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Investigation of the Impact of Current Controller Parameters in Field-Oriented Control on Fault Detection in PMSMs

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INTRODUCTION & AIM

Permanent magnet synchronous motors (PMSM) are widely used in various industrial applications, mainly in automation, electromobility, and everyday appliances. In drive systems, particularly with PMSM motors, vector control methods are of crucial importance. These methods enable precise regulation of dynamic properties, ensuring optimal performance and efficiency.

An important aspect of vector control is the selection of appropriate control parameters, which not only affect dynamic behavior but can also play a significant role in detecting potential faults. It should be noted that the control structure itself can mask existing faults, making them difficult to detect. PMSM motors, regardless of their application, are susceptible to faults such as demagnetization and short circuits of the winding. These faults can affect the operating parameters of the machine, making their early detection crucial to maintaining the reliability and performance of the system and reducing potential repair costs.

This study investigates the impact of the dynamics of controller parameters in field-oriented control (FOC) on the system's ability to detect faults. The main objective of the research is to select the appropriate current controller settings and analyze their impact on the content of fault symptoms in the control system signals. The mentioned studies will be carried out on a field-circuit model of a PMSM motor, in co-simulation studies to determine the impact of the occurrence of damage on the operation of the drive, as well as on an experimental stand. The obtained information in the form of fault symptoms will be a valuable indicator, allowing improvement of the reliability and effectiveness of diagnostic systems.

METHOD

When supplying a motor with voltage override, it is necessary to introduce a mechanism into the control system that separates the d-q coupled control lines. This enables a full control to be achieved even during dynamic states. The nonexistence of this solution leads to erroneous control, which can result in unstable operation and reduced motor efficiency. To achieve full control, it is necessary to use a decoupling technique for the motor current paths.

- ***Decoupling of current paths:***

The main goal of decoupling is to eliminate the dependence between the current tracks, allowing the currents in the *d* and *q* axes to be controlled independently. The practical result is that a change in current on one axis does not affect the current on the other axis. The additional advantage of decoupling is the generation of two additional signals E_{sd} and E_{sq}, described by the following relation:

$$\hat{E}_{sq} = p_p \Omega_m \Psi_{sd} \quad (1) \qquad \hat{E}_{sd} = -p_p \Omega_m \Psi_{sq} \quad (2)$$

In addition, the decoupling signals can be used for diagnostics, allowing for monitoring of the motor's condition and early detection of potential faults.

The studied Lenze PMSM 14H15 motor is a surface permanent magnet motor (SPMSM) with characteristics properties. Due to its construction, it is possible to write the equality between the inductance values L_s=L_d=L_q, which simplifies the control system design process. This allows the same controller dynamics to be assumed for both the *d* and *q* axes, which significantly simplifies the selection of controller settings. Additionally, assuming that the dynamics of the current controllers are close to inertial systems, their parameters can be effectively optimized.

$$\frac{I_{sd}(s)}{I_{sd}^{ref}(s)} = \frac{\omega_c}{s+\omega_c} = \frac{1}{T_c s + 1} \quad (3)$$

For the control structure thus developed (Fig. 1), experiments were carried out for various PMSM motor faults.

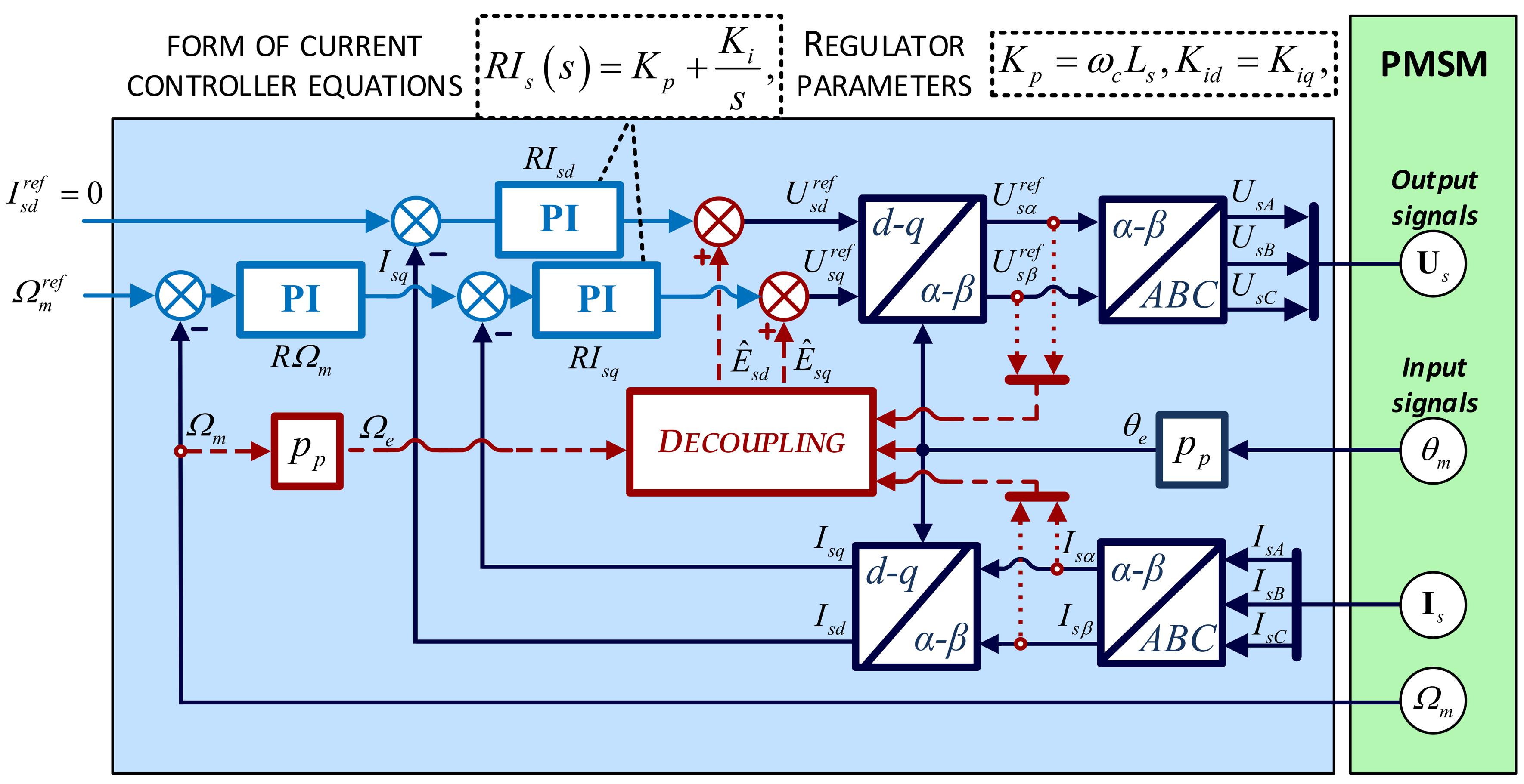

Fig.1 Diagram of FOC control with decoupling system and setting parameters of current regulators with bandwidth

RESULTS & DISCUSSION

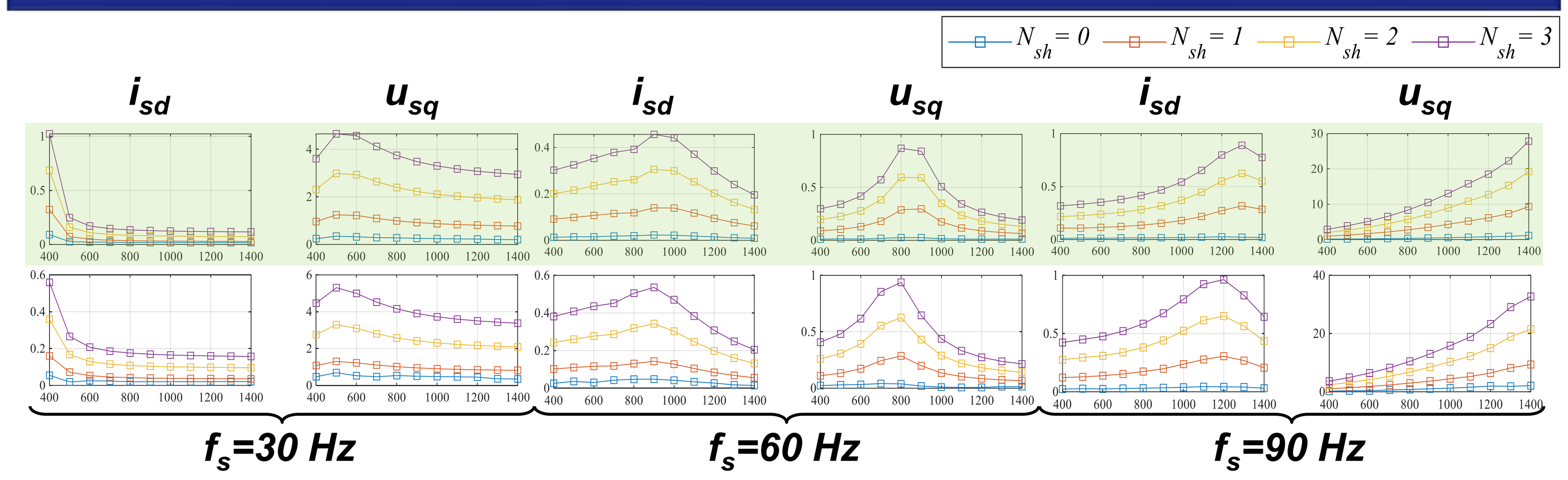

Fig.2 Comparison of 2f_s signal characteristics from the PMSM control system as a function of the current control system bandwidth for a shorted-turns (N_{sh} = 1-3) and a no-faulty motor; supply frequency f_s = 30, 60, 90 Hz, for ca. 0% (green frame) load torque and rated load torque; simulation results from the FEM model. Stator current components i_{sd} in [A], stator voltage components u_{sq} in [V], bandwidth in [Hz]

Simulation and experimental studies were conducted in accordance with the control structure presented. Simulation studies were carried out with faults in the form of stator winding short circuits of the stator winding (Fig. 2) and demagnetization (Fig. 3). The research was analyzed on the basis of changes in the bandwidth parameter ω_c. The above studies show a visible impact of faults on signals in the closed-loop control structure. Extremes dependent on the ω_c parameter and the machine supply frequency are noticeable. The studies were carried out over the full range of torque load T_L=0-1T_n. However, as analyzed, the components 2f_s (related to stator fault Fig. 2) and f_s (related to demagnetization Fig. 3) are independent of the torque. It can be observed in the operation of the powertrain that with the increase in the influence of the regulator settings (higher system dynamics), the system tends to hide the symptoms of faults in the control structure. The conducted analysis of a whole range of cases allows to notice that an appropriate relationship of current and voltage signals from the structure allows to determine effective diagnostic indicators. The simplest solution for a diagnostic system would be, for example, an increase in the indicator associated with a fault by 10% of the nominal value (e.g., the machine during initial operation). After reaching this threshold, a detailed analysis should be performed, or maintenance should be planned. The presented dependencies make it possible to develop precise tools for monitoring and assessing the system's condition, which is extremely important for ensuring its reliability and operational safety.

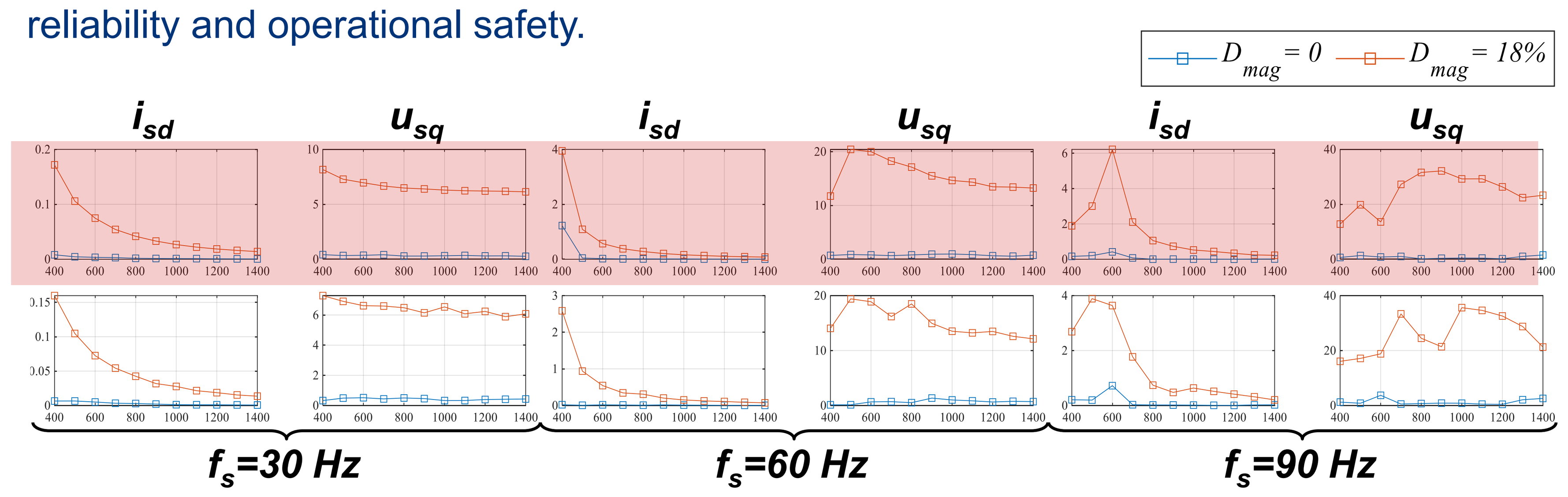

Fig.2 Comparison of f_s signal characteristics from the PMSM control system as a function of the current control system bandwidth for a demagnetization (N_{mag} = 18%) and a no-faulty motor; supply frequency f_s = 30, 60, 90 Hz, for ca. 0% (red frame) load torque and rated load torque; simulation results from the FEM model. Stator current components i_{sd} in [A], stator voltage components u_{sq} in [V], bandwidth in [Hz]

CONCLUSION

Analysis of the impact of the PMSM motor control structure on its operation during the occurrence of various damages plays a crucial role in fault diagnosis. It has been proven that the adopted value of the bandwidth of current controllers (different parameters) significantly affects the diagnostic symptoms that appear, in both current and voltage signals. As part of the research, comprehensive simulation and experimental studies were carried out to present this phenomenon. The performed co-simulations on a field-circuit model, considering various types of damage, such as short circuits and demagnetization, allow for accurate mapping of real engine operating conditions. This was presented under experimental conditions on a specially prepared laboratory stand, which allowed recording of motor signals in controlled conditions close to industrial conditions. These data were used to validate the simulation results and show a clear correlation between the symptom values and the controller parameters.

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