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Power Electronics and Drives

Introduction to the Special Section on Intelligent Fault Monitoring and Fault–Tolerant Control in Power Electronics, Drives and Renewable Energy Systems

Review Article

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Abstract: This article constitutes an introductory part of the special section on Intelligent Fault Monitoring and Fault-Tolerant Control in Power Electronics, Drives and Renewable Energy Systems. In the current issue of the journal, the first part of this section is published. Accepted articles are focussed mainly on the sensor-fault diagnosis methods for T-type inverter-fed dual-three phase PMSM drives, partial demagnetization, faults of the permanent magnet synchronous generator (PMSG) and online open phase fault detection (FD) in the sensorless five-phase induction motor drive implemented with an inverter output LC filter and third harmonic injection. Also, neural networks (NN) application in the detection of stator and rotor electrical faults of induction motors has been proposed in one of the papers, and the observer-based FD concept for unknown systems using input–output measurements was applied to a brushless direct current motor drive with unknown parameters.

Keywords: *electrical drives • permanent-magnet machines • induction motors • sensor faults • winding faults • demagnetization faults • neural networks • observers*

Variable speed AC motor drives and renewable energy systems with power electronic converters have been under development for a long time and are now a mature technology. Nowadays, this technology is widely used in industrial, commercial and domestic applications, and its use is still increasing in electric power systems. Therefore, the reliability of these systems is also an area of great interest for the power electronics community. This is particularly the case for the aerospace, military and automotive industries that are widely introducing variable speed drives in order to improve the system performance and efficiency as well as in renewable energy systems connected to the grid. In such applications, the continuous operation could be critical and must be insured, despite of failures that may occur in the inverter, motor/generator and control system. Based on the idea of keeping the system operational after an inverter or incipient motor/generator fault detection (FD), the need of diagnostic and fault-tolerant systems and techniques has inspired extensive research in this area in recent years.

The aim of this special session (SS) is to discuss recent developments concerning the FD and diagnosis methods as well as fault-tolerant control strategies for AC motor drives applied in different industrial processes and renewable energy systems, according to the topics listed below:

- monitoring and diagnostics of AC motor/generator faults, including converter, motor/generator and sensor faults,
- intelligent FD and diagnostics in power converters using different methods and techniques, including signal processing and artificial intelligence-based methods,

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– fault-tolerant control methods, including redundant or multiphase topologies of converters and motors,
– modern tools for fault diagnosis and fault-tolerant control: neural networks (NN), fuzzy logic, expert systems, estimators and observers, signal-processing techniques, sliding mode and predictive control.

In this issue of *Power Electronics and Drives*, we present the first part of this special section.

Two of the articles concern faults occurring in the PMSM drives. The first article, by Xueqing Wang, Zheng Wang, Wei Wang and Ming Cheng, investigated the sensor-fault diagnosis methods for T-type inverter-fed dual-three-phase PMSM drives. Diagnostic methods have been proposed for three types of sensor faults, including speed-sensor, voltage-sensor and current-sensor faults. Both the sudden error and gradual error changes of sensor faults are considered. The diagnosis of speed-sensor fault was achieved by observing the error between the speed of stator flux and the value from speed sensor. Next, the large high-frequency voltage ripple of voltage difference between the estimated voltage and its reference value was used to identify the voltage-sensor faults, and the faulty voltage sensor was determined according to the deviation of voltage difference. To detect the current sensor faults, the abnormal current amplitude on harmonic subspace was adopted, and the faulty current sensor was located by distinguishing the current trajectory on *x*–*y* subspace under faulty state. All proposed methods have been verified by experimental results from the laboratory setup.

The second article, by Roberto E. Quintal-Palomo, investigated the operation analysis of an interior permanent magnet (IPM) machine working as a permanent magnet synchronous generator (PMSG) under partial demagnetization. The performance of the generator–converter system controlled with direct field oriented control (DFOC) algorithm is analysed using co-simulation (finite element analysis (FEA) and MATLAB). The DFOC algorithm shows quite good robustness by maintaining the speed even with a 25% of demagnetized PMSG. Also, an analysis of the rotating reference frame DQ signals was conducted in order to assess the demagnetization. The analysis proved that the continuous operation of the PMSG after partial demagnetization is possible, and the partial demagnetization can be detected and assessed from the electrical feedback signals, that is, DQ currents (demagnetization diagnostics). It was demonstrated that a classical method from the mechanical vibration analysis, namely envelope spectrum, brings good results in detecting and assessing the level of demagnetization. As with most of the previous literature, a priori knowledge of the base-line signals is much necessary, that is, the amplitude of the healthy machine harmonics.

Next two articles discuss the FD in induction machines, namely open phase detection in multi-phase motors and NN-based detection of the stator and rotor electrical faults of three-phase induction motors.

Strankowski, Guzinski, Wilczynski, and Morawiec, in their article, presented a new idea of online open phase FD based on the frequency analysis of the estimated observer variables in the sensorless five-phase induction motor drive implemented with an inverter output LC filter and third harmonic injection. A speed observer for the first control system and a rotor flux observer for the second control system with LC-filter consideration were presented in order to obtain the sensorless control possibility that is based only on the current sensors and the DC-link voltage sensor in the voltage inverter. The open phase faults were generated with the help of circuit breakers during the drive operation. A continuous drive operation was possible after deactivation and reactivation of the phases. The frequency analysis of the estimated speed showed a second supply harmonics that occurs after the deactivation of the phase with dominant amplitude in the frequency spectrum. This occurrence allowed an online open phase FD through the frequency analysis of the estimated speed. The presented procedure provided reliable FD results during the drive operation that can be used in applications with five-phase induction motors.

The paper by Ewert presents the possibility of using multi-layer perceptron (MLP) NNs in the detection of stator and rotor electrical faults of induction motors. FD and identification are based on the analysis of symptoms obtained from the Fast Fourier Transform of a voltage induced by an axial flux in a measurement coil. NN teaching and testing were performed in a MATLAB–Simulink environment. The effectiveness of various NN structures to detect damage, its type (rotor or stator damage) and damage levels (number of rotor bars cracked or stator winding shorted-circuits) are presented. On the basis of laboratory tests, it can be stated that the data obtained by the spectral analysis of the voltage induced in the measurement coil by axial flux enable the diagnosis of electrical damage in induction motors. Relatively simple NN with one hidden layer can detect electrical damage in induction motor with high efficiency (over 95%) and the damage type (number of shorted turns or number of rotor broken bars) with an average effectiveness close to 85%. Application of the networks with two hidden layers increases the effectiveness of the type of damage detection to a small extent only (a few percent). The use of NNs automates the process of assessing the technical condition of the tested machine.

The last paper in this first part of SS is focussed on the design of the observer-based FD structure for unknown systems using input–output measurements. The authors, M.A. Eissa, R. Darwish, A. E. Bassiuny, have applied this theory to a brushless direct current (BLDC) drive with unknown parameters. In this article, they present the design of a novel observer for FD purposes using the input–output measurements of the system with unknown parameters and present the observer gain tuning, regardless of the mathematical representation of the plant. The effectiveness of the proposed observer is verified by an experimental application to BLDC motor and compared with classical Luenberger observer. The experimental and comparison results prove a feasibility and effectiveness of the proposed observer for FD purposes.

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