Assignment 1

Wednesday, October 8, 2025 2:05 PM

A three-phase two-level VSC is connected to a constant DC voltage source on its DC-side, and its AC-side is connected to an infinite bus through an LR filter. The VSC system has the following specifications:

- Grid voltage: 580 V (line-to-line, RMS) $= V_{LL,RMS}$
- Grid frequency: 60 Hz
- DC-link voltage: 1000 V
- Rated power: 100 kVA $= S_{base}$
- Modulation strategy: Sinusoidal PWM
- Control mode: GFL PQ control
- Switching frequency: 3.06 kHz

For all subsequent questions, you may use any design procedure to obtain your controller parameters. Bode plots, root locus, MATLAB SISOTOOL, Nyquist plot, state-space designs are all accepted, but trial-and-error methods are not acceptable.

You do not need to design the outer PQ controller loop: instead, divide your power set-points by grid voltage to obtain inner current controller references.

You can simulate the VSC system in either MATLAB/Simulink, PSCAD, or PLECS. Converter latency and higher-order harmonics can be neglected.

1. [**10 points**] Design the LR filter values for the VSC, using the procedure developed in class. Then use these values in all subsequent questions.

$S_{base} = 100\text{kVA}$ $\quad \omega_0 = 2\cdot\pi\cdot 60 = 376.99$

$V_{LL,RMS} = 580$ V

$$Z_{base} = \frac{V_{LL,RMS}^2}{S_{base}} = R_{base} = X_{base} = \frac{580^2}{100{,}000} = 3.364\ \Omega$$

$$L_{base} = \frac{X_{base}}{\omega_0} = \frac{3.364}{\omega_0} = 8.9\text{ mH}$$

- $L \sim 10\% - 20\%$ of L_{base}

$$\Rightarrow L = 0.15\,L_{base} = 0.15(8.9\text{ mH}) = 1.3\text{ mH}$$

- Quality factor: $Q = \frac{\omega_0 L}{R} = \frac{X_L}{R} \Rightarrow$ ideally $Q > 75\%$

- calculate $R = \frac{\omega_0 L}{Q}$

  ↳ set $Q = \omega_0 = 377$

  $\Rightarrow R = L = 1.3\text{ m}\Omega$

2. [**40 points**] Design PI current controller and PLL controller for the VSC, using the net control block diagram models developed in class.
   a. Show your detailed design procedure for current controller (e.g., provide bode plot/root locus plot of your system, any calculations you have done, and/or any code, and explain why you have chosen the final controller parameters) and provide the final

Bonus

PI controller design in the format of $G(s) = k_p + \frac{k_i}{s}$

PI controller design in the format of $C(s) = k_p + \frac{}{s}$

loop gain: $l(s) = \left(\frac{K_p}{Ls}\right) \frac{s + \frac{K_i}{K_p}}{s + R/L} \Rightarrow l(s) = \frac{K_p}{Ls}$

Closed-loop transfer function: $\frac{i_d(s)}{i_d^{ref}(s)} = G_i(s) = \frac{1}{\tau_i s + 1}$, choose $K_p = \frac{L}{\tau_i}$ (proportional gain) & $K_i = \frac{R}{\tau_i}$ (integral gain)

- Choose τ_i so it's small for fast current controller response, but large enough s.t. $\frac{1}{\tau_i}$ (B.W) is about 10× smaller than switching frequency ($f_{sw} = 3.06$ kHz)

$\Rightarrow \tau_i = 3$ ms & $\frac{1}{\tau_i} \sim 0.3$ kHz

$K_p = \frac{L}{\tau_i} = \frac{1.3 \text{ mH}}{3 \text{ ms}} = 0.43$ [V/A]

$K_i = \frac{R}{\tau_i} = \frac{1.3\ \Omega}{3 \text{ ms}} = 0.43$ [V/A]

$C(s) = 0.43 + \frac{0.43}{s}$

b. Show your detailed design procedure for PLL controller (e.g., provide bode plot/root locus plot of your system, any calculations you have done, and/or any code, and <u>explain why you have chosen the final controller parameters</u>) and provide the final PI controller design in the format of $H(s) = k_{pPLL} + \frac{k_{iPLL}}{s}$

- Goal: regulate V_{sq} at zero
  - $\omega(t) = H(s) V_{sq}(t)$ [(rad/s)/V]
  - $\frac{d\rho}{dt} = H(s) \hat{V}_s \sin(\omega_0 t + \theta_0 - \rho)$
  - $\Delta\omega = \frac{d\rho}{dt} = H(s) \hat{V}_s (\omega_0 t + \theta_0 - \rho)$

- Since linearizing around steady state ω_0, $\omega(0) = \omega_0$? $\omega_{min} \leq \omega \leq \omega_{max}$

- $[\omega_{min}, \omega_{max}] \sim [55, 65 \text{ Hz}]$ → close to ω_0 but not too close

- Closed-loop transfer function: $\frac{\rho}{\rho_{ref}} = \frac{G(s)}{1 + G(s)}$ where $G(s) = \hat{V}_s \left(K_p + \frac{K_i}{s}\right)\left(\frac{1}{s}\right)$

$$\frac{\rho}{\rho_{ref}} = \frac{\hat{V}_s \left(K_p + \frac{K_i}{s}\right)\left(\frac{1}{s}\right)}{1 + \hat{V}_s \left(K_p + \frac{K_i}{s}\right)\left(\frac{1}{s}\right)} = \frac{\hat{V}_s K_p s + \hat{V}_s K_i}{s^2 + \hat{V}_s K_p s + \hat{V}_s K_i}$$

Denominator: $s^2 + \hat{V}_s K_p s + \hat{V}_s K_i$

$$\omega_n^2 = \hat{V}_s K_i \Rightarrow \omega_n = \sqrt{\hat{V}_s K_i}$$

damping ratio: $\xi = \dfrac{V_s K_p}{2\sqrt{\hat{V}_s K_i}}$

$$\omega_{BW} = \omega_n \left[1 + 2\xi^2 + \sqrt{(1+2\xi^2)^2 + 1}\right)^{1/2}$$