EE 458/533 – Power Electronics Controls, Winter 2022
Homework 6
Due Date: Thursday March 10th 2022, 4:30 pm PT

Instructions. Include all MATLAB, Python and Plecs files.

Problem 1 [Modeling the Digital Controller]: In this problem we will include the effects of the digital control loop. Modify your switched simulation in HW 5 to match that in Fig. 1. The "ideal S/H" blocks indicate a sample-and-hold operation with infinite amplitude resolution and we assume the digital system can measure i_m and u_ff directly. In other words, we neglect the sensing path details and finite number of bits encountered in a real system.

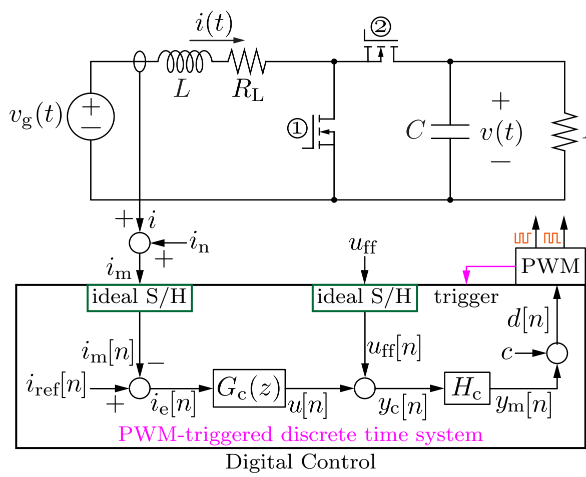

Figure 1: Boost converter with digital current control.

Perform the following:

(a) Discretize the controller from Problem 1 using Tustin or bilinear discretization using a step size of T_s (assume peak-valley sampling, get the other relevant information from HW 5). Write your z-domain transfer function analytically in terms of $T_\mathrm{s}, k_\mathrm{p}$, and k_i in the form below:

$$G(z) = \frac{a_1 z + a_0}{b_1 z + b_0}. \tag{1}$$

(b) Using the provided starter file, configure your simulation such that the controller resides within a system that is triggered to perform one computation each time the symmetric carrier equals zero. As shown in the starter file, you can use a "Pulse Generator" block to feed the trigger port of your digital controller and "IC" blocks to initialize your system properly. Attach screenshots of the overall system, as well as the internal contents of the triggered subsystem. To emulate the delay in digital systems, add a single time-step delay between the H_c scaling and PWM blocks.

(c) Simulate the events described in Homework 5. Overlay $i(t), i_\mathrm{ref}[n]$, and $i_\mathrm{m}[n]$ on one plot. On another plot overlay y_m, the carrier, and PWM output.

Problem 2: In this problem, we will study the details of a four pole machine (p=4) as shown in Fig. 2. The stator windings corresponding to the three phases are separated by 120° electrical angles. We only show the windings for one complete electrical cycle (or half mechanical cycle) : $0° < \theta_m < 180°$. In a complete machine, similar set of winding is repeated for another cycle $180° < \theta_m < 360°$. The current directions shown in the winding is due to an externally applied voltage source that is not shown in the figure. The three phase currents are denoted as i_a, i_b, i_c. The inductance and resistance of each phase winding is L and R respectively. Consider Φ_{pk} to be the peak flux and N, the number of turns of each coil per phase. In Fig. 2, we try to show only one such coil for each respective phase. Assume q axis leads d axis and all angles are measured with respect to $\perp_a$ (as in class notation).

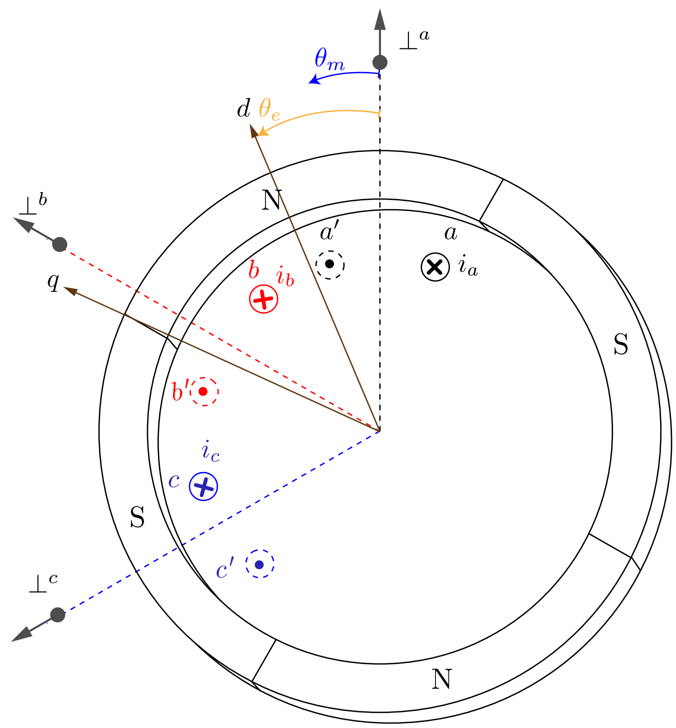

Figure 2: Magnetic ring with two pole pairs.

(a) Add the external voltage source v_a, v_b, v_c, and label its terminals correctly in Fig. 2 such that it matches the current directions labeled. A cross means current is going into the paper.

(b) Derive and sketch the equivalent circuit for the three phases. You should clearly show terminal voltages (v_a, v_b, v_c), stator currents (i_a, i_b, i_c) and speed-dependent voltages $(\mathcal{E}_\text{a}, \mathcal{E}_\text{b}, \mathcal{E}_\text{c})$ along with the other machine parameters as needed.

(c) Rewrite the previous set of equation in a rotating frame of reference as shown in Fig.2. From lecture notes you will follow that this happens when, $\theta_\text{d}(t) = \theta_e(t)$. Redraw the equivalent circuit in the dq reference frame and label the speed-dependent voltages, $\mathcal{E}_\text{d}$ and $\mathcal{E}_\text{q}$.

(d) Obtain the output power, $P_{\text{mech}} = (3/2)(\mathcal{E}_d i_d + \mathcal{E}_q i_q)$ in terms of $\Phi_{\text{pk}}, N, p, \omega_\text{m}$ and the stator currents in dq reference frame. Also obtain the mechanical torque from this expression.

(e) To generate a positive torque, and hence a positive power ($\omega_m > 0$ indicates counter-clockwise rotation), along which axis (d- or q-) should you excite a current and is the excited current positive or negative?

(f) In the Fig. 2 for a given θ_e, where $\theta_e = \theta_d$, label the direction of following space phasors : (i) Speed-dependent voltage ($\mathcal{E}$) (ii) Flux linkage due to permanent magnet ($N\Phi_{\mathrm{pk}}$).

(g) Verify using (e) and (f) that for the motoring operation, the stator flux (oriented along stator current) is leading the flux linkage due to rotor (oriented along $N\Phi_{\mathrm{pk}}$ space phasor) by 90°, ensuring a CCW rotation.

(h) Complete the table by filling the black spaces. CCW denotes counter-clockwise rotation of the rotor. Along which axis (d- or q-) should you excite a current and is the excited current positive, negative or zero, to ensure positive torque and hence positive power ($\omega_m > 0$ indicates counter-clockwise rotation). Assume q axis leads d axis and all angles are measured with respect to $\perp_a$ (as in class notation).

Orientation	Machine rotation	$i_d^\star(+,-,0)$	$i_q^\star(+,-,0)$
$\theta_{\mathrm{d}}(t) = \theta_e(t) + \pi/2$	CCW		
$\theta_{\mathrm{d}}(t) = \theta_e(t) + \pi$	CCW		
$\theta_{\mathrm{d}}(t) = \theta_e(t) + 3\pi/2$	CCW		
$\theta_{\mathrm{d}}(t) = \theta_e(t)$	CW		

(i) Now add the coils for the a,b and c phases for $180° < \theta_m < 360°$ and show the connection of those with the existing coils in Fig. 2 so that the back-emfs of these two coils add up. With these new coils, compare the power developed with the one you obtained in (d)