DEE-34206 Dynamics and Control of Grid-Connected Converters Final exam, 1.2.2017

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Use of own programmable calculator is allowed.

Problem 1 (max 8 points)

Power stage of a voltage-fed inverter with dq-domain output-current control is as shown in Figure 1.

a) Develop the inverter average model in dq-domain at open-loop, $\left(\langle i_{\text{in}}\rangle = \frac{3}{2} d_{\text{d}} \langle i_{\text{Ld}}\rangle + \frac{3}{2} d_{\text{q}} \langle i_{\text{Lq}}\rangle\right)$.

b) Draw the equivalent linear circuit in dq-domain (DC input port and two AC output ports).

c) How do you have to modify the duty ratio d and q-components (by adding x_{d} and x_{q}) to make the inverter output currents independent of the grid voltage d and q-components? I.e., how to implement grid voltage feedforward?

d) How do you realize decoupling of the current d and q-components? Use the average model to obtain necessary control laws / scaling coefficients.

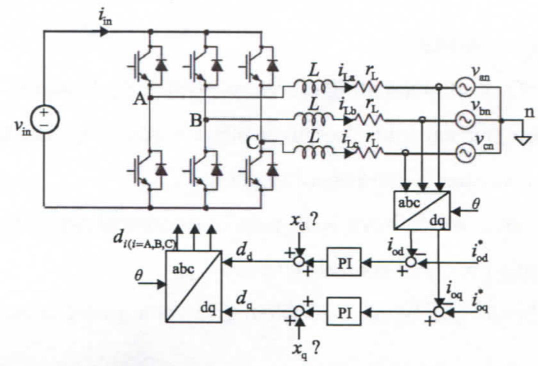

Figure 1: Voltage-fed inverter with output-current control.

Problem 2 (max 4 points)

Instantaneous apparent power can be defined as the product of voltage space-vector and the complex-conjugate of current space-vector in the stationary reference frame as in (1).

a) Define real and imaginary power in the synchronous reference frame, i.e., in the dq-domain. The space vector is assumed to rotate at the fundamental grid frequency ω_{s} .

b) Explain (based on the previous result), how the real and imaginary power produced by three-phase inverter can be controlled independently.

$$s = v^{\alpha\beta} \cdot \left(i^{\alpha\beta}\right)^{*} \tag{1}$$

Problem 3 (max 6 points)

Control block diagram of a phase-locked-loop is as shown in Figure 2. The feedforward term ω_{ff} is a constant which improves start-up. The Park's transformation can be linearized as $\hat{v}'_{\text{q}} = \hat{v}_{\text{q}} - V_{\text{d}}\hat{\theta}$ where $\hat{v}_{\text{q}}$ denotes the ideal grid voltage q-component.

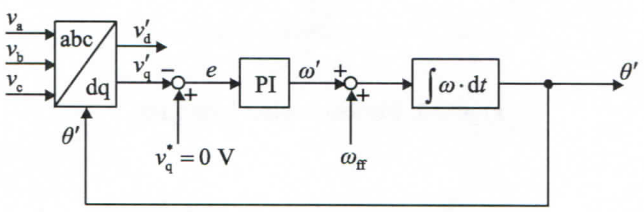

Figure 2: Phase-locked-loop.

a) Draw the linearized control block diagram and define control loop gain of the PLL.

b) Solve transfer function from the reference input $\hat{v}_q^*$ to the controlled variable $\hat{v}_q'$ in dq-domain.

c) The transfer function from reference to the controlled variable can be written as a second-order system as in (2). Find out the damping ratio ξ and natural frequency ω_n in terms of controller parameters. You can assume that the controller transfer function is as given in (3).

$$G = \left(2\xi\omega_n s + \omega_n^2\right) / \left(s^2 + 2\xi\omega_n s + \omega_n^2\right) \quad (2)$$

$$G_c = \frac{(-1)\cdot K\left(s/\omega_z + 1\right)}{s} \quad (3)$$

Problem 4 (max 6 points)

Give short answers to following questions.

1. What is the main benefit of implementing current control in dq-domain?
2. How can one implement current control of three-phase inverter outside dq-domain?
3. Why do you need to solve steady-state operating point?
4. Can you stabilize converter which has a RHP-pole in its control dynamics? How?
5. Give short definition of a cascaded control scheme?
6. How should the PLL bandwidth be selected when grid voltages are unbalanced?

Problem 5 (max 6 points)

Figure 3 shows current control loop gain with a simple unity-gain integrator as the controller (4). Comment on the stability and expected performance of the current control. Propose a controller transfer function to increase stability margins and explain how to select controller parameters (poles/zeros/gains). The control loop gain should have a crossover frequency around few kilohertz. You don't need to give specific values for controller parameters. You may sketch bode diagrams to justify the tuning process.

$$L_{out} = G_{cod\text{-}o} \cdot \frac{1}{s} \quad (4)$$

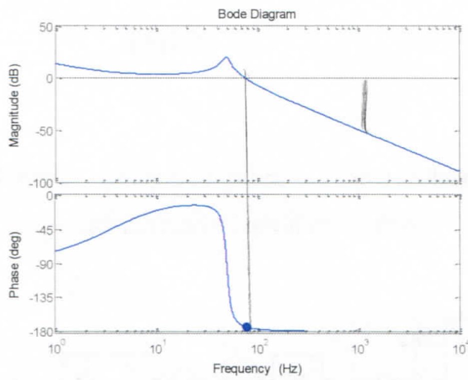

Figure 3: Current control loop gain.