Rotor Faults Diagnosis in Traction Drives Using Virtual Current Technique for Railway Application

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Abstract— **This paper presents the Virtual Current Technique as a new model-based diagnostic procedure for the diagnosis of rotor faults in traction drives for railway applications. A rotor fault in a traction drive based on induction motors produces due to some oscillations at twice the slip frequency in the rotor flux as well as in the magnetizing current component. The amplitude of these oscillation, using some motor and controller parameters are measured and one can reconstruct a virtual magnetizing current component and after normalization, which can be used to detect and quantify the extension of rotor faults in a drive subjected to a direct rotor field oriented control scheme.**
The simulation results demonstrate that with this diagnostic technique, it is possible to diagnose effectively rotor faults, independently of the drive operating conditions, both in steady-state and transient regime.

Keywords—**Rotor Fault, Field oriented controlled drive, virtual current, diagnosis, virtual technique.**

I. Introduction

Now days many research efforts have been focused on the diagnosis of motor faults in vector-controlled induction motor drives. This type of systems in different areas of application is driving the development of adequate diagnostic techniques which can cope with the additional difficulties introduced by the control system regarding the diagnosis of motor fault. In the sector of traction drives there is an increasing demand for the development of adequate motor diagnostic strategies for railway applications, such as the ones found in high speed trains. Hence, this paper presents a new diagnostic procedure developed for the diagnosis of rotor faults in induction motors used in traction drives for railway applications.

II. Rotor Faults Diagnosis of Field Oriented Controlled Drives

Some of the diagnostic techniques are used i.e. the Vienna Monitoring Method [1], the estimated rotor flux [8], the error signals of the dq current components [5] and the injection of high-frequency signals [3],[6] in the diagnosis of rotor faults in vector-controlled drives. A comparison study presented in [7] pointed out that most of the proposed methods fail in fulfilling one of the main aims of a diagnostic technique: to allow the detection and quantification of a given fault in a way independent of the motor working conditions, namely with regard to the motor load level and reference speed of the drive. Without these features, a diagnostic technique becomes inefficient as it does not allow the user to draw an evident conclusion about the condition of the machine. Moreover, in the particular field of traction drives, the low switching frequencies of the IGBTs used in the power converters (hundreds of Hertz in the particular drive studied in this paper) is too low to allow the injection of high-frequency signals by the diagnostic system, while low-frequency signals cannot be injected without significantly affecting the normal operation of the drive. In order to overcome these limitations, and to overcome the difficulties presented by a traction drive where the speed of the system and demanded torque change significantly over time, it is presented in this paper a new diagnostic technique for the diagnosis of rotor faults in Direct Rotor Field Oriented Controlled (DRFOC) induction motors used in traction drives. The technique is applicable when the motor is operating in steady-state and transient conditions as well.

III. Virtual Current Technique (VCT)

The diagnostic technique proposed in this work to diagnose rotor faults in traction drives lies on the fact that in a DRFOC drive, a rotor fault gives rise to the appearance of oscillations in the rotor flux, in a synchronous reference frame, at a frequency of $2sf$, where s and f stand for the rotor slip and motor supply frequency, respectively [4, 9]. This is true provided that the bandwidth of the flux loop is much smaller than the $2sf$ frequency [10]. As the bandwidth of this control loop increases to values comparable or higher than the $2sf$ frequency, part of the effect of the fault is shifted to the

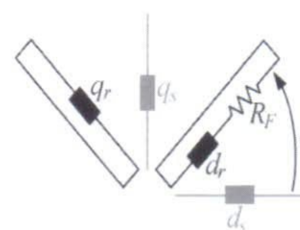

Fig. 1. Two-phase asymmetrical machine considered for the analysis of the behavior of a DRFOC induction motor drive with a rotor fault.

magnetizing current component (*ids*) [11]. If the flux control loop bandwidth was infinite, the rotor flux oscillations would vanish completely and all the effect of the fault would appear as oscillations at $2sf$ in i_{ds}.

We consider as a starting point an approximate model of an asymmetrical two phase induction machine, in *dq*-axes, where this machine is subjected to a direct rotor field oriented control scheme (Fig. 1)

If the flux control loop bandwidth of this system was infinite, then number of broken rotor bars is given by

$$n_F \simeq \frac{\Delta i_{ds}}{\bar{i}_{qs}} N_b , \qquad (1)$$

Where n_F, N_b, and Δi_{ds} are the number of adjacent broken bars, the total number of rotor bars, the average value of the torque-producing current component, and the amplitude of the oscillations at a frequency of $2sf$ present in the magnetizing current component, respectively.

As a consequence of that, for high extensions of the fault it is preferable to use the relation [10]:

$$n_F \simeq \frac{k}{1-k/2} N_b , \qquad (2)$$

where

$$k = \frac{\Delta i_{ds}}{\bar{i}_{qs}} . \qquad (3)$$

The simple relations presented before can only be used in an ideal system, where the flux loop bandwidth is infinite. In a real system, the flux loop bandwidth is usually small, in the range of a few Hertz for low-voltage low-power motors, or even less than 1 Hz for a high power traction drive. As a consequence of that, the oscillations that would be found solely in i_{ds} in the ideal system are now partly shifted to the rotor flux, with special emphasis on the *d*-axis component ψ_{dr}. Virtual Current Technique (VCT) is developed by measuring the amplitude of the oscillations present in ψ_{dr} and having knowledge of the controller and motor parameters shown in Fig. 2, namely the magnetizing inductance *Lm* and rotor time constant τr, it is possible to reconstruct the oscillations that would appear in *ids* if the flux control loop bandwidth was infinite. These oscillations are represented in Fig. 2 by the virtual current $\Delta i_d sf$.

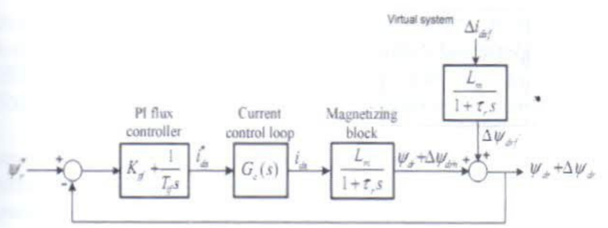

Fig. 2. Block diagram showing how the effects of a rotor fault can be incorporated in the flux control loop of the traction drive under analysis.

In this way, if $\Delta i_d s_{fis}$ calculated and used in (2) instead of Δi_{ds}, this approximate relationship can be applied to any DRFOC drive to detect and quantify broken rotor bars. The diagnostic process starts with the measurement of the amplitude of the rotor flux oscillations $\Delta\psi_{dr}$. . With this information and with the knowledge of the frequency response (gain and phase shift) of the blocks containing the flux controller, current control loop and magnetizing block, measured at the frequency $2sf$, one obtains the amplitude and phase shift of $\Delta\psi_{drh}$. The subtraction of this component from $\Delta\psi_{dr}$ and the product of the obtained result by the inverse gain of the magnetizing block leads to $\Delta i_d sf$ (Fig. 3).The ratio between $\Delta i_d sf$ and the average value of *iqs* gives the degree of asymmetry of the motor or the number of adjacent broken bars, if the total number of rotor bars is known.

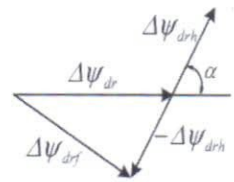

Fig. 3. Demonstration on how the virtual flux component $\Delta\psi_{drf}$ is calculated.

IV. INTEGRATION OF THE VCT INTO THE CONTROL SYSTEM OF THE DRIVE

The motor parameters are calculated during the commissioning phase of the drive. There is a need for two additional modules: one, very simple, whose aim is to calculate the average value of i_{qs} and another one which tracks the amplitude of the oscillations present in ψ_{dr} at a frequency of $2sf$ (which will allow, in a second step, to calculate the amplitudes of($\Delta\psi_{drf}$ and Δi_{drf}). This second module, represented in Fig. 4, is composed by a Variable Frequency Average (VFA) block and by a variable frequency selective filter (VFSF).

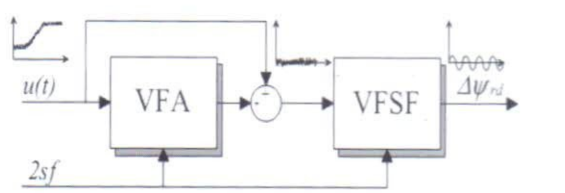

Fig. 4. Block diagram of the module composed by the Variable Frequency Average (VFA) block and the Variable Frequency Selective Filter (VFSF) for the extraction of the fault component.

The VFA block diagram is very similar to the one described in [12] and allows to calculate an instantaneous local average value of the input signal u (t). The output of the VFA is then subtracted from the original signal and the result of this operation is further processed in the variable frequency selective filter (VFSF), thus obtaining the specific spectral fault oscillation component.

V. Simulation Results

In this Section, some simulation results are shown, demonstrating the difficulties usually found in the diagnosis of faults in a traction drive and the applicability of the VCT in this domain. The simulation model used to produce the simulation results includes a motor model and the control system of the drive. The stator windings of the motor are considered to have a sinusoidal distribution [13]. The bandwidth of flux control loop of the traction drive was set to 0.5Hz. Since the rotor flux level is adjusted directly proportional to the square root of the demanded torque, the $2sf$ frequency is fixed and equal to 1.4 Hz, independently of the motor load level. Fig. 5(a) shows the estimated *d*-axis rotor flux component of the motor for the case of one and two broken rotor bars (BRBs).As can be seen, when a rotor fault occurs, the estimated rotor flux, in the controller's reference frame, contains a dc component (which represents the fundamental component of the rotor flux of the machine) and an oscillating component at the frequency $2sf$. If the high order harmonic content is eliminated with the aid of a low-pass digital filter, the results obtained are the ones shown in Fig. 5(b). Hence, to eliminate noise and unwanted high-order harmonics not directly related to the fault, the flux and/or current signals should be filtered before being used by the diagnostic system. As mentioned before, when the flux control loop bandwidth is comparable or even lower than $2sf$, as in the present case, the effect of the fault is spread between the rotor flux and the current component i_{ds} (Figs. 6 and 7).

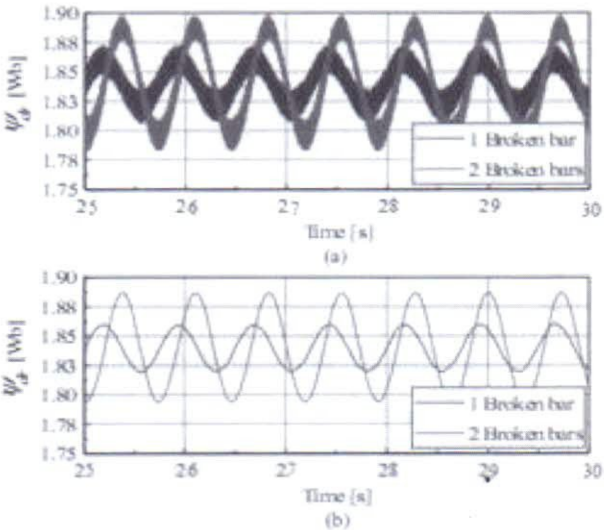

Fig. 5 Estimated d-axis rotor flux component for the case of one and two broken rotor bars: (a) unfiltered signal and (b) signal filtered with a digital low pass filter. The drive is running at rated load and constant speed

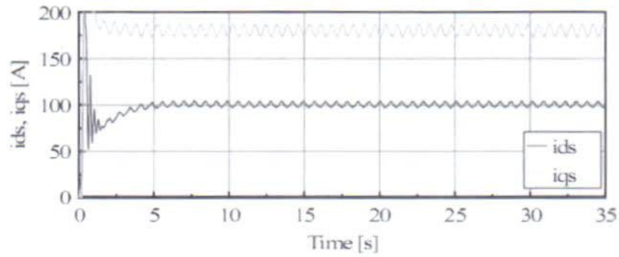

Fig. 6 Motor supply current components in the synchronous reference frame, for the case of two broken bars.

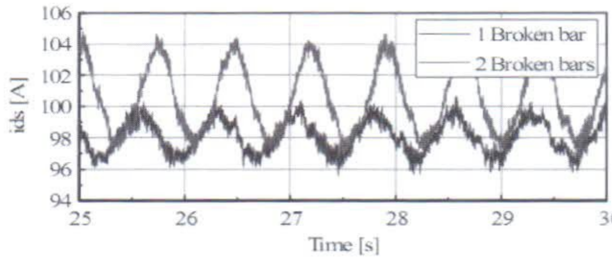

Fig. 7 Oscillations, at a frequency of 2sf, in the magnetizing current component, in the controller's reference frame, for two different rotor fault conditions.

VI. Conclusion

This paper presents the Virtual Current Technique as a new technique for the diagnosis of rotor faults in traction drives with a direct rotor field oriented control scheme. When a rotor fault occurs in the motor, some oscillations at a frequency of $2sf$ will appear in the *d*-axis component of the estimated rotor flux of the motor. Using this information and some motor and controller parameters, it is possible to reconstruct a virtual magnetizing current component whose oscillations at $2sf$, after normalization using the average value of the *q*-axis current component, can be used to quantify the extension of a rotor fault.

The presented diagnostic procedure is generalised and can be used in any DRFOC drive, independently of the working conditions of the motor and tuning of the controller parameters, both in steady-state and transient conditions.

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