Written examination in Control of Electrical Drive Systems and Converters

8th semester

- All usual helping aids are allowed, including text books, slides, personal notes, and exercise solutions.
- Calculators and laptop computers are allowed, provided that all wireless and wired communication equipment is turned off.
- Internet access is strictly forbidden.
- Any kind of communication with other students is not allowed.
- Remember to write your study number on **all** answer sheets.
- The complete description of the solution of the questions must be attached separately.
- Only results with a complete description of the solution will be taken into account.
- All intermediate steps and calculations should be included in your answer sheets --- printing the final result is **NOT** sufficient.
- This exam contains **3** parts. The percentage is indicated for every part.

Part 1 (50 %)

1.1 How is soft switching realized and what are the advantages and disadvantages compared to hard switching? Use also the switching trajectory in your explanation (10%)

1.2 How is three-phase PWM implemented in an analog application? (10%)

1.3 Discuss in detail Table 14-2 from the book 'Power Electronics Converters, Application and Design. N. Mohan, T.M. Undeland and W.P. Robbins (cover at least 6 parameters). (10%)

Table 14-2 Comparison of Adjustable Frequency Drives

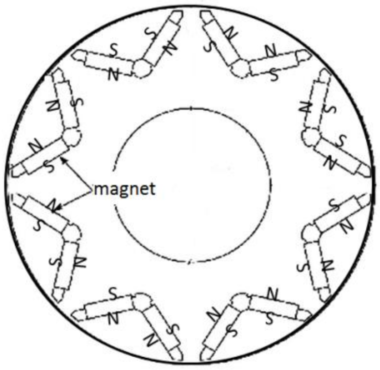
Parameter	*PWM*	*Square Wave*	*CSI*
Input power factor	+	−	−−
Torque pulsations	++	−	−
Multimotor capability	+	+	−
Regeneration	−	−	++
Short-circuit protection	−	−	++
Open-circuit protection	+	+	−
Ability to handle undersized motor	+	+	−
Ability to handle oversized motor	−	−	−
Efficiency at low speeds	−	+	+
Size and weight	+	+	−−
Ride-through capability	+	−	−

1.4 What is discontinuous PWM and what are the advantages and disadvantages of such modulation techniques compared to ST-PWM? How can these be implemented? (20%)

For all questions: besides explaining with your own words, use also figures in your answers.

Part 2 (30%)

An interior permanent magnet machine's rotor is shown below. Modelled in a synchronously rotating dq-reference frame, we have:



$$u_q = Ri_q + p\lambda_q + \omega_r \lambda_d \qquad \lambda_q = (L_{ls} + L_{mq})i_q = L_q i_q$$

$$u_d = Ri_d + p\lambda_d - \omega_r \lambda_q \qquad \lambda_d = (L_{ls} + L_{md})i_d + \lambda_{mpm} = L_d i_d + \lambda_{mpm}$$

The torque equation is

$$T_e = \frac{3}{2} p(\lambda_d i_q - \lambda_q i_d)$$

where p in the torque equation is the number of pole pairs and λ represents the flux linkage.

1. Please add the dq-reference frame to the rotor shown above, and explain why. The rotor is assumed to rotate in **<u>clockwise</u>** direction (*important to notice this!*).

2. Please determine for this rotor, if (Ld > Lq) or (Ld < Lq), and explain why. In the dq-frame you have drawn above, please indicate the desired location for the current vector (a rough indication with respect to the q-axis is enough), and explain why.

3. For field oriented control of PM machine, please give the control block diagram in order to control the d-axis current to follow a reference current command; add the back-EMF decoupling term to this control block diagram; simply the control block diagram considering back-EMF decoupling effects.

4. Please indicate the back-EMF term appearing in the q-axis voltage equation; what is the back-EMF decoupling term that should be introduced to the q-axis current regulation block diagram? Please use the machine equations to give mathematical proof that supports your statement.

5. **5.** Knowing R=0.2 (Ohm), Ld = 2 (mH). The inverter switches at 5 kHz and the equivalent delay the inverter introduces to the controller is considered to be 1.5/5000 (s). In the PI controller, Kp = 3 and Ki = 100. Please calculate the bandwidth of this d-axis current control loop. Please give the bandwidth in Hz.

Part 3 (20%)

The mathematical model of an induction machine may be expressed as:

The stator side:

$$u_{qs} = r_s i_{qs} + p\lambda_{qs} + \omega_e \lambda_{ds} \qquad \lambda_{qs} = L_{ls} i_{qs} + L_m (i_{qs} + i_{qr})$$

$$u_{ds} = r_s i_{ds} + p\lambda_{ds} - \omega_e \lambda_{qs} \qquad \lambda_{ds} = L_{ls} i_{ds} + L_m (i_{ds} + i_{dr})$$

The rotor side:

$$u_{qr} = r_r i_{qr} + p\lambda_{qr} + (\omega_e - \omega_r)\lambda_{dr} \qquad \lambda_{qr} = L_{lr} i_{qr} + L_m (i_{qs} + i_{qr})$$

$$u_{dr} = r_r i_{dr} + p\lambda_{dr} - (\omega_e - \omega_r)\lambda_{qr} \qquad \lambda_{dr} = L_{lr} i_{dr} + L_m (i_{ds} + i_{dr})$$

where λ represents the flux linkage. The voltage supplied to the rotor windings is zero, assuming it is a squirrel cage induction machine.

1. You will implement rotor-flux oriented control for this induction machine. Please give the stator, rotor voltage equations and the torque equation expressed in the rotor flux-oriented reference frame.

2. Please list the motor parameters needed in realization of the rotor-flux oriented FOC.

3. For the given induction machine listed below, please calculate the rated d-axis current reference value to be used in the rotor flux oriented FOC.

V. Δ/Y	Hz	kW	rpm	A. Δ/Y	COS Φ
230/400	50	0.3	905	1.9/1.1	0.64

Stator and rotor resistances

Rs = 26.5 (Om)

Rr = 23.9 (Om)

Stator and rotor self-inductances

Ls = 0.79 (H)

Lr = 0.79 (H)

Magnetization inductance

Lm = 0.71 (H)