Problem 1: Flux estimation based on the current model

The rotor flux of the induction motor can be estimated in many ways. If the drive is equipped with a speed sensor, a current-model based flux estimator in synchronous coordinates can be used:

$$\frac{\mathrm{d}\hat{\psi}_\mathrm{R}}{\mathrm{d}t} = \hat{R}_\mathrm{R}\left(i_\mathrm{d} - \frac{\hat{\psi}_\mathrm{R}}{\hat{L}_\mathrm{M}}\right) \quad \text{and} \quad \frac{\mathrm{d}\hat{\vartheta}_\mathrm{s}}{\mathrm{d}t} = \omega_\mathrm{m} + \frac{\hat{R}_\mathrm{R} i_\mathrm{q}}{\hat{\psi}_\mathrm{R}}$$

where $\hat{\psi}_\mathrm{R}$ is the estimate of the flux magnitude and $\hat{\vartheta}_\mathrm{s}$ is the estimate of the flux angle. Derive these equations starting from the voltage and flux equations in stator coordinates. Draw also the block diagram of the rotor-flux-oriented control system.

Problem 2: Calculation of operating points

The rated values of a three-phase induction motor are: $U_\mathrm{N} = 400$ V; $f_\mathrm{N} = 50$ Hz; $n_\mathrm{N} = 1460$ r/min. The motor parameters are:

$$R_\mathrm{s} = 0.45\ \Omega \qquad R_\mathrm{R} = 0.28\ \Omega \qquad L_\mathrm{M} = 0.075\ \mathrm{H} \qquad L_\sigma = 7.1\ \mathrm{mH}$$

(a) Rotor-flux-oriented vector control is used. Calculate the stator current components i_d and i_q as well as the mechanical power in the rated operating point.

(b) The motor is driven in the field-weakening region. Evaluate the slip angular frequency and the torque in the steady state when i_d is reduced to 50% but i_q is kept constant. Calculate also the stator frequency and the stator voltage assuming that the rotor speed is two times the rated speed.

Problem 3: Flux dynamics

The rotor flux of an induction motor is controlled by the stator current component i_d in rotor-flux coordinates. At $t = 0$, a stepwise change Δi_d is assumed in the d-component of the stator current. Derive expressions for the change $\Delta\psi_\mathrm{R}(t)$ in the rotor flux and for the change $\Delta i_\mathrm{Rd}(t)$ in the d-component of the rotor current (that is parallel to the rotor flux).