Answer all five questions (in English, Finnish, or Swedish). No support materials are allowed. Using a calculator is allowed, but all memory must be cleared!

1. Describe the field-oriented control system for 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.

2. Answer briefly to the following questions:
   (a) Why three-phase machines are preferred to single-phase AC machines?
   (b) How the physical size of the motor approximately depends on the rated values of the motor?
   (c) Why the antiwindup is used in PI controllers?

3. A DC motor with a separately excited field winding is considered. The rated armature voltage is $u_\mathrm{N} = 400$ V, rated torque $\tau_\mathrm{N} = 20$ Nm, rated speed $n_\mathrm{N} = 1\,000$ r/min, and maximum speed $n_\mathrm{max} = 3\,000$ 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 current i_N is not exceeded.
   (c) Sketch the armature voltage u, flux factor k_f, torque τ_M, and mechanical power p_M as a function of the speed, when the armature current is kept at i_N.

4. Consider a three-phase four-pole permanent-magnet synchronous motor. The stator inductance is $L_\mathrm{s} = 0.035$ H 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 7.3 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. Draw also the vector diagram.

5. A four-pole surface-mounted PM synchronous motor is fed from a current-controlled inverter. The shaft of the rotor is connected to a fan, whose load-torque profile $|\tau_L| = k\omega_M^2$ is quadratic. The current components are controlled in rotor coordinates. The d-axis current i_d is kept at zero, while two different pulses are applied on the q-axis current i_q, as shown in the figures below. Based on the waveforms, determine the total inertia J and the load-torque coefficient k. You may use assumptions, but justify them briefly.

[Hint: Determine first the PM flux constant ψ_f.]