Written examination in

Dynamic Models of Electrical Machines and Control Systems

1st semester M.Sc. (PED/EPSH/WPS/MCE)

Duration: 4 hours

- All usual helping aids are allowed, including text books, slides, personal notes, and exercise solutions
- Calculators and laptop computers are allowed, provided 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
- All intermediate steps and calculations should be included in your answer sheets --- printing the final result is insufficient

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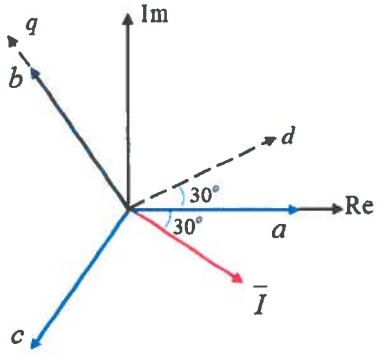
The set consists of 4 problems

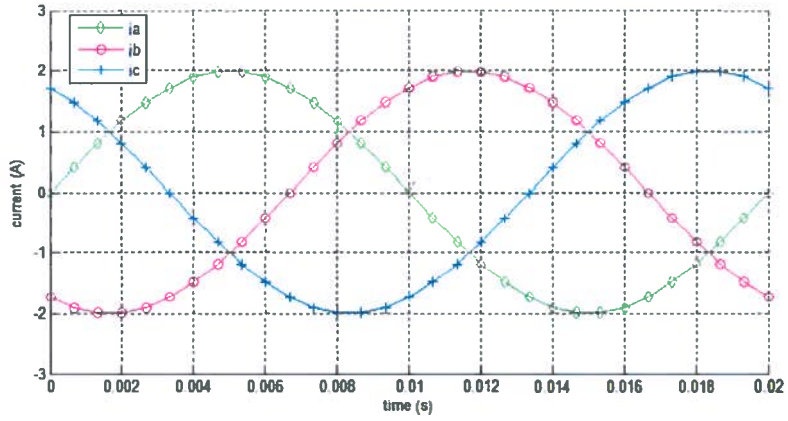
Problem 1 (25%)

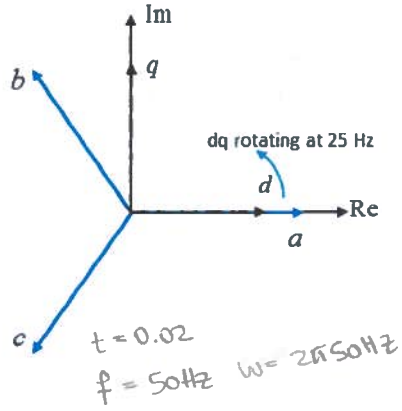
(1) At a particular moment, the current space vector $\bar{I}$ is as shown below. Knowing that the magnitude of the current vector is 1 (A), please calculate the following

- The corresponding values for phase-a, phase-b and phase–c currents.
- The corresponding values for the $\alpha\beta$ current components.
- The corresponding values for the dq current components.



(2) Observed the following instantaneous a, b and c current waveforms



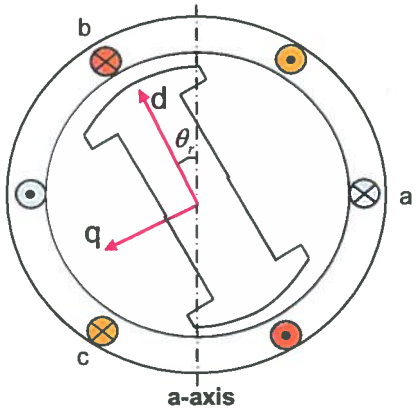


- Please show the current space vector with respect to phase-a axis at time t = 0.002 (seconds)
- Please draw the corresponding $\alpha\beta$ components for the time interval of [0, 0.02] seconds.
- A rotating dq reference frame is chosen. Its rotating frequency is at 25 Hz, anticlockwise direction. At t = 0, its d-axis is aligned with phase a-axis (as indicated above). Please draw the corresponding dq components for the time interval of [0, 0.02] seconds.

(***Be sure to get the amplitudes correct in your waveforms to be drawn.***)

Problem 2 (25%)

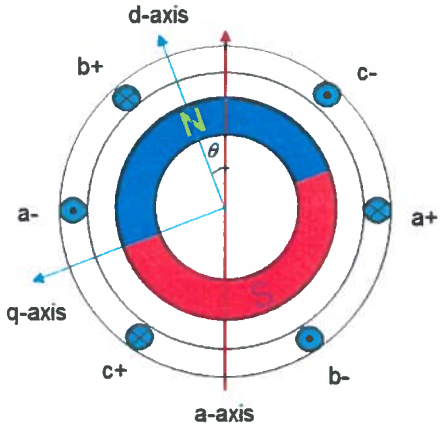
A sketch of a synchronous machine is shown below.



(1) Please show how the mutual inductance between phase-c and phase-a may be derived.

(2) Please find the position which makes this mutual inductance to be at its minimum value.

A simple single-phase PM machine is shown below. Knowing the PM flux linkage as $\lambda_{pm,a} = \lambda_{mpm} \cos\theta$. (where λ_{mpm} is its peak value and θ is the rotor position as indicated in the following figure).



(3) When phase-a is supplied with a current of $i_a = -I_m \sin\theta$ (where I_m is the peak value of the current), please determine the instantaneous waveform for the torque produced by phase-a current.

(4) Please determine the PM flux linkage expression for phase-c; following the given phase-a current, please determine the current expression to be used for phase-c.

(5) Add the instantaneous torque waveform produced by phase-c current to that produced by phase-a.

Problem 3 (25 %)

An induction motor has the following data (**the rotor windings are short-circuited; the machine is Y-connected**):

Rated shaft power	7.5 kW
Rated speed	1160 rpm
Rated stator frequency	60 Hz
Number of poles	6
Rated stator voltage	380 V RMS (line-to-line)
Rated power factor cos φ	0.8 inductive
Stator resistance	0.28 Ohm
Main (magnetization) inductance	39.4 mH
Stator leakage inductance	1.4 mH

(1) Please give the stator side voltage equation represented by voltage and current space vectors and in the $\alpha\beta$-reference frame.

(2) You will apply V/f control to this machine. The output of your V/f controller is the peak phase voltage command. What is the value of the constant V/f ratio you will use in your controller?

(3) Now it is asked to control the motor running at 1 Hz (electrical frequency). In order to maintain the same stator flux level as experienced at the rated condition, compensation of the voltage drop on the stator resistance needs to be introduced to the V/f control. In steady state, the phase-a RMS current is found to be 0.5 (A) and phase-a current is lagging phase-a voltage by 30 degrees. Please determine the magnitude of the phase voltage after stator resistance voltage drop compensation.

(4) The stator frequency command is now 60 Hz and the machine is supplied with the rated voltage. When the machine is loaded by 1/2 of its rated load, please calculate the frequency that needs to be added to the frequency command in order to make the shaft speed to be 60/3 = 20 Hz (mechanical frequency).

$I_{ey} = I_{fy}$ $V_{ey} = \sqrt{3} \cdot V_{fy}$

Problem 4 (25 %)

The stator voltage equation of a permanent magnet synchronous machine may be given as (*same notations as used in the lecture slides*):

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

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

(1) The machine has 8 poles. Stator winding open-circuit test has shown that at 1200 rpm shaft speed, the measured phase line-to-line voltage is 100 (V), rms. Please determine the value of the peak rotor PM flux linkage λ_{mpm} to be used in the above equation.

(2) The machine is controlled to have Id = 0. In a particular steady state operation condition, it is observed that the peak phase-a current value is 2 (A), Please calculate the corresponding torque produced by this machine.

(3) In I/f control of the PM machine, should the current vector to be placed lagging the q-axis or should it be leading the q-axis? Please give your explanations.

(4) In steady state, you observe the phase-b voltage and current waveforms are as shown below (10 V for voltage and 2 A for current peak values). At t = 0, phase-b voltage reaches its peak value. It is measured that the power factor is 0.707. Please calculate the EXACT moment that phase-b current reaches its peak value. At t = 0, the corresponding rotor position is found to be at 90 electrical degrees (dq-reference frame). Please add the voltage space vector, the current space vector and the rotor dq-axes with respect to the phase-a axis given below; the locations and magnitudes of the voltage and current vectors should represent the given instantaneous waveforms.