Exam questions for MM1-MM5 of Control of Electrical Drive Systems and Converters (50%)

1. Draw a generic drive system showing the hardware setup including switching devices and the software loops and choose a simple speed control or a torque control schematic and explain each block within the control loops. (10%)
2. Which modulation techniques would you use for an IM drive control? Please explain/draw your choice and detail your reasoning. (5%)
3. Why do you need storage in grid connected renewable applications and what is the advantage of such a storage solution? (5%)
4. What is electromagnetic braking? (5%)
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 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	+	−	−

6. What type of variable frequency converters can you mention and for which application would you recommend each of them? (5%)
7. What are the advantages of soft-switching resonant converters compared to hard switching converters? When explaining also draw and comment on the switching loci for both cases. (10%)

Questions 3

A 4-pole surface mounted Permanent Magnet (PM) machine may be modeled in a synchronously rotating reference frame as:

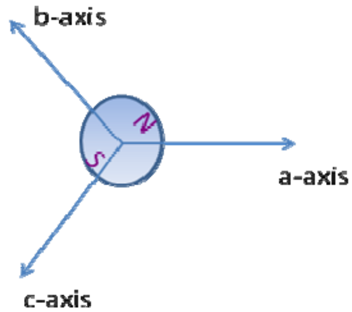
$$u_q = Ri_q + p\lambda_q + \omega_r\lambda_d \qquad \lambda_q = (L_{ls} + L_{mq})i_q = L_q i_q$$
$$u_d = Ri_d + p\lambda_d - \omega_r\lambda_q \qquad \lambda_d = (L_{ls} + L_{md})i_d + \lambda_{mpm} = L_d i_d + \lambda_{mpm}$$

and the torque equation is

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

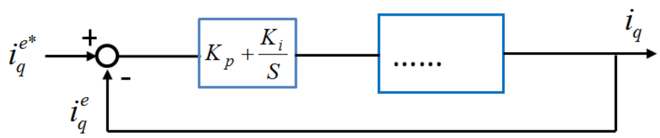
where p in the torque equation is the number of pole pairs and λ represents the flux linkage.

1. Please draw the rotor dq reference frame in the figure below.



2. At a moment, the shaft speed is measured to be 1000 rpm. What is the value of ω_r that should be used in the machine equations given above?
3. Please indicate the back-EMF terms for this PM machine. What is the back-EMF decoupling term that should be introduced to the q-axis current regulation block diagram? Please use the machine equations some mathematic proves to support your statement.
4. Please show the control block diagram for the **<u>q-axis</u>** current regulation loop **<u>with and without</u>** the back-EMF decoupling term.
5. In your q-axis current regulation loop with the back-EMF decoupling term, a delay unit is required to be included. This delay unit accounts for time delay introduced by the software and hardware in implementation. This time delay is known to be T_d and may be approximated by a first order system. Please give the **<u>closed-loop</u>** transfer function for this q-axis current regulation loop. Please indicate how you may choose the PI values to simply the transfer function to be a classical second order system (e.g. like the system given on page 24 of the lecture 1 course slides.)

Note, the ‘q-axis current regulation loop’ may be shown as:



Question 4

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:

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

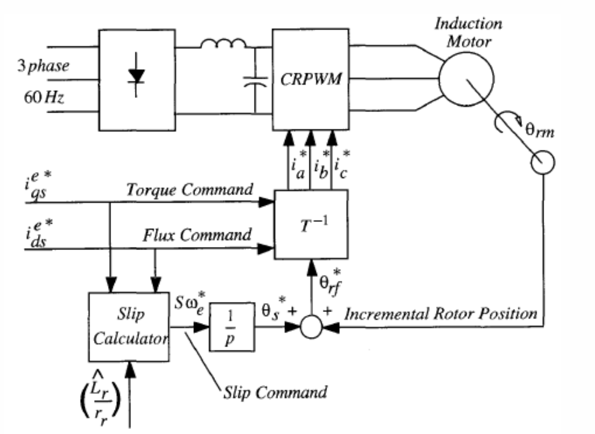
$$u_{dr} = r_r i_{dr} + p\lambda_{dr} - (\omega_e - \omega_r)\lambda_{qr} \qquad \lambda_{dr} = L_{lr} i_{dr} + L_m (i_{ds} + i_{dr})$$

and the torque equation

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

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.

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



'*' means reference value.

'e' means rotating reference frame.

4. Suppose the motor has the following information. It is required to maintain the machine flux at its rated value, then what is the stator d-axis current reference value you need to set in your indirect rotor flux oriented controller?

% Induction motor constant parameters

Lm = 235.0e-3;	% magnetizing inductivity [H]
Lls = 9.2e-3;	% stator leakage inductivity [H]
Llr = 12.29e-3;	% rotor leakage inductivity [H]
Rs = 3.67;	% stator resistance [ohms]
Rr = 2.32;	% rotor resistance [ohms]
p = 2.0;	% number of pole-pairs
J=0.0069;	% rotor inertia moment [Nm^2]

% Induction motor nameplate

Pn = 2200;	% nominal power [W]
Un = 220;	% nominal phase voltage RMS[V]
In = 5.1;	% nominal current RMS[A]
fn = 50;	% nominal frequency [Hz]
PF = 0.81;	% nominal power factor [pu]
nn = 1430;	% nominal shaft speed