Exam in Control of Electrical Drives

Time and place: 2002-12-16.

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The exam has 5 questions, each of them giving maximally 10 points. The grade limits are at each decade (0-10p:1,10-20p:2,20-30p:3,30-40p:4,40-50p:5).

1

A speed control system the disc in a DVD player is to be designed. The disc is driven by a torque controlled synchronous machine with a sampling frequency $1/T_S$ in the torque loop. The speed is measured and filtered with a time constant τ_f:>>T_S.The equivalent inertia is J_{ekv}.

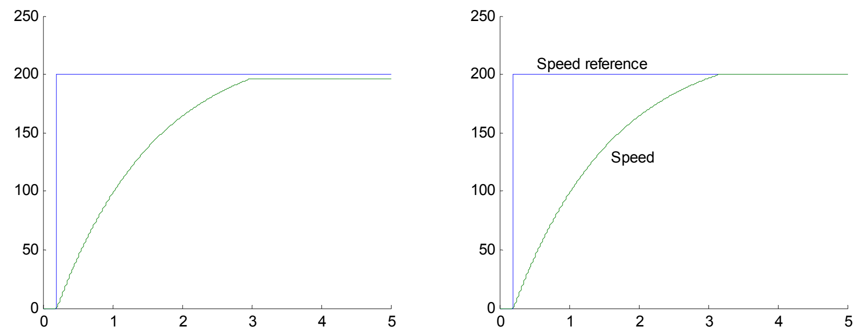
a) Assuming that T_S and τ_f both can be disregarded, what would be a suitable type of speed controller in order to eliminate the stationary speed error when the load torque is non-zero, and what would be suitable controller parameters? Discuss a possible inadequacy of your choice, (4p)

Solution: Infinite gain will eliminate any speed error. Infinite gain is not possible.

b) Assuming that neither T_S nor τ_f both can be neglected, what would be a suitable type of speed controller in order to minimize the stationary speed error when the load torque is non-zero, and what would be suitable controller parameters. (3p)

Solution: Symmetric optimum with τ_f instead of T_s.

c) The following two simulation results show the step response of a PI speed controller. The driven system is setting up a speed dependent load torque. In one of the simulations the Integral part of the speed controller is omitted (only P-control) and one is using the whole PI-controller. A torque limitation is engaged and active in both cases. Which is which? (3p)



Solution: Left is with P-controller since there is a stationary speed error.

2

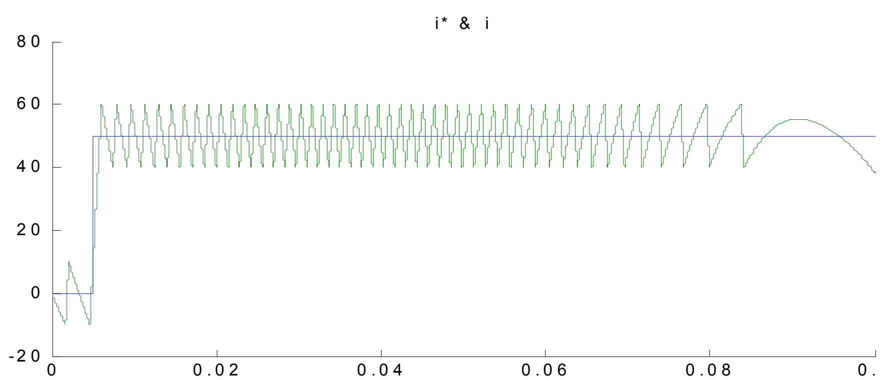
A 2-quadrant DC converter is used for current control. Two alternative controllers can be used, a PI-controller with carrier wave modulation, and a Direct Current Controller. The DC link voltage is 300 V, the Load data is L=5mH and R=0.5 Ohm.

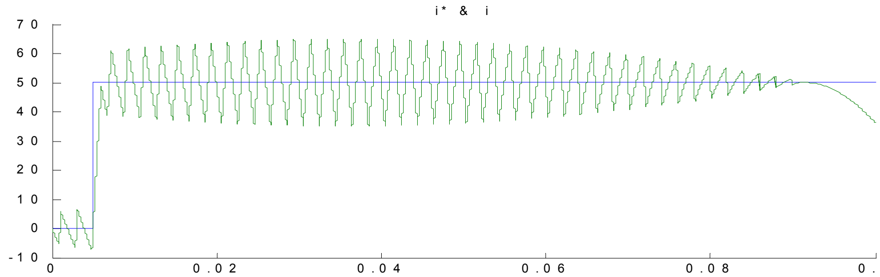
a) Design a PI-controller for the converter, with Ts=1 ms. [3p]

b) What would be the initial voltage reference if a 50 A current step is required, starting from zero current and 30 V load emf? [4p]

Solution: u=L*50/Ts+R/2*50=…

c) In the two figures below, such a 50 AM current step is simulated with the two controllers when the load emf is ramping up from 30 V to almost 300 V during the simulation. Which is which? [3p]





Solution: Upper is DCC – constant current ripple

3

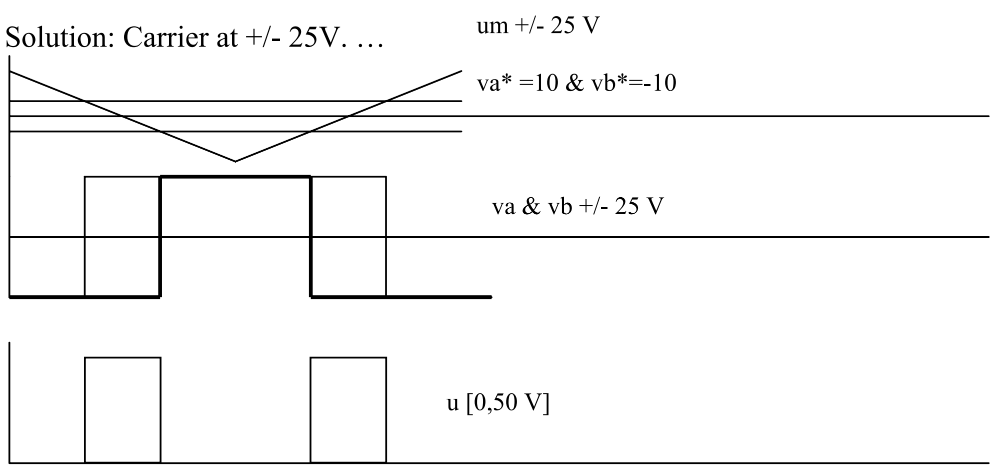
A class F audio amplifier (= 4 quadrant DC converter), used in most home-cinema-equipment today, is used to drive a loudspeaker. The DC link voltage is 50 V and loudspeaker data is R=2 Ohm, L=0.5 mH. The load emf varies with the movement of the cone.

a) What is the lowest possible modulation frequency if the lowest ripple frequency of the amplifier is required to be 200 kHz? (3p)

Solution: 4Q DC converter. 100 kHz with symmetric modulation.

b) What will be the peak value of the carrier wave, with the modulation frequency of your choice in a) ? Draw one period of the carrier wave, phase potential references, phase potentials and output voltage for a case when the voltage reference is 20 V . (3p)

Solution: Carrier at +/- 25V. …



d) Assume that the desired function of the amplifier-loudspeaker-system is to control the acceleration of the cone in the loudspeaker. The acceleration of the cone is governed by Newton's law stating that the acceleration is equal to the force/mass. The force on the cone is proportional to the current through the coil in the loudspeaker. How would you use the 4-quadrant DC converter, as a voltage amplifier only, or current controlled? (2p)

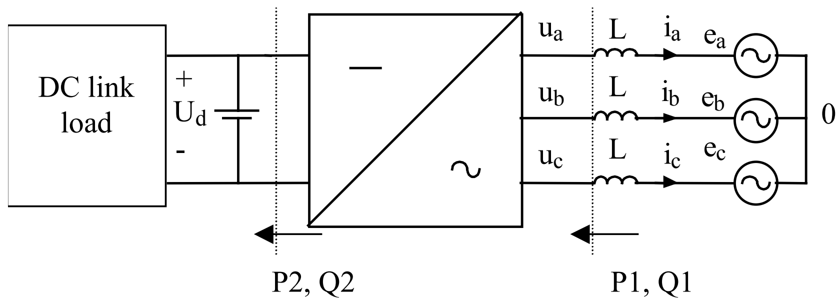
Solution: Current controlled, of course

e) What type of current controller would you use, a PI-controller with modulation or a DCC? Motivate your choise! (2p)

Solution: PI-controller with modulation. A DCC is difficult to predict regarding switching frequency, and thus it is hard to control the spectrum of the output voltage.

4

A three phase self commutated power converter is connected to the utility grid. The grid voltages is a symmetrical three phase system and the line currents are controlled with vector control whereas the converter is carrier wave modulated.



The grid voltages can be expressed in the α/β-frame with a vector equation according to:

$$\vec{u} = L \cdot \frac{d\vec{i}}{dt} + \vec{e}$$

where

$$\vec{e} = e_h \cdot e^{j\omega t}$$

The inductance is L = 3 mH, the DC link voltage U_d = 300 V and the rms values of the phase-to-phase voltages are e_h = 150 V. The frequency of the AC system is 60 Hz. The active and reactive current components must be controlled separately. The converter is modulated with a carrier wave modulation with the modulation frequency $1/T_s$ where T_s = 1 ms.

a) Propose a suitable current control method (choise of reference frame etc) and derive suitable current controllers for the currents in question. Draw a block diagram of the entire control system. (3p)

Soluion: from the book.

b) The current controller is used to supply power to a load connected to the DC link. The DC link load is consuming P2=50 kW active power. In the same time the converter supplies the line with Q1=-20 kVAr reactive power. Calculate the current vector (length and angle, or components) in a d/q-reference frame aligned with the grid flux (integral of grid voltage vector). Also give the levels of Q1 and P2. (4p)

Solution: p=eq*iq -> iq= 50000/150=333 A. id=2/5*333=133 A. Q2=0!!!! P1= 50kW.

c) Propose a connection for active filtering (3p)

Solution: In the book

5

A permanently magnetized synchronous machine is used as a traction motor in an electric vechicle.

a) Draw the torque expression in rotor coordinates, and describe your interpretation of the terms in the expression, and how they relate to the rotor geometry and magnetization. (4p)

b) Explain, in a qualitative sense, what is the best locus for the stator current vector to minimize the amount of current needed for torque production, knowing that Lmy>Lmx. (3p)

c) Explain the restrictions to the stator current loci that are imposed when the need for stator voltage is higher than the maximum available voltage. (3p)

All solutions in the book.

Formulas:

$$\vec{s} = K\cdot\left[s_a + s_b\cdot e^{j\cdot\frac{2\cdot\pi}{3}} + s_c\cdot e^{j\cdot\frac{4\cdot\pi}{3}}\right] = K\cdot\left[\frac{3}{2}\cdot s_a + j\cdot\frac{\sqrt{3}}{2}\left(s_b - s_c\right)\right] = s_\alpha + j\cdot s_\beta$$

Power invariant

Three phase –> two phase conversion

$$s_\alpha = \sqrt{\frac{3}{2}}\cdot s_a$$

$$s_\beta = \frac{1}{\sqrt{2}}\cdot\left(s_b - s_c\right)$$

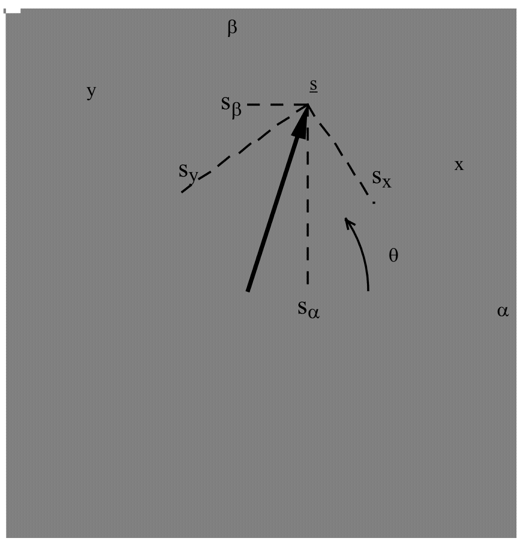
Power invariant

Two phase –> three phase conversion

$$s_a = \sqrt{\frac{2}{3}}\cdot s_\alpha$$

$$s_b = -\frac{1}{\sqrt{6}}\, s_\alpha + \frac{1}{\sqrt{2}}\cdot s_\beta$$

$$s_c = -\frac{1}{\sqrt{6}}\, s_\alpha - \frac{1}{\sqrt{2}}\cdot s_\beta$$



$$s_\alpha = \left(s_x\cdot\cos\theta - s_y\cdot\sin\theta\right)$$

$$s_\beta = \left(s_y\cdot\cos\theta + s_x\cdot\sin\theta\right)$$

$$s_x = \left(s_\alpha\cdot\cos\theta + s_\beta\cdot\sin\theta\right)$$

$$s_y = \left(s_\beta\cdot\cos\theta - s_\alpha\cdot\sin\theta\right)$$

Relations for "symmetric optimum":

$$T_i = a^2\cdot T_{str} \quad ; \quad K = \frac{J\cdot a}{T_i\cdot K_{str}} \quad ; \quad \zeta = \frac{a-1}{2}$$

The solution of some integrals:

$$\int \frac{dx}{a + b \cdot x^2} = \frac{1}{2 \cdot \sqrt{-a \cdot b}} \log\left(\frac{a + x \cdot \sqrt{-ab}}{a - x \cdot \sqrt{-ab}}\right)$$

$$\int \frac{x \cdot dx}{a + b \cdot x^3} = \frac{1}{3 \cdot b \cdot k} \cdot \left[\frac{1}{2} \log\left(\frac{a + bx^3}{(k + x)^3}\right) + \sqrt{3} \cdot \tan^{-1}\left(\frac{2 \cdot x - k}{k \cdot \sqrt{3}}\right)\right] \quad ; \quad k = \sqrt[3]{\frac{a}{b}}$$