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Real-time encoder faults detection and rotor position estimation for permanent magnet synchronous motor drives fault tolerant sensorless control using digital signal controller

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Abstract

As it is known, encoder is one of the most used devices in permanent magnet synchronous motor (PMSM) drives, especially when a closed loop operating is required. It gives important information for PMSMs vector control. However, this sensor is sensitive to many types of faults such as the total loss of the position information, the position disturbance by noises and the frequency variation of the position due to vibrations phenomena. In this paper, the first issue deals with real-time encoder faults detection using the discrete wavelet transform — based multiresolution analysis (DWT–MRA). Then, the second issue discusses the PMSM rotor position estimation using an efficient high frequency signal injection (HFSI) in order to ensure the PMSM fault tolerant sensorless control (FTSC). A digital signal controller (DSC) dsPIC30F6010A has been used for DWT–MRA and HFSI algorithms implementation.

Keywords: PMSM; DWT–MRA; HFSI; Faults detection; Fault tolerant sensorless control

1. Introduction

In recent years, the automation development in industrial processes has created a demand for different types of electric machines which are characterized by precision and rapidness. Given this fact, electric machines and their controls are increasingly used in all industrial sectors, as well as in technologic sectors [20], such as: home automation, military equipments, textile, land transports (road and rail, industrial vehicles), maritime transports (ship transport, marine propulsion systems), avionics (aircraft propulsion systems), machine tools, servo motors, robotics, wind turbines. In fact, Permanent Magnet Synchronous Machine (PMSM) is one of the most used machines in these applications.

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Furthermore, in such high performance applications that require high accuracy for PMSMs Adjustable Speed Drives (ASDs) vector control, the use of a position/speed sensor is mandatory. Indeed, the ASDs service continuity, incorporating position/speed sensors, depends intimately on the measurement availability. In the case of sensor faults occurrence (such as total or partial loss of the position information, offset, disturbances, measure deviation, channel mismatch, etc. [1,6,10]), measurements cannot be performed in a good way. This may affect the ASD normal operating and lead to dangerous system operation and instability or even to the PMSM drive breakdown.

For service continuity and in the case of position/speed sensor faults, a sensorless control algorithm is paramount in order to maintain the PMSM operating and therefore increase the drive reliability [1,5,13,16,17,19]. This algorithm known as Fault Tolerant Control (FTC) is a mandatory step in applications involving the concept of service continuity. However, to ensure this step, firstly, faults that may affect PMSM must be detected using faults detection techniques. Secondly, PMSM rotor position estimation should be performed. Anyway, faults detection and position estimation must be performed as fast as possible in order to ensure the control reconfiguration of the PMSM-ASD.

More recently, FTC, in the case of position sensor faults, has attracted more and more attention in both industry and academic communities due to increased demands for productivity, high system performance, safety and operating efficiency. Thus, FTC can be performed only if the fault detection is ensured. Indeed, the Discrete Wavelet Transform—based MultiResolution Analysis (DWT–MRA) is one of the widespread used methods in faults detection. The DWT–MRA decomposes a given signal into approximations and details signals, from which the original signal can be reconstructed. The DWT–MRA is based on the use of filter banks that form the multiresolution analysis (MRA) basis.

On the other hand, the wavelet transform properties allow the multiresolution analysis to be a very powerful detection tool of transients and singularities appearing in a signal. It is very effective in the case of events that cause abrupt changes (short term). Indeed, the transients detection efficiency depends on the correlation between the waveform of the analyzing wavelet and that of transients or singularities. In fact, the DWT–MRA has been largely investigated in electrical and mechanical fault detection occurring in AC electric machines or their associated inverters, [2,8,11,14]. In fact, such signal processing technique allow the detection of transients and signal singularities due to faults occurrence, and also the faults feature extraction in such systems.

Therefore, this technique offers interesting proprieties and characteristics which can be used in many applications, and especially in the supervision, diagnosis and control reconfiguration of electric machines. In fact, they give relevant information that are related to signals in the case of faults occurrence.

In previous works, two encoder faults detection has been performed based on simulation results, which are the total loss of the position information and the disturbance of position information by a high level noise [6].

In this paper, simulations and experimental results are given in order to prove the detection efficiency of the implemented DWT–MRA for encoder faults. The DWT–MRA has been applied to the PMSM stator currents in order to detect encoder faults, namely the total loss of the position information, the position disturbance by noises and the frequency variation of position due to vibrations phenomena. On the other hand, the second part is devoted to the PMSM rotor position estimation using an efficient High Frequency Signal Injection (HFSI) in order to ensure a fast and effective PMSM Fault Tolerant Sensorless Control (FTSC). In addition, this issue is especially addressed to low speed PMSM operating, where challenges still need to be solved. In fact, according to the existing works, fault tolerant control has been done especially at middle and high-speed ranges. However, FTC at low speeds has not been largely investigated. Moreover, the FTC methods which are used at middle and high speeds are not effective at low speeds. That is why an alternative method has been used in this work in order to ensure the PMSM-FTC after position sensor fault occurrence. This method can ensure acceptable performances at low and very low speeds.

2. Techniques used for PMSM fault tolerant sensorless control (FTSC)

2.1. Multiresolution analysis—based discrete wavelet transform for encoder faults detection

The DWT–MRA is based on a numerical filter bank, which is composed by low-pass filters (LPF) and high-pass filters (HPF), [18]. These filters are used for the construction of the multiresolution time–frequency plane. The discrete-time signal $S(n)$ passes through the analysis bank as shown by Fig. 1. This signal is filtered using $h(n)$ and $g(n)$ functions that allow separating the frequency content of the input signal in frequency bands with equal width. The filters $h(n)$ and $g(n)$ are respectively low-pass and high-pass filters. The output of each filter contains half of the frequency content, but an equal number of samples as the input signal. Thus, the two filters outputs contain together