Exercise 2

The objective of this exercise is to understand, practice and apply the concept of space vector modulation (SVM) assuming a three-phase two-level voltage source inverter.

2.1 Space vector modulation for a two-level inverter: Preparation

Consider the three-phase two-level voltage source inverter shown in Fig. 1. The total dc-link voltage V_{dc} is assumed to be constant and equal to 550 V. The rated values of the system are provided in Table 1. The system parameters are summarized in Table 2.

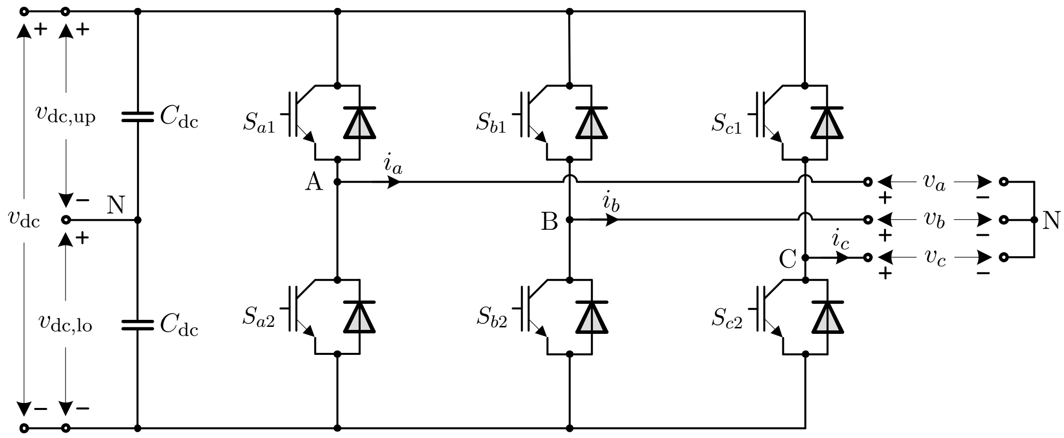

Figure 1: Three-phase two-level voltage source inverter

Table 1: Rated values of the system

Parameter	Symbol	SI value
Voltage	V_R	400 V
Angular frequency	ω_R	$2\pi 50$ rad/s

Table 2: Parameters in the SI of the two-level inverter

Parameter	Symbol	SI value
Dc-link voltage	V_{dc}	550 V

1. Preparation: Download the Matlab/Simulink files from the course webpage. Start Matlab and open the Simulink model inv.slx. A few comments are provided hereafter:

   - The initialization file systemIni.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 block, which generates the modulating signal according to the SVM principle (Matlab function named SVM), needs to be completed.

- The block within the subsystem "Modulator" which generates the three-phase switch position $\boldsymbol{u}_{abc}$ (Matlab function named modulator), needs to be completed.
- The system is simulated at the short sampling interval T_s of $1\,\mu$s, while the controller is run at the longer sampling interval $T_c > T_s$. To achieve this, several rate transition blocks are used in the Simulink model. Note that T_c is small enough, though, to approximate an "analog" implementation of the modulation stage.
- Note that the SimPowerSystems toolbox is not used. Instead, the inverter has been reduced to a gain, i.e., to $0.5V_{\mathrm{dc}}$.
- Note that the powergui block is used. This will help us to compute the harmonic spectra of the signals of interest.

2. Derive the p.u. values of the system based on the rated values given in Table 1. Use these values to complete the initialization file systemIni.m.

2.2 Space vector modulation for a two-level inverter: Natural sampling

After having completed the former tasks, we will now implement and test the modulation stage. SVM with natural sampling is considered. To simplify the implementation, it is assumed that the inverter is controlled in open loop. Thus, the inverter output voltage should be such that it follows the desired reference value.

1. Compute the amplitude of the reference voltage v^* (v_ref in the initialization file) such that the modulation index m is the maximum achievable within the linear modulation region.
2. The User-Defined functions (shown as red boxes) that generate the reference signal $\boldsymbol{v}^*_{abc}$ need to be completed. At this point assume that the operating angular frequency ω (omega in the initialization file) is the rated one.
3. For pulse ratio $f_c/f_1 = 39$—and for the above operating conditions—complete the functions SVM and modulator.
4. Compute the harmonic spectrum of the switch position (single phase and differential-mode) up to 8000 Hz. For that you will use the "FFT analysis" from the powergui block. When computing the spectrum, it is recommended to skip the first period of the signal so as to avoid any undesirable effects due to the initialization. Does it suffice to compute the spectrum over one fundamental period? Why? How can you show that the SVM you implemented performs as desired?
5. Change the amplitude of the reference voltage to $v^* = 8\,$p.u. at $t = 0.05\,$s. What do you observe? How does the harmonic spectrum look like? What is the switching frequency?
6. Changing back to the maximum achievable modulation index within the linear modulation region, the fundamental angular frequency is halved at $t = 0.05\,$s. What do you observe? How does the harmonic spectrum look like? What is the switching frequency?

2.3 Space vector modulation for a two-level inverter: Asymmetric regular sampling

After having implemented and tested SVM with natural sampling, we will now implement it with asymmetric regular sampling.

1. For the same modulation index as in task (1) of the former exercise, angular frequency $\omega = \omega_R$, and pulse ratio $f_c/f_1 = 39$ complete the relevant part in the function modulator.

   Hint: Due to the chosen sampling interval T_s, the range of values for the maximum and minimum of the carrier signal do not appear at 1 and -1, respectively, but very close to these. Observe this deviation and take it into account when implementing regularly sampled SVM.

2. While operating under the above conditions compute the harmonic spectrum of the switch position (single phase and common-mode) up to 8000 Hz. Compare the generated harmonic spectrum with that of naturally sampled SVM.