Answer all five questions (in English, Finnish, or Swedish).

1. Describe the field-oriented control system of permanent-magnet synchronous motors. Draw also the block diagram of the control system, label the signals in the diagram, and describe the tasks of the blocks.

   Solution:

   See lectures and readings.

2. Answer briefly to the following questions:
   (a) Why a speed reduction gear is often used in electric drives?
   (b) Why three-phase machines are preferred to single-phase AC machines?
   (c) What is the expression for the current space vector as a function of the phase currents i_a, i_b, and i_c?

   Solution:

   See lectures, exercises, and readings.

3. A converter-fed permanent-magnet DC motor drive is used to start a mechanical load. The rated power of the motor is 4 kW and the rated rotation speed is 1 500 r/min. As seen by the motor, the total moment of inertia is 10 kgm^2 and the load torque is constant 25 Nm. The current limit of the converter has been set to twice the rated motor current. How long does it take to accelerate the motor and its connected mechanical load from zero to the speed of 1 500 r/min?

   Solution:

   The rated angular rotor speed is

$$\omega_\mathrm{N} = 2\pi n_\mathrm{N} = 2\pi \cdot \frac{1\,500\ \mathrm{r/min}}{60\ \mathrm{s/min}} = 157.08\ \mathrm{rad/s}$$

   The rated torque of the motor is

$$T_\mathrm{N} = \frac{P_\mathrm{N}}{\omega_\mathrm{N}} = \frac{4\,000\ \mathrm{W}}{157.08\ \mathrm{rad/s}} = 25.46\ \mathrm{Nm}$$

   During the acceleration, the armature current of the motor is twice its rated value. Since the torque of the permanent-magnet DC motor is proportional to the armature current, the motor produces twice the rated torque $T_\mathrm{M} = 2T_\mathrm{N}$. Hence, the acceleration time is

$$\Delta t = J\frac{\Delta\omega_\mathrm{M}}{T_\mathrm{M} - T_\mathrm{L}} = 10\ \mathrm{kgm}^2 \cdot \frac{157.08\ \mathrm{rad/s}}{2 \cdot 25.46\ \mathrm{Nm} - 25\ \mathrm{Nm}} = 60.6\ \mathrm{s} \approx 1\ \mathrm{min}$$

4. A DC motor with a separately excited field winding is considered. The rated armature voltage is $U_\mathrm{N} = 500$ V, rated torque $T_\mathrm{N} = 220$ Nm, rated speed $n_\mathrm{N} = 1\,600$ r/min, and maximum speed $n_\mathrm{max} = 3\,200$ 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. Clearly label axes of your graph.

Solution:

This problem corresponds to Problem 1 in Exercise 1 with different numerical values.

5. Consider a three-phase four-pole permanent-magnet synchronous motor. The stator inductance is $L_\mathrm{s} = 2$ mH and the stator resistance can be assumed to be zero. The permanent magnets induce the rated voltage of 400 V at the rotational speed of 1 500 r/min. The rated current is 10.3 A.

(a) The control principle $i_\mathrm{d} = 0$ is used. The motor is operated at the rated voltage and current. Calculate the rotational speed, torque, and mechanical power.

(b) The motor is driven in the field-weakening region at the rated voltage and current. The speed is increased until the absolute values of i_d and i_q are equal. Calculate the rotational speed, torque, and mechanical power.

Draw also the vector diagrams.

Solution:

This problem corresponds to Problem 3 in Exercise 6 with different numerical values.