2016

# Written examination in
# Control of Electrical Drive Systems and Converters

**8th semester**

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- 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.

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# 2016

## Part 1 (50 %)

1.1 Explain in your own words how three-phase PWM is done in theory. Also discuss the different ranges of the modulation index. (10%)

1.2 A three-phase inverter works in square-wave mode. VLL=200V with f=52Hz with a load shown in Fig.8-25a with L=100mH. Calculate the current ripple based on Fig.8-26a. (10%)

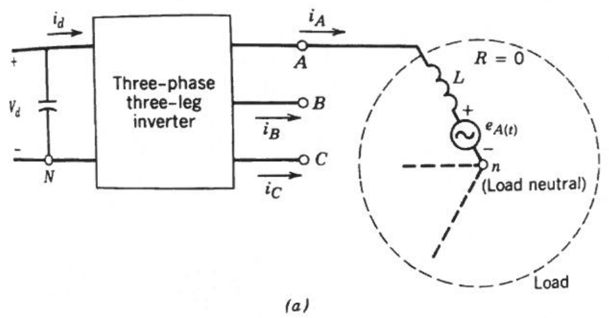



Fig.8-25a

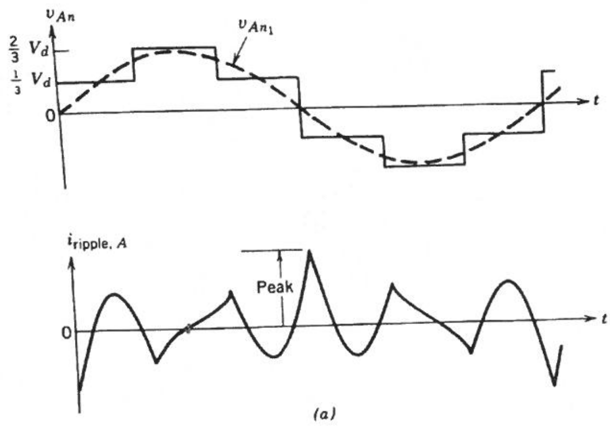



Fig.8-26a

1.3 What do you mean by increasing the linear range of a PWM technique and how is this done? Please explain/draw your choice and detail your reasoning. (5%)

1.4 How is electromagnetic braking achieved? Give an example (5%)

1.5 Explain why a PWM converter has better/worse performance than a CSI from the point of view of (10%):

a) Power factor
b) Torque pulsation
c) Short circuit protection
d) Open circuit protection
e) Regeneration

1.6 What is the difference between hard and soft switching in case of power electronic converters? Explain with your own words, use also drawings in your explanations. (10%)

## Part 2 (30%)

A 4-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

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

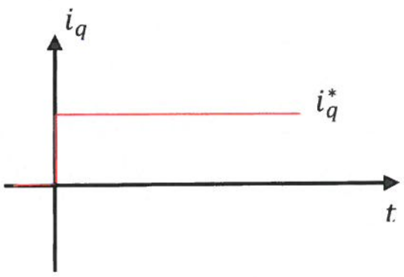
where $p$ in the torque equation is the number of pole pairs and $\lambda$ represents the flux linkage.

1. Please sketch the rotor structure and add the dq-reference frame on the rotor.

2. Please indicate how the rotor position is defined? Now it is desired to force the rotor to be at its zero position, what currents should be applied to a, b, and c phase windings? To achieve this, what are the alfa-belta voltage commands? (Suppose the desired phase-a current is $I$ and the machine parameters are given in the above equations.)

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

4. Knowing $R = 0.18\ (\Omega)$, $L_d = L_q = 2$ (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*).



## 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 $\lambda$ represents the flux linkage. The voltage supplied to the rotor side is zero, assuming it is a squirrel cage induction machine.

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.

2. If rotor flux oriented Field Oriented Control (FOC) is to be implemented, please define your dq reference frame and explain which torque equation you will choose and why?

3. In the rotor flux oriented controller, now a step change is observed in the stator d-axis current. Please derive an equation linking the rotor flux linkage to the stator d-axis current, and an equation linking the rotor d-axis current to the stator d-axis current. Please draw in sketch the rotor flux linkage and rotor d-axis current responses to this stator d-axis current step change.