Written examination in Control of Electrical Drive Systems and Converters

8^{th} 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 with several questions. The percentage is indicated for each part.

2015

Part 1 (50 %)

1.1 Explain how single-phase analog PWM technique is done. (10%)
1.2 Why is discontinuous PWM preferred in certain applications? How is this technique implemented? (10%)
1.3 An electric drive switches from "motor-mode" to "generator-mode". What happens with the DC-link of the converter and what is the reason for that? (5%)
1.4 How can the phenomena from Question 1.3 be limited? (5%)
1.5 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 7 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	+	−	−

1.6 What happens when an MOSFET/IGBT is turned-ON and turned-OFF? (the focus is on current and voltage vs time) How can the switching trajectories be improved? (10%)

Part 2 (30%)

A 6-pole **surface mounted** Permanent Magnet (PM) machine is modeled in a synchronously rotating dq-reference frame as:

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

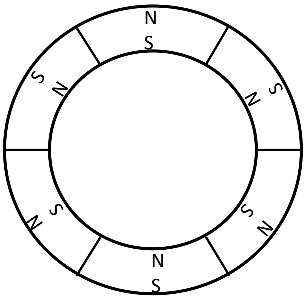
$$u_d = Ri_d + p\lambda_d - \omega_r\lambda_q \qquad \lambda_d = (L_{ls} + L_{md})i_d + \lambda_{mpm} = L_d i_d + \lambda_{mpm}$$

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.

2.1 Please add the dq-reference frame in the figure below.



2.2 Please give the torque equation expressed by machine d-, q-axes inductances and d-, q-axes currents. Please explain how you will determine d-, and q-axes current references for Field Oriented Control of this machine, and why?

2.3 What is the machine's shaft speed in rpm when it is observed that ω_r in the above machine equation has a value of 377 (rad/s).

2.4 It is recommended to tune the current loop PI parameters at zero speed. Please explain why.

2.5 Please give the control block diagram for the q-axis current loop with the back-EMF decoupling term. Please give the open-loop transfer function including the PI controller.

2.6 Now the motor is running at 1000 rpm in steady state. The speed error in rpm is the input to the speed loop PI controller, which generates q-axis current reference command. It is given for the speed loop PI, the proportional gain Kp= 0.2 and the integral gain Ki = 10. Suddenly a new speed reference of 1100 rpm is introduced. Please show the change of the q-axis current reference command for the next 0.1 seconds. (***Asking for the profile of the speed loop PI output (the q-axis current reference command) vs. time, and the time interval is [0, 0.1] seconds.***) Please give also the final q-axis current reference value obtained after 0.1 seconds. (***The real shaft speed of 1000 rpm is assumed to be maintained constant during the time period [0,0.1] seconds, due to a large rotor inertia.***)

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:

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

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

and the torque equation may have different forms, such as

$$\tau = \frac{3}{2} p L_m \operatorname{Im}\left(\bar{i}_{qds} \cdot \bar{i}^{*}_{qdr}\right) \qquad \tau = \frac{3}{2} p \frac{L_m}{L_s} \operatorname{Im}\left(\bar{\lambda}_{qds} \cdot \bar{i}^{*}_{qdr}\right) \qquad \tau = \frac{3}{2} p \frac{L_m}{L_r} \operatorname{Im}\left(\bar{i}_{qds} \cdot \bar{\lambda}^{*}_{qdr}\right)$$

where p in the torque equation is the number of pole pairs and λ represents the flux linkage. The voltage supplied to the rotor side is zero, assuming it is a squirrel cage induction machine.

3.1 If the voltage supplied to the motor is 50 Hz, please calculate the rotational speed of the rotor field, stator field, and the air-gap field in radians / second.

3.2 If rotor flux oriented Field Oriented Control (FOC) is to be implemented, which torque equation you will choose? Please give the final (simplified) torque equation in the rotor flux oriented frame.

3.3 In the rotor flux oriented reference frame, where d-axis is aligned with the rotor flux vector, please give an expression, linking the rotor flux magnitude and the stator d-axis current. Please draw **roughly**, when a step change of the stator d-axis current is introduced, how the rotor flux will respond?

3.4 Among the three possible FOC topologies for induction machine: rotor-flux oriented, air-gap flux oriented, and the stator flux oriented, which one will give the simplest structure in realization? Please list the motor parameters needed in implementing the simplest FOC topology you choose.