signals, and measured rotor position to check deviations in terms of instantaneous torque obtained by two different machine models. Also, signal injection techniques were proposed, relying on methods that are similar to those adopted for sensorless drive control [15].

Anyway, for time-varying conditions, the most commonly adopted techniques are based on time–frequency analysis. Complex techniques were presented to cope with this issue, including high-frequency resolution methods [16], time–frequency distributions [17], [18], and wavelets [19]–[22]. All the above methods require heavy computation and complex procedures to analyze the time–frequency distribution and to retrieve the information related to rotor faults. Although the computation time itself is not an issue provided that data are sampled, stored, and postprocessed, in industrial applications, the requirement of minimum complexity is a mandatory issue. In fact, with time–frequency analysis, a few major shortcomings appear.

1) The latency is very high, and a large memory is required to store the data that will be processed.
2) A large number of samples are required to achieve reliable results.
3) Specialized hardware is required.

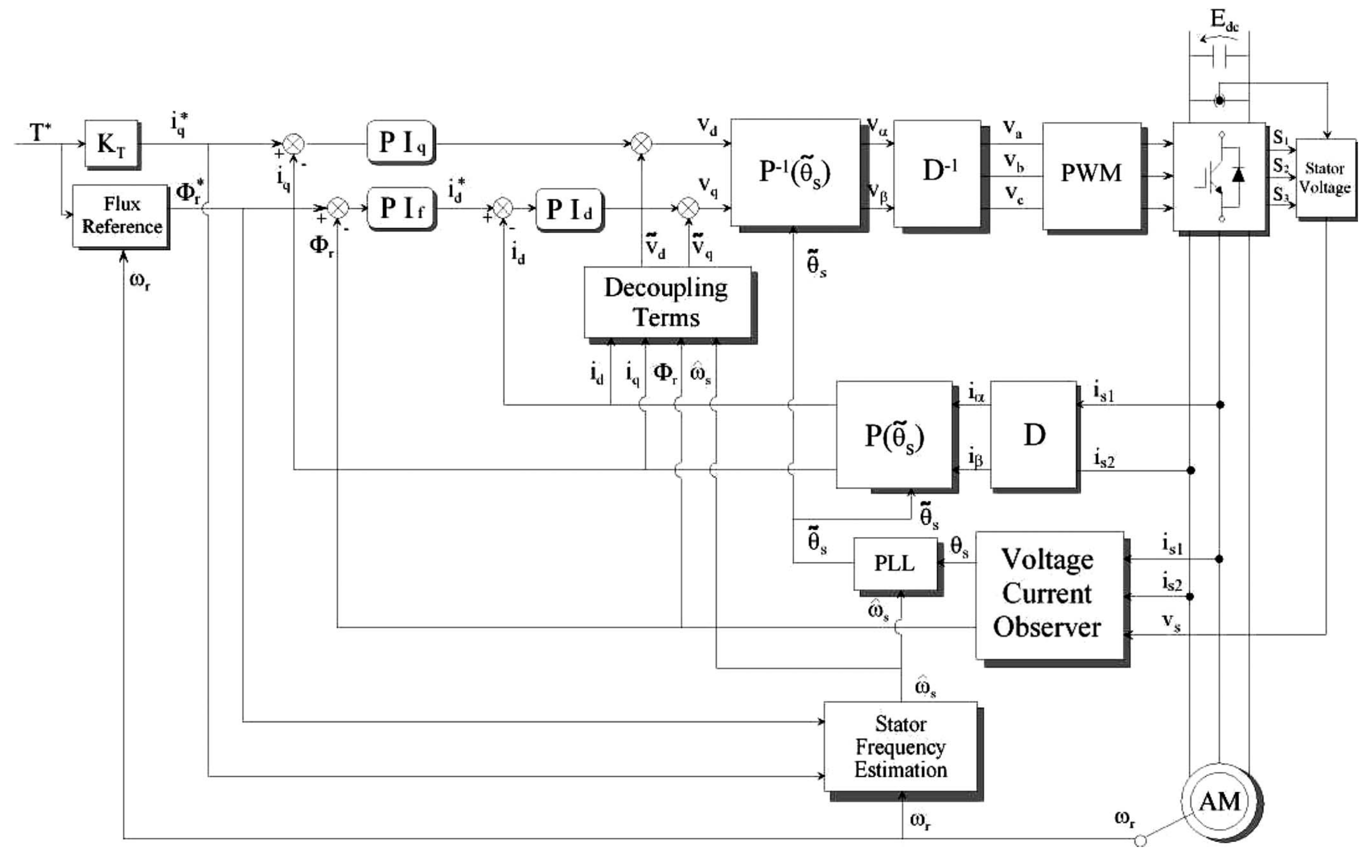

Fig. 1. Block diagram of the control scheme for a typical direct rotor flux field-oriented vector drive.

A simpler method could provide accurate fault detection in time-varying conditions even with a reduced number of samples. Moreover, it can be included in the available firmware used for the drive control, allowing the realization of an effective fault diagnosis at no additional hardware cost.

A typical example of transient behavior is the case of traction applications, where torque and speed vary depending on the journey, preventing the use of the MCSA and classical spectral analysis. In this paper, experiments are performed referring to the typical specifications of a railway application system; however, the proposed method is general, provided that a similar control architecture is used in the drive.

Electric drives for traction applications operate in a field-weakening mode at the cruise speed. Nevertheless, the most relevant accelerations are usually in the constant torque mode since the load torque is lower, being proportional to the square of the speed. Here, reference is made to time-varying conditions and, thus, to constant torque mode.

The issue of rotor fault detection can be solved if a diagnostic index is defined that is independent of slip and stator frequency. Here, a simple demodulation procedure in the time domain is proposed that processes the stator currents, relying on stator frequency and machine slip accurately retrieved by the drive control. After the demodulation process, a component is obtained, whose amplitude is related to the rotor fault and whose frequency is constant, independently of the stator frequency and speed.

This paper is organized as follows. Section II describes a typical induction machine drive for high-power applications. Section III describes the demodulation technique to compute a component that is independent of slip and stator frequency, a diagnostic index that is suitable for time-varying conditions, and the proposed diagnostic procedure. Section IV reports the simulation results to validate the proposed method, and Section V reports the experimental results for an induction machine drive. The results obtained with the proposed approach are compared with the classical spectral analysis methods to demonstrate their performance.

The demodulation technique presented here is applied to stator currents but can also be applied to other variables to extract the faulty components.

II. Control Strategy of Induction Machine Drives

Nowadays, common solutions for high-power applications are based on drives that include a voltage source inverter (VSI) feeding an induction motor or a permanent magnet synchronous motor. However, old-fashioned solutions based on a current source inverter or on thyristors are still employed, whereas old schemes based on dc series motors or direct dc motors are no longer used. Different control schemes are adopted and tailored to the specific application. Typically, variable structure controls are used for high-performance traction drive systems that change according to the operating conditions, particularly according to the speed and flux levels. The basic structure is a direct rotor flux field-oriented vector control, whose scheme is shown in Fig. 1. The vector control algorithm consists of two current loops for flux and torque regulation. Moreover, an