DEE-34206 Dynamics and Control of Grid-Connected Converters Final exam, 24.1.2019

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Use of own programmable calculator is allowed.

Problem 1 (max 5 points)

Figure 1 shows the control scheme of a grid-connected converter. Answer the following questions:

a) In which reference frame is the current control implemented in? What is the benefit of using this reference frame?

b) Justify why the DC voltage can be regulated by changing the value of inductor current d-component.

c) How would you modify the control system if you implemented the current control in the stationary reference frame?

d) Why is the term ω_{PLL} multiplied with the inductance value and subsequently multiplied with current value and then added in the output of the PI-controller? How does this additional signal loop affect the converter operation during transients?

e) To which voltage does the converter synchronize its output currents into? How can you see this from the control diagram?

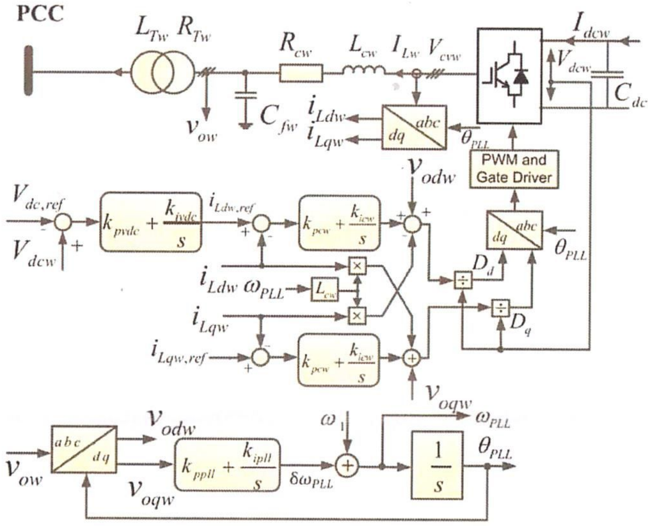

Figure 1: Control system of a grid-connected converter.

Problem 2 (max 5 points)

A voltage-fed inverter is as shown in Figure 2. Define the average model in the dq-domain. Use the average model to derive the decoupling gains in current control and the grid-voltage feedforward gains. I.e., how should you modify control inputs to decouple current d and q-components and to reduce the effect of grid voltage harmonics? Give the appropriate gains. Note that variables c_d and c_q are now the control variables. (Hint: Derive the model first assuming d_d and d_q as inputs, and subsequently add the effect of gains k_1 and k_2).

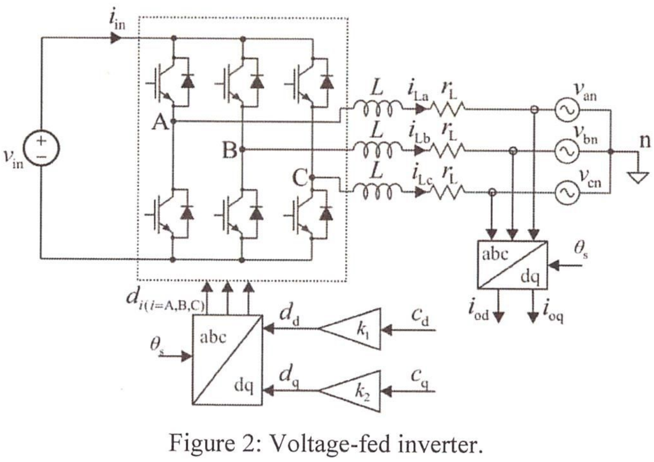

Figure 2: Voltage-fed inverter.

Problem 3 (max 5 points)

Transfer function matrix of a grid-connected photovoltaic inverter is given at open-loop in (1).

a) Draw the control block diagrams that represent the inverter output dynamics in dq-domain and include the output current controllers, sensing gains and PWM modulator gain.

b) Draw a control block diagram where cascaded control scheme is implemented to regulate the PV voltage. You can assume that DC-side dynamics depend mainly on d-components and that cross-couplings between d and q-components can be neglected.

c) Use the control block diagram to solve the transfer function of the DC voltage control loop gain.

d) Explain the tuning process of the cascaded control loops.

e) Solve the output admittance q-component from the block diagram. You can assume the output current q-component is not affected by any of the d-components.

$$\begin{bmatrix} \hat{v}_{PV} \\ \hat{i}_{od} \\ \hat{i}_{oq} \end{bmatrix} = \begin{bmatrix} G_{11}^{OL} & G_{12}^{OL} & G_{13}^{OL} & G_{14}^{OL} & G_{15}^{OL} \\ G_{21}^{OL} & G_{22}^{OL} & G_{23}^{OL} & G_{24}^{OL} & G_{25}^{OL} \\ G_{31}^{OL} & G_{32}^{OL} & G_{33}^{OL} & G_{34}^{OL} & G_{35}^{OL} \end{bmatrix} \begin{bmatrix} \hat{i}_{PV} \\ \hat{v}_{od} \\ \hat{v}_{oq} \\ \hat{d}_{d} \\ \hat{d}_{q} \end{bmatrix} \quad (1)$$

Problem 4 (max 5 points)

Three-phase LCL-filter is shown in Figure 3. Solve the average state-space model of the filter in the dq-domain. You can assume that the three-phase input and output voltages are balanced. The zero component can be neglected. Draw the electrical circuits of the filter in dq-domain (separately for d and q-components), $\left(\mathbf{x}^{\alpha\beta} = \mathbf{x}^{dq} \cdot e^{j\omega_s t}\right), \left(\mathbf{T}^{abc\rightarrow\alpha\beta} \cdot [k \quad k \quad k]^{T} = [0 \quad 0 \quad k]^{T}\right)$.

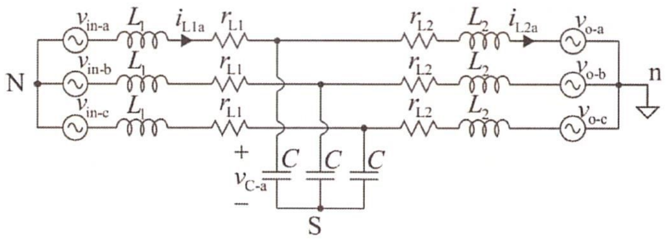

Figure 3: Three-phase LCL-type filter.

Hints:

$$\frac{d}{dt} i_{L1}^{dq} = f\left(v_{NS}, v_{in\text{-}d}, v_{in\text{-}q}, v_{C\text{-}d}, v_{C\text{-}q}\right)?$$

$$\frac{d}{dt} v_{C}^{dq} = f\left(i_{L1d}, i_{L1q}, i_{L2d}, i_{L2q}\right)?$$

$$\frac{d}{dt} i_{L2}^{dq} = f\left(v_{nS}, v_{C\text{-}d}, v_{C\text{-}q}, v_{o\text{-}d}, v_{o\text{-}q}\right)?$$