Re-examination

in

Dynamic Models of Electrical Machines and Control Systems

INTRO 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 %)

For a given space vector $\bar{f} = e^{-j\omega_e t}$, where $\omega_e = 2\pi \cdot 50$, please

(1) find the expressions for its corresponding afa-, beta-components. Please DRAW their waveforms as functions of the time.

(2) find the expressions for its corresponding a-, b-, c-components. Please DRAW their waveforms as functions of the time.

(3) Now you are given a dq-reference frame. At time t=0, its d-axis is aligned with phase-a axis. It rotates positively (anti-clockwise direction), at a speed of $\omega_e = 2\pi \cdot 50$. Please find the expressions for the dq-components when the original space vector $\bar{f} = e^{-j\omega_e t}$ is transformed to this dq-reference frame. Please DRAW dq-component waveforms as functions of the time.

(4) There are three independent RL-circuits with identical resistance and inductance parameters. There is no electrical connection between these circuits. Now you supply the following three-phase voltages to these three circuits:

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

Suppose you find the current in the first RL-circuit (with voltage supply of v_a) is

$$i_a = I_{pk}\cos(\omega_e t - \varphi)$$

Please draw the voltage and current space vectors representing these three-phase a, b, c voltages and currents.

Knowing the instantaneous power equation as $p = v_a i_a + v_b i_b + v_c i_c$. Please calculate the power using afa-, beta-components.

<u>**Note**</u> we have already derived from lecture-1 exercise that

$p = v_a i_a + v_b i_b + v_c i_c = \frac{3}{2}(v_d i_d + v_q i_q + v_0 i_0)$, and there exists a relationship

$v_d i_d + v_q i_q = \mathrm{Re}\left[(v_d + jv_q)(i_d + ji_q)^*\right] = \mathrm{Re}\left[(v_d + jv_q)(i_d - ji_q)\right]$, where '*' stands for complex conjugate of $(i_d + ji_q)$.

Problem 2 (25 %)

A sketch of a synchronous machine is shown below.

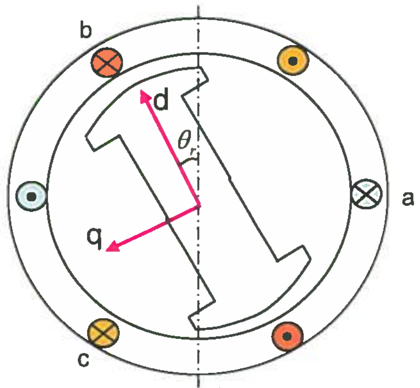
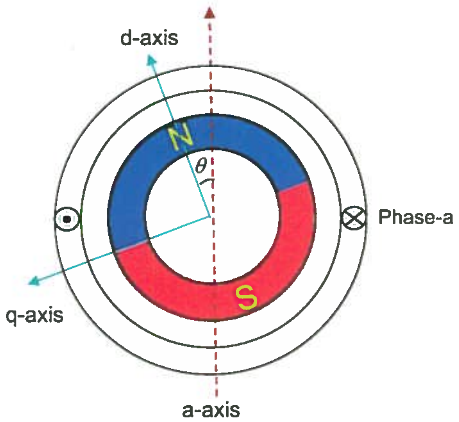


Fig. 1

(1) Please tell how the mutual inductance between phase-b and phase-c is found.
(2) Please find the minimum and maximum value of this mutual inductance and at which positions, the minimum and maximum values are achieved?

A simple single-phase PM machine is shown below.

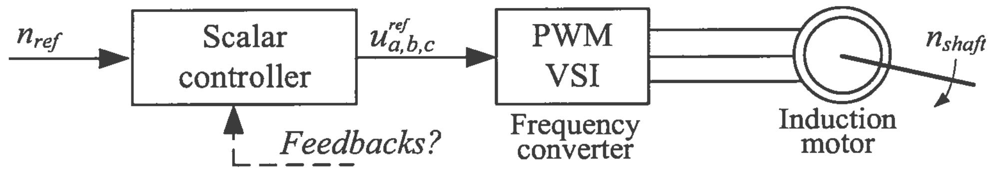


(3) Now the PM flux linkage for phase-a contains a 3rd harmonic, i.e. $\lambda_{pm,a} = \lambda_{m1}\cos(\theta) + \lambda_{m2}\cos(3\theta)$, when phase-a is supplied with current $i_a = -I_{m1}\sin\theta$, what is the instantaneous torque? Please **sketch** this torque waveform.

Please answer the following
(4) In an unbalanced system, i.e. there exists zero-component of the voltage and current. Will this zero-component current produce any torque? and why?

Problem 3 (25%)

The figure below shows an overall block diagram of a scalar control system for an induction motor drive. The input to the system is the shaft speed reference value n_{ref} and the objective is to control the motor in such a way that the actual shaft speed n_{shaft} tracks the reference irrespective of the load applied to the motor shaft.



The block denoted "Scalar Controller" outputs the instantaneous voltage references for a three-phase pulse-width modulated (PWM) voltage-source inverter (VSI), which is connected to the induction motor.

Answer the following:

(1) Make a detailed block diagram of your proposal to a practical "Scalar Controller" block. This should include descriptions/illustrations of how the whole system works during both steady-state and dynamic operation (such as change of n_{ref} or change of load torque)

Note: As indicated in the figure, optional feedbacks may be added if needed.

(2) List the motor data/parameters you need to know in order to determine the parameters in your scalar controller

Problem 4 (25 %)

Given the differential equation

$$(*) \qquad \frac{d^2x}{dt^2} + \left(f(x) + x\frac{dx}{dt}\right)\frac{dx}{dt} + g(x) = 0$$

where $f: R \to R, g: R \to R$ are C^1-functions. It is assumed that $f(x) > 0$ for all $x \in R$, and $xg(x) > 0$ for $x \in R\setminus\{0\}$.

1. Make a state space formulation $(**)$ of $(*)$, using $x_1 = x$ and $x_2 = \frac{dx}{dt}$. Show that for any C^1-function $\varphi: R \to R_+$ the function $V(x_1, x_2)$ is a positive definite function

$$V(x_1, x_2) = \frac{1}{2}x_2^2\varphi(x_1) + \int_0^{x_1} \varphi(u)g(u)du \quad ; \quad (x_1, x_2) \in R^2$$

with $\frac{dV(x_1,x_2)}{dt} = x_2^3\left(\frac{1}{2}\frac{d\varphi(x_1)}{dx_1} - x_1\varphi(x_1)\right) - x_2^2\varphi(x_1)f(x_1) \quad ; \quad (x_1, x_2) \in R^2$

(with respect to $(**)$). Show that the function φ can be chosen so that $V(x_1, x_2)$ becomes a Lyapunov function for $(**)$ in R^2, and determine the applicable functions φ.

2. Now let φ denote one of the applicable functions. Show that (0,0) is an asymptotically stable singular point for $(**)$.

{Hint: Find the largest invariant set}

3. Account for that (0,0) becomes a globally asymptotically stable singular point, if there exist positive numbers δ and x_0, such that $|g(x)| > \delta$ for $|x| \geq x_0$.

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$\int_0^{x_1} \varphi(u)\, d(u)\, du$

$\frac{1}{2}$

$\frac{2}{2} x_2^2 \cdot \dot{x}_2 \cdot \varphi(x_1)$