Written re-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 5 problems

Problem 1 (25%)

(1) Suppose now you have a set of 3-phase signals as:

$$v_a = V_{pk}\sin(\omega_e t),\quad v_b = V_{pk}\sin\left(\omega_e t - \frac{2\pi}{3}\right),\quad v_c = V_{pk}\sin\left(\omega_e t + \frac{2\pi}{3}\right)$$

where $\omega_e = 2\pi \cdot 50$ and $V_{pk} = 1$

a) Please give the space vector formed by these three-phase signals in the abc-frame $\overline{V}_{abc}$.

b) Please draw the location of this space vector at

- $t = \dfrac{1}{300}$ (seconds)

(2) Now phase-b and phase-c are exchanged, which yields

$$v_a = V_{pk}\sin(\omega_e t),\quad v_b = V_{pk}\sin\left(\omega_e t + \frac{2\pi}{3}\right),\quad v_c = V_{pk}\sin\left(\omega_e t - \frac{2\pi}{3}\right)$$

a) Please give the space vector formed by these three-phase signals in the abc-frame $\overline{V}_{abc}$.

b) Please draw the location of this space vector at

- $t = \dfrac{1}{300}$ (seconds)

(3) Transform the above a, b, c signals

$$(v_a = V_{pk}\sin(\omega_e t), v_b = V_{pk}\sin\left(\omega_e t + \frac{2\pi}{3}\right), v_c = V_{pk}\sin\left(\omega_e t - \frac{2\pi}{3}\right))$$

to a rotating dq-frame. This dq-frame is rotating positively (anti-clockwise direction) at a frequency of 50 Hz.

Question 2 (25%)

A sketch of a synchronous machine is shown below.

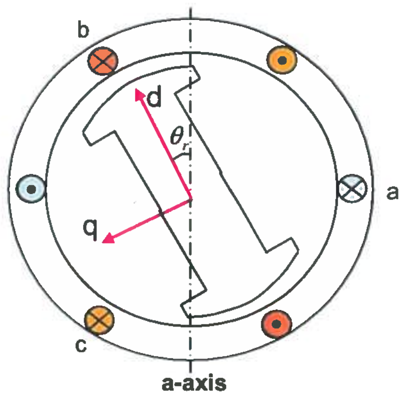


Fig. 1

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

A simple single-phase PM machine is shown below in Fig. 2(a). Now another phase (naming it phase-b) is added to this machine, as indicated in Fig. 2(b).

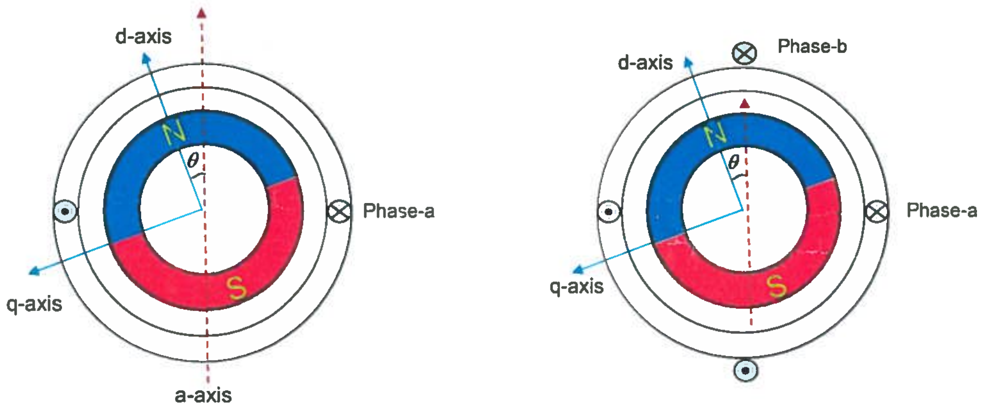


Fig. 2(a) Fig. 2(b)

(2) If the phase-a PM flux linkage waveform is expressed as: $\lambda_{pm,a} = \lambda_{mpm} \cos\theta$. (where λ_{mpm} is its peak value and θ is the rotor position as indicated in Fig. 2), please give the PM flux linkage waveform for phase-b.

(3) If phase-a is now supplied with a current of $i_a = -I_m \sin\theta$ (where I_m is the peak value of the current), please determine the needed current waveform for phase-b.

(4) Please show the instantaneous torque produced by phase-a and phase-b, respectively.

(5) Please give an expression for the total torque produced by phase-a and phase-b together.

Question 3 (10%)

There is a transformer with two coils sketched as below.

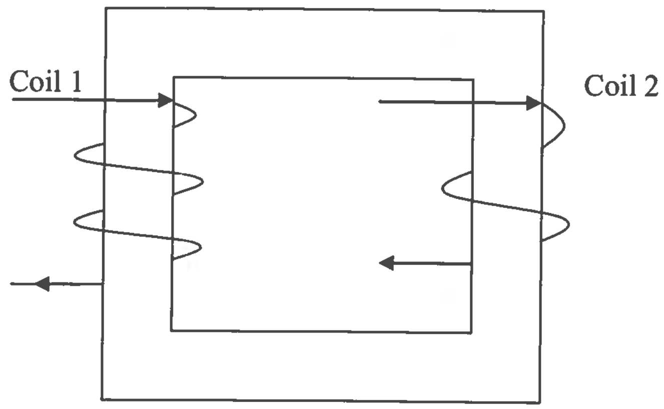


Fig. 3

(1) Please express the flux linkage for coil 1 using the coils 1 self-inductance (L1) and the mutual inductance (M) between coil 1 and coil 2. The positive current directions are given in Fig. 3.

(2) Suppose coil 1 has N1 turns, and coils 2 has N2 turns. If it is desired to perform turns ratio transformation, **to let coil 1 to have the same number of turns as coil 2** (*<u>this is different from what you learned from the lectures</u>*). How the flux linkage equation derived before should be modified?

Problem 4 (20 %)

A four-pole induction motor has the following data (**the rotor windings are short-circuited**):

Rated shaft power	1.9 kW
Rated speed	1440 rpm
Rated stator frequency	50 Hz
Rated stator voltage	380 V RMS (line-to-line)
Rated stator current	4.1 A RMS
Rated power factor cos φ	0.8 inductive
Stator resistance	2.5 Ohm
Main (magnetization) inductance	0.27 H
Stator leakage inductance	0.01 H

(1) The machine is supplied with the rated voltage and rated frequency. The load torque is zero. Please calculate the corresponding stator phase current in RMS for this operation point.

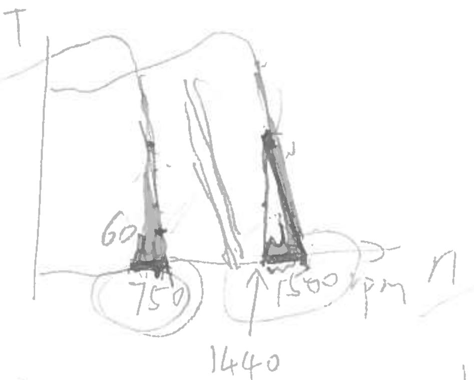
(2) In V/f control, it is measured that phase-a peak voltage is 150 (V), and the voltage period is 0.04 seconds. Please calculate V/f ratio that is used in this V/f control.

$T = 0.04 \Rightarrow f = \frac{1}{0.04} = 25$

$\frac{V}{f} = \frac{150}{25} = 6\ V/Hz$

(3) The machine is supplied with the rated voltage and rated frequency and running at no-load. What is the rotor electrical speed represented in Hz? When the machine is loaded with half of the rated load torque, what is the active current value (i_{sd}, *find more information on slide P15 of the lecture discussing about scalar control of induction machine with slip compensation*) that is proportional to the machine torque? Please neglect the stator resistance in this calculation.

(4) In V/f control, the stator frequency is now 50% of the rated frequency. The load torque is 25% of the rated torque. What is the slip frequency in Hz that needs to be compensated in order to make the electrical rotor shaft speed to be 25Hz?



50 — 48 Hz   2 Hz   0.5 Hz

$s = \frac{\omega_s - \omega_r}{\omega_{b,s}} = s_f \omega_s = f_{slip}$

ration   15   60

$\frac{1}{4} = \frac{T_{e,now}}{T_{e,rated}} = \frac{f_{s,se}}{f_{s,rated}}$

$s_{25} = \frac{60}{750}$

$s_{50} = \frac{60}{1500}$

$\frac{60}{1500} = \frac{2}{50} = 4\%$

$\frac{1}{4} = \frac{f_{se}}{s f}$

slip frequency

Problem 5 (20 %)

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

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

The machine has **4 poles**.

(1) This PM machine is driven by another DC motor and running at a constant speed of 1200 rpm. When the stator windings are open-circuited, measured line-to-line RMS voltage is 120 (Vols). Please determine the value of λ_{mpm} to be used in the above machine equations.

(2) For this machine, the d-, q-axes inductances are equal. The machine is running at steady state at 1200 rpm (mechanical shaft speed). At a particular instant, it is observed that the rotor dq-axes and voltage, current vectors are as shown below. The current vector magnitude is 2 (A). The voltage vector magnitude is 100 (v) (the vectors shown below are not in the right scales). Please draw the waveforms for the phase-a voltage and current for one period starting from this instant. Please also calculate the corresponding torque.

Lecture 7

slide 10