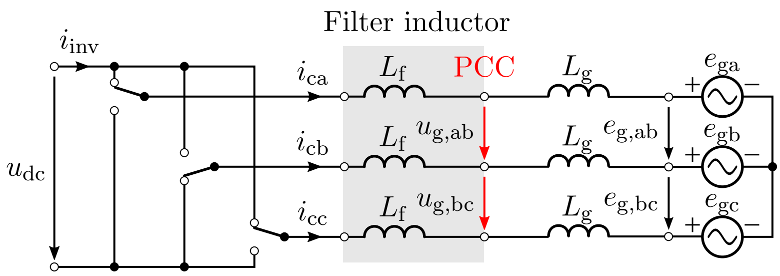
Problem 1: operating point of a grid forming converter

The figure below shows a 10-kVA grid converter, and filter inductance is $L_\mathrm{f} = 5$ mH. The electric grid is assumed to be a balanced three-phase voltage source with frequency of 50 Hz and phase-to-phase rms voltage of 400 V with a grid inductance $L_g = 15$ mH. The converter can be assumed to be lossless and switching-cycle-averaged quantities are considered. For this application, Grid forming (GFM) control method is studied and then compared to grid following (GFL) in terms of operating points. The active power reference is $p_\mathrm{c,ref} = 8$ kW and the voltage magnitude reference u_ref and grid nominal voltage e_g^N are $u_\mathrm{ref} = e_\mathrm{g}^\mathrm{N} = \sqrt{2/3} \cdot 400$ V. The corresponding load angle between the grid voltage $\boldsymbol{e}_\mathrm{g}$ and the converter voltage $\boldsymbol{u}_\mathrm{c}$ is $\delta = \vartheta_\mathrm{c} - \vartheta_\mathrm{g} = 0.32$ rad.

(a) Calculate the converter current vector and the PCC voltage magnitude in steady state when a grid forming (GFM) converter is used.

(b) Calculate the converter current vector and the PCC voltage magnitude in steady state when a grid following (GFL) converter is used with the same active power reference and when the reactive power reference is set to zero.

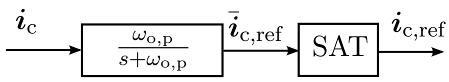


Problem 2: Current limitation of a grid forming converter

This exercise is about the current limitation action embedded in the control law presented in the lecture. There, an active resistance is used to damp the current oscillations by acting on the converter output voltage

$$\boldsymbol{u}_\mathrm{c,ref} = \boldsymbol{u}_\mathrm{ref} + R_\mathrm{a}(\boldsymbol{i}_\mathrm{c,ref} - \boldsymbol{i}_\mathrm{c})$$

where R_a is the active resistance gain, $\boldsymbol{u}_\mathrm{ref} = u_\mathrm{ref} + 0\mathrm{j}$ is the voltage reference and $\boldsymbol{i}_\mathrm{c,ref}$ is defined in the Figure below, using block diagram.



This current is named the current reference and can be limited to a user-defined value, here denoted by i_max in order to mitigate the current transients and to avoid too high overcurrents. In this case q-axis current is prioritized as

$$\boldsymbol{i}_\mathrm{c,ref} = \begin{cases} 0 - \mathrm{j}i_\mathrm{max} & \text{if} \quad |\bar{\boldsymbol{i}}_\mathrm{c,ref}| > i_\mathrm{max} \\ \bar{\boldsymbol{i}}_\mathrm{c,ref} & \text{otherwise} \end{cases}$$

A three-phase short circuit occurs when the converter is providing zero active power, forcing the grid voltage to zero such that $|\boldsymbol{e}_\mathrm{g}| = 0$, thus activating the current limitation action. In this problem, the converter frequency is assumed to be constant in steady state ($\omega_\mathrm{c} = \omega_\mathrm{g,ref}$). In this problem, $i_\mathrm{max} = 30$ A and $R_\mathrm{a} = 3.2\ \Omega$.

(a) Calculate the steady-state converter current vector $\boldsymbol{i}_\mathrm{c}$ and its magnitude during the fault state ($|\boldsymbol{e}_\mathrm{g}| = 0$).

(b) Calculate the corresponding converter output and PCC voltage magnitudes during the fault state.