Problem 1: Steady-state characteristics of a DC motor

A DC motor with a separately excited field winding is considered. The rated armature voltage is $U_\mathrm{N} = 600$ V, rated torque $T_\mathrm{N} = 420$ Nm, rated speed $n_\mathrm{N} = 1600$ r/min, and maximum speed $n_\mathrm{max} = 3200$ r/min. The losses are omitted.

(a) The flux factor k_f is kept constant at its rated value. When the armature voltage is varied from 0 to U_N, the speed varies from 0 to n_N. Determine the rated armature current I_N.

(b) A load is to be driven in the speed range from n_N to n_max by weakening the flux factor while the armature voltage is kept constant at U_N. Determine the torque available at maximum speed, if the rated armature current I_N is not exceeded.

(c) Sketch the armature voltage U_a, flux factor k_f, torque T_M, and mechanical power P_M as a function of the speed, when the armature current is kept at I_N.

Problem 2: Transfer functions

(a) A DC motor is considered. Derive the transfer function from the terminal voltage $u_\mathrm{a}(s)$ to the terminal current $i_\mathrm{a}(s)$.

(b) A lumped thermal capacity model is considered:

$$p_\mathrm{d}(t) = \frac{1}{R_\mathrm{th}}\theta(t) + C_\mathrm{th}\frac{\mathrm{d}\theta(t)}{\mathrm{d}t}$$

Derive the transfer function from the power loss $p_\mathrm{d}(s)$ to the temperature rise $\theta(s)$.

Problem 3: Properties of first-order systems

Consider a first-order system

$$G(s) = \frac{K}{1 + s\tau}$$

(a) What is the steady-state gain of the system?

(b) Derive the rise time from 10% to 90% for a step input.

(c) What is the 3-dB bandwidth α of the system?