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Faults diagnosis and control in a low-cost fault-tolerant induction motor drive system

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Highlights

- The analysis of the inverter voltages under the drive faulty mode was carried out.
- The open-switch fault diagnostic technique was experimentally proved.
- The speed sensor fault diagnosis was achieved by model reference adaptive system.
- The post-fault drive operation was provided under the unbalanced DC-link voltages.
- Both diagnostic techniques were based on a software solution.

Abstract

The paper deals with faults diagnosis and control methods for a fault-tolerant direct field-oriented controlled by Space Vector Modulation (SVM) two-level voltage-inverter-fed induction motor drive. In order to maintain an uninterrupted motor drive operation even under its faulty condition, two diagnostic algorithms as well as post-fault control techniques are developed. According to the first diagnostic system, that is related to single open-circuit faults in two-level voltage inverter, a failure diagnosis is performed by monitoring a time presence of a reference inverter voltage vector in particular sectors of the α–β coordinate system. After the fault detection, to maintain a high-quality drive performance, a switch-redundant inverter scheme is utilized. In case of the second diagnostic system, for the speed sensor failure detection, a motor speed estimator, that is based on a model reference adaptive system, is utilized. This algorithm is used for the post-fault motor drive operation as well. Both fault monitoring methods are based on a software solution, therefore they do not generate additional implementation costs.

To validate the described fault-tolerant control scheme, chosen simulation tests, which were carried out in MATLAB/Simulink, are presented. Additionally, in case of the transistor failure diagnosis, experimental tests were carried out.

Keywords: Fault-tolerant induction motor drives; Open-switch fault; Speed sensor fault; Speed estimator; Fault diagnosis

1. Introduction

High-performance vector-controlled AC motor drives have been commonly used in many industrial applications. However, the functionality of these drives can be significantly disturbed by faults of power electronics and sensor failures, among other things [16]. In order to increase the reliability of electrical drive systems, many fault monitoring

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algorithms have been investigated. Regarding to the type of fault, a high-quality drive operation can be maintained by applying a various remedial control techniques [5,7–9,14,16,21].

As mentioned before, a reliability of power electronic converters, especially inverters, is crucial to any variable frequency motor drive systems, therefore failures leading to transistor faults are considered in this work. The classification of open-switch fault diagnosis techniques can be based on the analysis of easily accessible signals, namely current, voltage, speed or control signals [1,8,31]. Some of the voltage based techniques require dedicated measurement systems for the fault identification [30] which increase the implementation cost of the drive and thus their application is limited. According to current based methods, which are summarized in paper [11], the stator phase currents are utilized as diagnostic signals. Regarding the fact that sensors of the stator currents are essential parts of electrical drives and they are utilized for necessary measurements of control variables, the current based diagnostic techniques can be treated as low-cost solutions. A combination of voltage and current based signals for the inverter fault identification can be also accomplished [2]. A more detailed review of the literature concerning the open-switch faults in the inverter-fed AC drives has been submitted in the papers [10,12,13,15,20,29].

As previously mentioned, to maintain the high-performance of the drive system, after the faulty semiconductor device is identified the remedial action has to be carried out. In this case redundant converter topologies were applied. Their classification was evaluated in papers [32,33].

In literature, methods that allow a drive speed control without a mechanical speed or position sensor are called speed-sensorless control algorithms. These techniques can be divided into three groups: methods based on a signal injection, artificial intelligence techniques and algorithms based on analytical model of the controlled machine. In the case of the first group an identification of the rotor position or speed of the machine is carried out by applying high frequency signal injection into the control signals [18,24,23,34].
The information about rotor position is contained in the easily accessible stator, e.g. currents [18]. In the case of the second group of the sensorless algorithms neural networks or fuzzy logic can be used [17,19,24]. Due to the relatively high computational requirements of these methods their industrial applications are significantly limited. The last group of the speed-sensorless control algorithms are mathematical model based techniques, like state observers [22,27,35], Model Reference Adaptive Systems (MRAS) [6,15,21,25,28] and Kalman filters [3,4]. These all techniques can substitute the drive speed sensor under its faulty condition [21].

In the literature, methods that permit drive control under its faulty condition are called fault-tolerant control techniques [5,9,16,21]. In order to achieve high-performance of the faulty motor drive, the previously mentioned fault diagnostic methods, redundant converter topologies as well as the speed sensorless algorithms are applied [9,21].

This paper deals with a fault-tolerant control technique for an induction motor (IM) drive. The main idea of the proposed method is based on a simple open-switch fault monitoring system that uses a reference voltage vector analysis in the stationary α–β coordinates for the failure detection, a redundant converter topology to compensate the transistor faults and a speed sensorless technique that is utilized as a remedial technique in case of a speed sensor failure. The main advantage of the proposed transistor faults diagnostic method, whose an experimental validation is the major achievement of this work, is not only full robustness against false alarms but also low computational requirements and simple hardware implementation of the algorithm, which can be realized using a microprocessor system or FPGA. Our findings show that the speed-sensor fault tolerance has been obtained by generating a residual which is calculated as an average absolute value of an error between the measured and an estimated motor speed, for the sensor fault diagnosis. Furthermore, the signal of the estimated speed is used after the speed sensor failure detection, which is common for the fault-tolerant motor drive systems [21]. An additional achievement of the presented research is the validation of the speed sensorless technique in the motor drive system fed by a four-switch voltage inverter. This inverter is used as the remedial converter topology applied after the transistor fault detection. The described fault-tolerant control method assures high-quality performance of the IM drive system under inverter open-switch faults as well as under a speed measurement system failure. To validate the proposed strategy, simulation tests in Matlab/Simulink environment were carried out. Additionally, the transistor fault diagnostic algorithm was validated in experimental tests.

2. Fault-tolerant control strategy

2.1. General remarks

A design of the fault-tolerant control strategy involves three main steps: fault detection, fault isolation and remedial action [9]. In the proposed drive control technique a diagnosis of the measuring system failure and the open-