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 questions. The percentage is indicated for every question.

2014

Question 1 (50 %)

1. Why do we need PWM and how is this achieved in an analog world? (10%)

2. What modulation technique can be used to decrease the switching losses? Explain with your own words and use visual aids as well in your explanations. (10%)

3. What is the major disadvantage of renewable energy sources, like wind or solar? What solution would you recommend to increase the penetration and decrease the negative influence of such renewable systems within the electrical network? (5%)

4. Draw a vector diagram for an RL load, where V_C is the converter voltage (ideal sinusoidal source), I_C is the converter current, I_R is the resistive current and I_L is the inductive current. How would V_C and I_C look in the time domain if drawn on the same graph? (5%)

5. How would you increase the range of an electric car if the battery size is fixed? (5%)

6. Explain with your own words why a Square Wave modulated converter has better/worse performance than a PWM converter from the point of view of (10%):
   a. Power factor
   b. Torque pulsation
   c. Efficiency at low speed
   d. Ride-through capability
   e. Short circuit protection

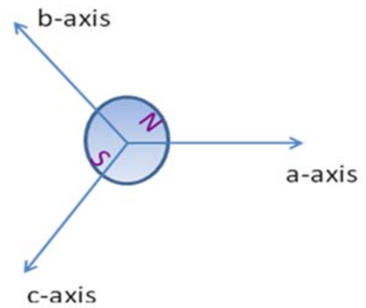
7. What is soft switching in case of power electronic converters and how is it achieved? Explain with your own words; use also drawings in your explanations. (5%)

Questions 2 (32%)

A 8-pole surface mounted Permanent Magnet (PM) machine may be modeled in a synchronously rotating reference frame as:

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

1. Please draw the rotor dq-reference frame in the figure below, and indicate the rotor position θ_r.

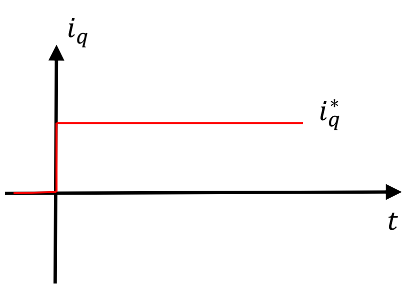


2. In order to find the initial rotor position $\theta_r = 0$, what a, b, c currents need to be supplied to the motor? What are these currents when represented in the $\alpha\beta$-reference frame.

3. At a moment, the shaft speed is measured to be 1200 rpm. What is the value of ω_r that should be used in the machine equations given above?

4. Please
   a) Give the control block diagram in order to control the q-axis current to follow a reference current command, which is used in the filed oriented control of PM machine.
   b) Add back-emf decoupling term to a)
   c) Give the final transfer function (real motor q-axis current vs. command q-axis current) for the q-axis current regulation.

5. Knowing $R = 0.18$ (Ω), $L_d = L_q = 2$ (mH) $\lambda_{mpm} = 0.12$ (Wb), and for the q-axis current loop PI, $K_p = 3$, $K_i = 100$, please calculate the bandwidth of the q-axis current loop. Please draw in the **TIME DOMAIN** the motor q-axis current response at zero speed, for a step reference current command (i_q^*) given below. (*Please be sure that at least we may observe the bandwidth of the current loop by looking at its time domain current response*).



Question 3 (18%)

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:

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

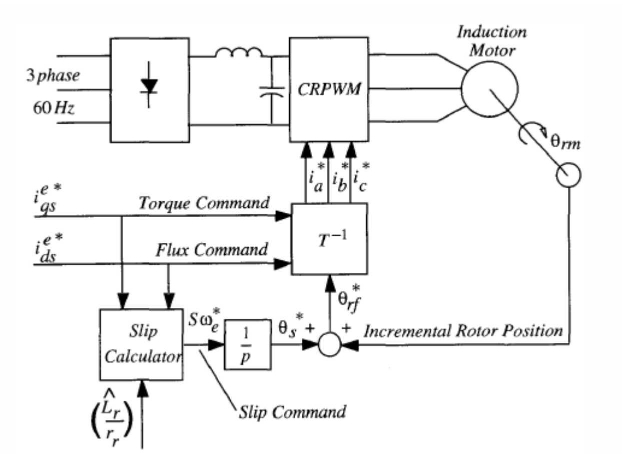
$$u_{dr} = r_r i_{dr} + p\lambda_{dr} - (\omega_e - \omega_r)\lambda_{qr} \qquad \lambda_{dr} = L_{lr} i_{dr} + L_m (i_{ds} + i_{dr})$$

and the torque equation may have different forms, such as

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

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

1. The d-axis of the reference frame is chosen to be aligned with the rotor flux. Please give the FINAL torque equation (utilizing the chosen reference frame information) that should be used.
2. In the rotor flux oriented controller, what are the stator side and rotor side equations represented in this reference frame?
3. A vector controller is realized in the rotor flux oriented reference frame, as shown in the following figure. Please tell when a step change of the d-axis current command is suddenly introduced, how the **rotor d-axis** current will react? If a sudden step change is applied to the q-axis current command, how the **rotor q-axis** current will react?



'*' means reference value.
'e' means rotating reference frame.