Exercise 2

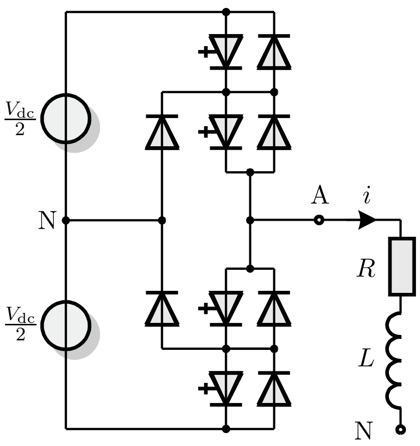
The objective of this exercise is to understand, practice and apply the concept of one-step predictive current control to a single-phase RL load, see Section 4.1. Directly related to this are the following topics:

- Analysis of predictions to debug the controller and to ensure that it works as desired.
- Tuning procedure.
- Steady-state and transient performance, see Section 4.1.5.
- Switching frequency of a three-level converter phase leg, see Section 2.4.1.

The understanding developed in this exercise will be instrumental when developing more elaborate predictive controllers.

2.1 Predictive current control: Implementation

Consider the single-phase system shown in Fig. 1. A three-level neutral-point-clamped (NPC) inverter phase leg with the total dc-link voltage V_{dc} is connected to a passive RL load. The SI parameters of the system are provided below. Note that V_R denotes the rated rms *phase* voltage, not the line-to-line voltage.



$$V_{dc} = 5.2\,\text{kV}$$
$$V_R = \frac{1}{\sqrt{3}}3.3\,\text{kV}$$
$$f = 50\,\text{Hz}$$
$$L = 2\,\text{mH}$$
$$R = 2\,\Omega$$

Figure 1: Single-phase three-level inverter with a (passive) RL load

1. Preparation: Download the Matlab/Simulink files from the course webpage. Start Matlab and open the Simulink model singlePhase_passiveRL.slx. A few comments are provided hereafter:
   - The file predCurrCtrl_ini.m is called when the simulation is started, see Model Settings / Model Properties / Callbacks / InitFcn. The parameter and controller settings are provided in this file.
   - The yellow blocks need to be completed. These blocks compute the current reference (Matlab function named currRef), execute the current controller (Matlab function named currCtrl), compute the gating signal and derive the switching frequency.

- The power electronics system is simulated at the short sampling interval of $5\,\mu$s, while the controller is run at the (often much) longer sampling interval $T_s > 5\,\mu$s. To achieve this, three rate transition blocks are used in the Simulink model.
- All signals in the Simulink model are in the SI system (rather than in a per unit system).

2. What is the rated phase current I_R? To this end, complement in predCurrCtrl_ini.m the part relating to the per unit system.

3. Implement the current reference function currRef. Compute the current reference at time steps k and $k+1$. Set the current amplitude to 80% of the base current.

4. Implement the gating signal block (function gatingSignal) that translates the switch position $u(k)$ into the four gating signals, one for each active semiconductor.

5. To help you get started, a simple hysteresis controller has been implemented as a preliminary current controller. This hysteresis controller maintains the phase current within symmetrical upper and lower limits around its reference value. In the positive half-wave of the current reference, the controller switches between $u(k) = 0$ and 1, whereas in the negative half-wave it switches between -1 and 0. This simplistic approach assumes the power factor to be close to one.

   You should now be able to run the simulation. Explore the impact the current error band of the hysteresis controller has on the current ripple and the number of switching transitions.

6. Derive the discrete-time prediction model $i(k+1) = Ai(k) + Bu(k)$, see (4.3), using SI units and forward Euler discretization. What are the values of A and B for $T_s = 25\,\mu$s?

7. Implement the predictive current controller in the function currCtrl. Adopt SI units and use a prediction horizon of one step. In the objective function normalize the predicted current error with the base current I_B.

2.2 Predictive current control: Testing and analysis

After having implemented the current controller, it will be tested and analyzed hereafter.

1. Test the predictive controller with the settings $T_s = 25\,\mu$s and the penalty on switching $\lambda_u = 5 \cdot 10^{-3}$. How does the closed-loop performance of the predictive controller compare with Fig. 4.5? How does it compare with the hysteresis controller? Why is that so?

2. Consider $T_s = 200\,\mu$s and $\lambda_u = 20 \cdot 10^{-3}$. Analyze the current over the first quarter of the fundamental period. Is the current waveform as expected? To better understand the shape of the current, display and analyze at several time steps the different values of the objective function, based on which the controller decides on the switch position. Simulate the current waveform for $\lambda_u = 25 \cdot 10^{-3}$.

3. Write a post-processing script that is based on the stored sequence of switch positions, i.e., $[u(0)\ u(1)\ \ldots]^T$. What is the switching frequency when operating at $T_s = 25\,\mu$s and $\lambda_u = 5 \cdot 10^{-3}$? Alternatively, the switching frequency block can be used to compute the switching frequency.

4. Simulate the controller for $\lambda_u = 0$. What is the influence of the controller sampling interval on the current ripple and the switching frequency?

5. Choose $T_s = 25\,\mu$s and $\lambda_u = 2 \cdot 10^{-3}$. Apply steps to the current reference. Switch from 80% rated current to 20% current at $t = 5$ ms. Switch back to 80% current at $t = 15$ ms. Is the switching constraint enforced? What happens when the switching constraint is removed? Why are the settling times different during the two steps?

6. Penalize the current error using the ℓ_1-norm. Tune λ_u such that you obtain a similar switching frequency as with the ℓ_2-norm and $\lambda_u = 5 \cdot 10^{-3}$. Is this possible? Why (not)?

7. Investigate the robustness of the predictive controller to modeling errors. Simulate the case, in which the prediction model uses half the actual system inductance. What happens if the prediction model uses twice the actual inductance? Explain the behavior of the controller in both cases.