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Analysis of the fault tolerant induction motor drive system

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In the paper the influence of the chosen sensors faults (rotor speed and stator current sensors) to the properties of vector controlled induction motor drive system are tested. Faults detection algorithms based on the simple signals from internal control structure are developed. The simulation tests carried out in Matlab/SimPowerSystem software. The proposed solution can be successfully applied in the fault tolerant drive systems.

KEYWORDS: Fault Tolerant Control (FTC), induction motor drive, diagnostic system, sensor faults, DFOC, MRAS

1. Introduction

For the proper operation of induction motors drives information about the machine state variables are necessary. Those signals (informations) can be obtained by direct measurement or estimation mechanical and electrical state variables[1]. Electronic components and measuring instruments may deteriorate or can be mechanically damaged, so it is necessary to limit their quantity in the control loop through the use of more advanced estimators [2]. To ensure the correct functioning of complex drive systems it is necessary to take into account diagnostic techniques and control which, in a timely manner will allow to detect fault and respond appropriately to control structure. It is said then about the fault-tolerant systems (FTC(S) - Fault Tolerant Control (Systems)) [3, 4].

In this paper the simple algorithmic methods to the diagnosis and detection of damage of the chosen sensors are presented. Proposed solutions are based on the basic internal state variables of induction motor drive, controlled by DFOC [1]. In studies rotor flux is calculated from the current model of the induction motor [1, 2]. Speed is estimated by MRAS type estimator [2]. An analysis of fault tolerant structures are proposed. The study was performed in MATLAB-SimPowerSystem.

2. Diagnostics of an induction motor

A failure of the speed sensor is associated with the creation of uncontrollable phenomena in the drive. Depending on the type of damage to the encoder, fault may even lead to destruction of parts of the motor or frequency converter. In

Fig. 1 the reference, actual, measured and estimated rotor speed during the faulted speed sensor conditions are presented.

The effects of speed sensor failure in the vector-controlled drives are the most visible in the electromagnetic torque, stator current components and the rotor speed [6]. Moreover, signals coupled with these values can be successfully used in the diagnostic systems.

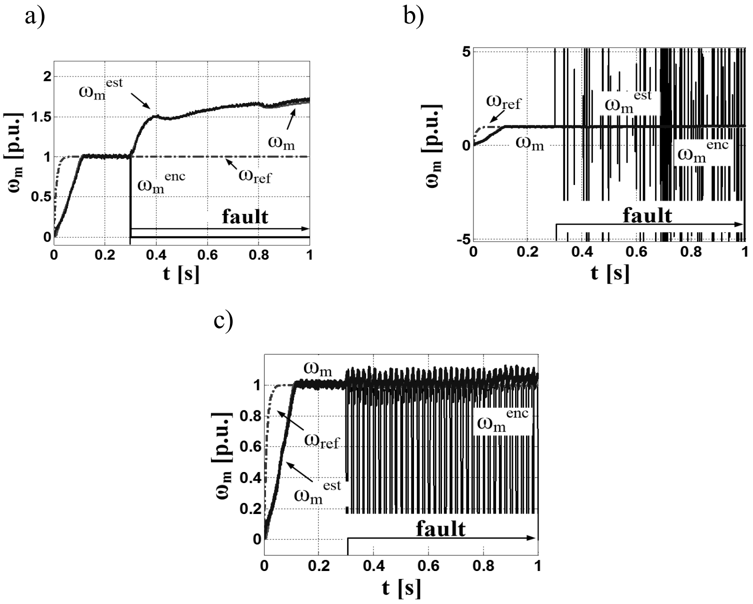

Fig. 1. Transients of measured and estimated speed for a total failure of the speed sensor (a), for partial failure of individual pulses of the speed sensor (b) and for cyclic interruption of specific pulses from the encoder (c)

The article focuses on algorithmic detectors which are based on the basis signals from internal control structure. A common approach to identify speed sensor fault is to utilize a speed observer and compare the estimated speed with the measured value to generate speed residual [16], [8]. If the residual exceeds a threshold, a speed-sensor fault is detected. [2] (Fig. 2). In addition, in order to increase the accuracy of the algorithm an additional signal - component of the stator current i_{sy} may be used.

A major difficulty in this type of algorithm is to determine the threshold value of the error between these signals, for which the detector should be activated. After the speed sensor fault the diagnostic algorithm switches the system from measured speed to the estimated speed [2]. The principle of operation can be described by the relation (1):

$$IF\left|\omega_m - \omega_m^{est}\right| \geq x \quad THEN \quad \omega_m^{est} \quad ELSE \quad \omega_m \tag{1}$$

where x is the maximum speed error.

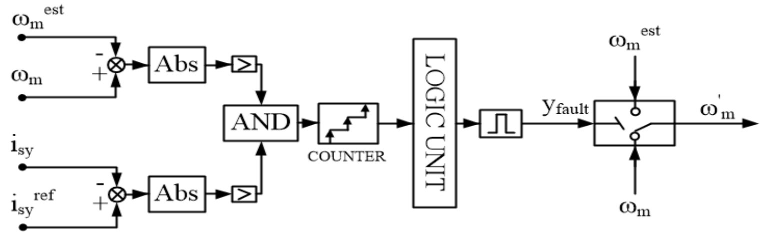

Fig. 2. Block diagram of the speed sensor failures detector for DFOC

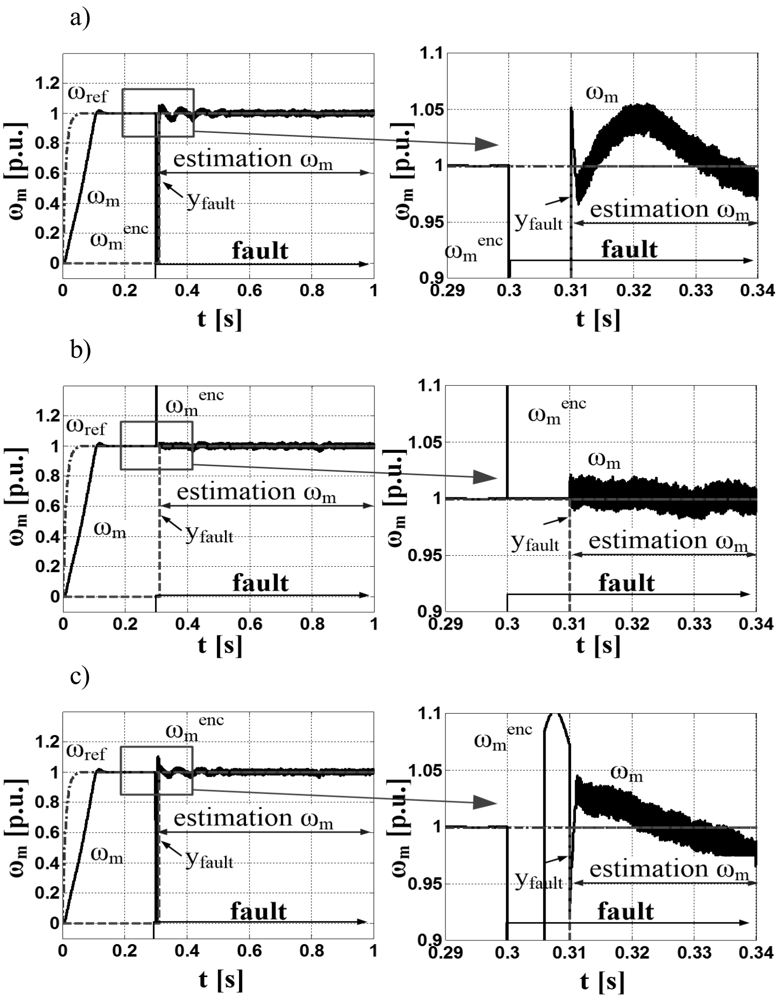

Fig. 3. Transients of mechanical and estimated speed for total failure of the speed sensor (a), for failure of individual pulses of the measurement signal (b) and for cyclic interruption of specific pulses from the encoder (c)

The result of such a detector is the absolute value compared with the permissible speed error. If the absolute value is greater than a threshold then the system generates a logic pulse indicating the occurrence of damage. Confirmed failure of the sensor will switch between the measured speed and estimated using the estimator $MRAS^{CC}$ [2] and this value can be used in the internal speed control loop.

In Fig. 3 the Fault Tolerant structure during the faulted conditions is presented. After the speed sensor fault for *t = 0.3 s* detection mechanism changed the topology of the drive to the sensorless system with $MRAS^{CC}$ estimator. In all cases fault is detected after ~ 0.01 s. In addition, short pulses are noticeable in the waveforms of the measured speed, but they do not affect significantly to the performance of the entire control system.

3. An influence of the stator current sensor fault to the properties of the induction motor drive

This chapter presents the effects of the stator current sensor failure to the performance of the drive system controlled by DFOC method. The study was performed for the drive operating in a nominal speed, for *t = 0.4 s* and *t = 0.8 s* motor has been loaded with torques $0,5m_{oN}$ and m_{oN} respectively. For *t = 0.3 s* the speed sensor is damaged. In this paper only the angular speed transients are presented to illustrate an influence of the faulted operation to the drive. Detailed studies are presented in the paper [6]. In Fig. 4 the effect of the sensor phases A and B fault of the stator current sensor for operation of the induction motor drive are presented.

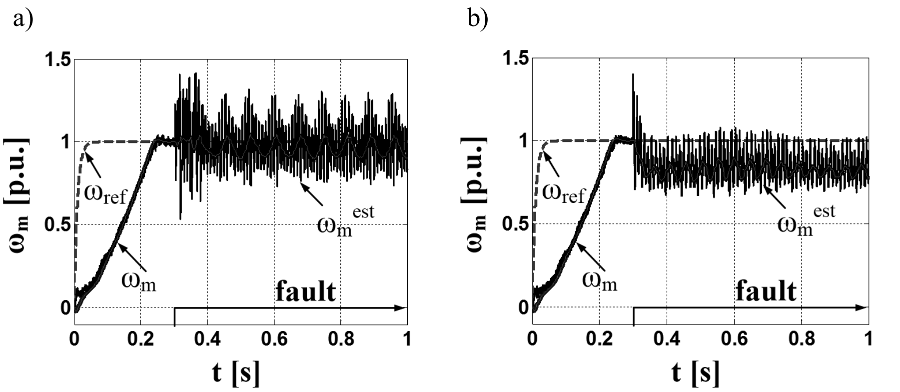

Fig. 4. Transients of measured and estimated speed for the cyclical intermittent measurement signal from the sensor phase A (a) and B (b) and for the disappearance of the measurement signal from the sensor phase A (c) and B (d)

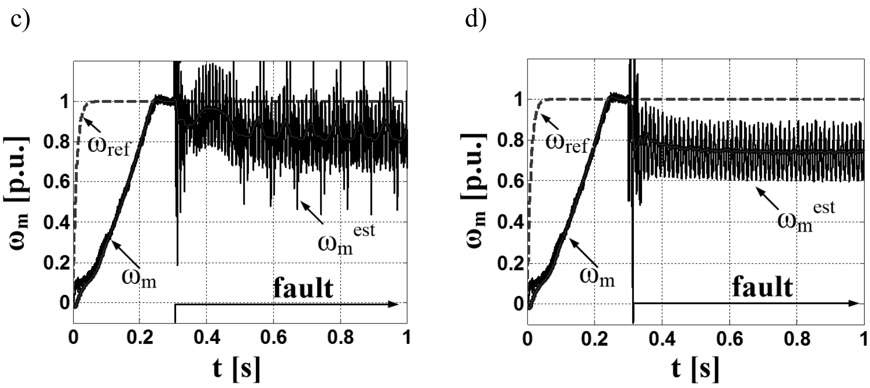

Fig. 4. Transients of measured and estimated speed for the cyclical intermittent measurement signal from the sensor phase A (a) and B (b) and for the disappearance of the measurement signal from the sensor phase A (c) and B (d)

The biggest impact of current sensor failures occurred for a total cessation of feedback and periodically intermittent measurement signal. Intermittent measurement signal causes oscillations of great amplitude and frequency of the mechanical and estimated speed, and as a result of the electromagnetic torque. Interruption of feedback causes oscillation of the speed and torque of less than in the previous case frequency. For all kinds of faults important, for the diagnostic point of view, has i_{sx} component of the stator current.

4. Fault detection stator current sensor

Proposed stator current sensor fault detection system is based on observation of the estimated value of the rotor flux. In addition, Field Oriented Control structure uses information about the component i_{sx} of stator current. Fig. 5 presents a block diagram of a proposed detector of a current sensor fault. For Field Oriented Control structure condition (2) must be fulfilled:

$$IF\left|\frac{d}{dt}i_{sx}\right| \geq y_1 \quad AND \quad \frac{d}{dt}\psi_r^{est} \geq y_2 \tag{2}$$

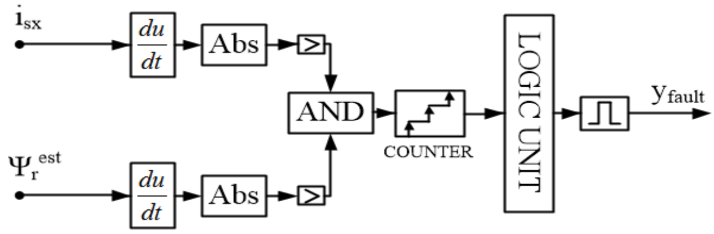

Fig. 5. Block diagram of a detector for a current sensor fault

The principle of the algorithm based on derivative of estimated value of the rotor flux. The signal is further sampled and delayed to avoid accidental failure determination during transient. In addition, stator current component i_{sx} is observed. The result of such a detector is compared with the value of the permitted limit. If the value is greater than threshold then the system generates a logic pulse indicating the occurrence of damage. After the confirmation of the stator current sensor fault, the additional sensor is switch on (in phase C) and the current in third phase is calculated from equation: (3):

$$i_A = -(i_B + i_C) \tag{3}$$

As a result, proper operation of the drive is possible in the occurrence of sensor fault. This method cannot be used if two sensors are broken.

In the control system α-β components of the stator current are obtained by measuring the phase currents A and B. Thus, it is possible to determine which sensor has failed. If, after detection of fault component of the stator current α differs from the measuring signal from phase A, it means that the first sensor has a failure ($i_{s\alpha} = i_{sA}$), otherwise the second sensor - the phase B.

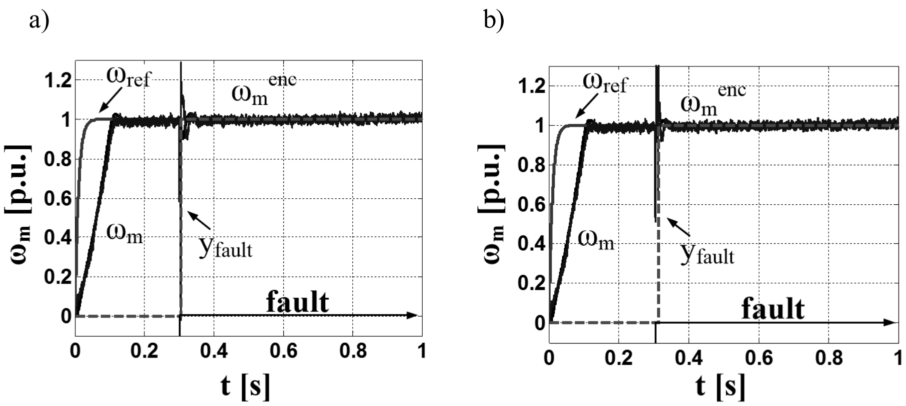

Fig. 6. Transients of mechanical and estimated speed for stator current faulted operation (phase A): total failure of the sensor (a), intermittent measurement signal (b)

The current sensor fault can be detected after approximately 0.01 s. after a failure occurred (Fig. 6). The proposed solution for fault tolerant system based on the redundancy of the stator current measurement allowed the detection of failures and thereby enable further operation of the system and the correct estimation of speed.

5. Conclusions

The article proposes systems to detect faults of the speed and stator current sensors which can be successfully used in drives with an increased degree of safety. It should be noted that the proposed detection algorithms are very simple in design, not charged to the complete propulsion system and based on the signals available in the internal structures of the vector control. It is possible to develop a more complex and reliable sensors fault detection systems based on the state estimators or neural networks.

Acknowledgment

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