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Current Sensor Fault-Tolerant Vector Control of Induction Motor Drive Systems – Fault Detection, Localization and Compensation

The doctoral thesis focuses on the drive systems with induction motors that tolerate current sensor faults. This topic is particularly significant considering that the information on the stator current is necessary for implementing vector control structures, allowing precise control over motor speed. A comprehensive analysis of the impact of various types of current sensor faults has shown the necessity of employing fault-tolerant strategies, especially in systems with a high level of safety, such as electric vehicles.

Within the scope of the doctoral thesis, a literature review was conducted on the detection and compensation of current sensor faults. Based on the state of the art, stator current estimators were proposed, enabling the maintenance of full control over the drive system, even in the case when all current sensors become faulty. Furthermore, by applying an original modification to the classical Luenberger observer, it was possible to significantly reduce the sensitivity of the proposed algorithm to changes in the parameters of the induction motor, by over 90% in some operating points, which represents a significant improvement compared to the solutions known in the literature.

Additionally, as part of this doctoral thesis, a rotor resistance estimator was developed, and a comparative analysis was conducted with solutions known from the literature. The conducted research demonstrated a significant improvement in the quality of stator current estimation when using the developed rotor resistance estimator. Moreover, the proportional adaptation of the stator resistance further reduced the stator current estimation error. In the context of improving the quality of stator current estimation, the need to compensate for the voltage inverter dead time was also presented.

Based on the analysis of the influence of the coefficient k_0 in the observer gain matrix **G** on the quality of stator current estimation, a dual modified Luenberger observer was developed. This observer is characterized by high-quality reconstruction of the current both in the stator winding phase where a fault occurred (for fault compensation) and in the phase where current measurement is still available (for potential fault detection). Using this algorithm, the current sensor fault-tolerant control system was developed.

According to the state of the art in the analyzed topic, a significant challenge in the model-based detection methods is determining of the threshold error value between the measured and estimated current values. In this thesis, an adaptive threshold coefficient dependent on the load torque and motor angular velocity was proposed. Experimental studies demonstrated that the detector allowed for the detection of current sensor faults that could be harmful to the drive system. In the case of gain errors, which, according to the analysis conducted, did not cause a loss of drive system stability, the detector was effective when the error was ±30% or ±50% but not effective when it was in the range of ±10%. It is important to note that this represents a significant improvement compared to the literature, where the case of 80% gain error was only considered.

The research on current sensor fault-tolerant control systems was conducted in three scenarios: speed changes at constant load, load changes at constant speed, and at very low angular velocity values. The analysis showed that the solutions proposed in this thesis provide high accuracy in detecting and compensating for current sensor faults in various drive operating conditions. Additionally, the sensor faults were correctly detected, localized, and compensated for both transient and steady-state operating conditions, during both regenerating and motoring modes, and even at very low angular velocity (2% of the rated value).

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