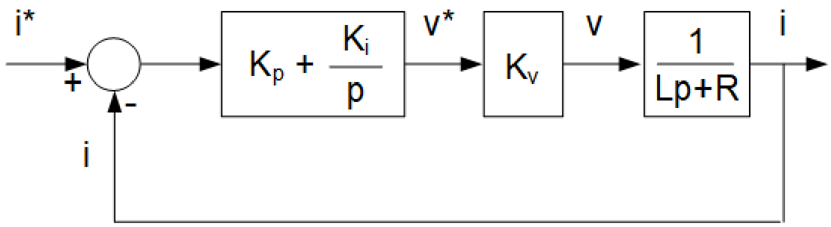
Homework #2 – Due November 16th, 2020

Analysis of DC Current Regulators for High Performance Drives

You are the controls engineer for XYZ Company and your boss has asked you to analyze and "tune" a current controller for a DC motor drive system. Not having a lot of experience tuning current regulators, you decide to systematically analyze the system and simulate its dynamic response.

To do:

a. Given the two different DC motors from HW1, determine the values of K_p and K_i to yield a 1000 Hz bandwidth at locked rotor (zero speed). Assume that there is a voltage amplifier gain $K_v = 680\frac{V}{V}$. See figure 1. Note: the current regulator gain formula in the notes don't assume there is a voltage amplifier gain so you will need to account for this additional gain when calculating the values of K_p and K_i.



$$i = \left(K_p + \frac{K_i}{p}\right)\left(\frac{K_v}{Lp+R}\right)(i^* - i) = \frac{K_i}{p}(\tau_c p + 1)\left(\frac{K_v/_R}{\tau_e p+1}\right)(i^* - i)$$

where

$$\tau_c = \frac{K_p}{K_i} \text{ and } \tau_e = \frac{L}{R}$$

setting

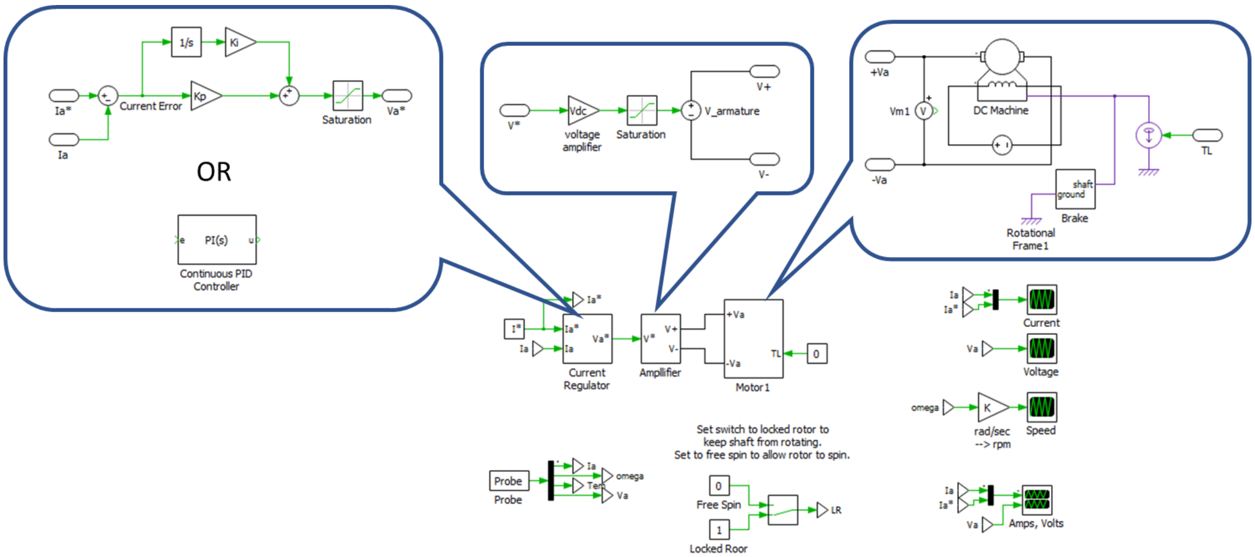
$$\tau_c = \tau_e$$

$$i = \frac{K_i}{p}\left(\frac{K_v}{R}\right)(i^* - i) \quad \text{or} \quad \frac{i}{i^*} = \frac{\frac{K_i}{p}\left(\frac{K_v}{R}\right)}{1+\frac{K_i}{p}\left(\frac{K_v}{R}\right)} = \frac{K_i K_v}{Rp + K_i K_v}$$

setting

$$R(2\pi f_{BW}) = K_i K_v \quad \text{or} \quad \boxed{K_i = \frac{2\pi f_{BW} R}{K_v} \quad \text{and} \quad K_p = \frac{2\pi f_{BW} L}{K_v}}$$

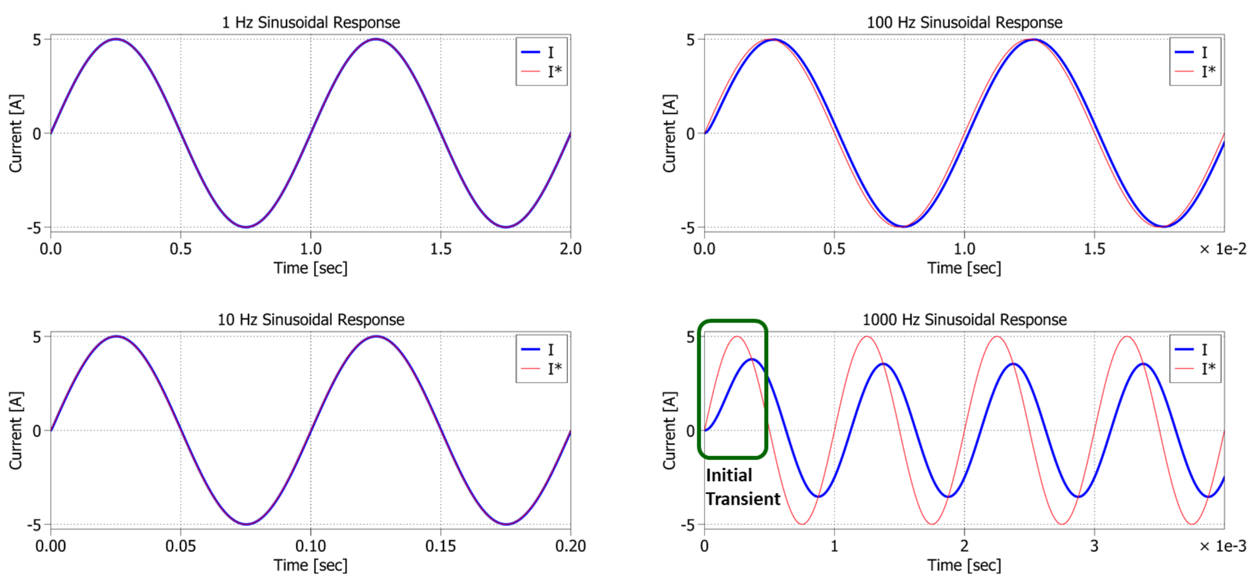
b. Implement proportional plus integral (PI) control in PLECS.
provided in attached PLECS file, here's the blocks



c. Using PLECS, simulate the motors at locked rotor conditions using an ideal voltage source. Use a saturation block to limit the maximum voltage to +/- 680V.
provided in attached PLECS file, shown in part b.

d. Given a current command of $i^*(t) = I_o \sin(2\pi f_c t)$ where I_o = 5A and f_c = 1, 10, 100, and 1000 Hz, plot the command and response of the current regulator as functions of time.

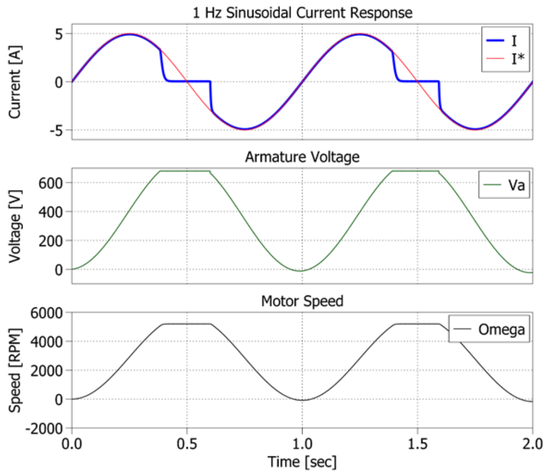
both systems look the same with ideal amplifier and locked rotor

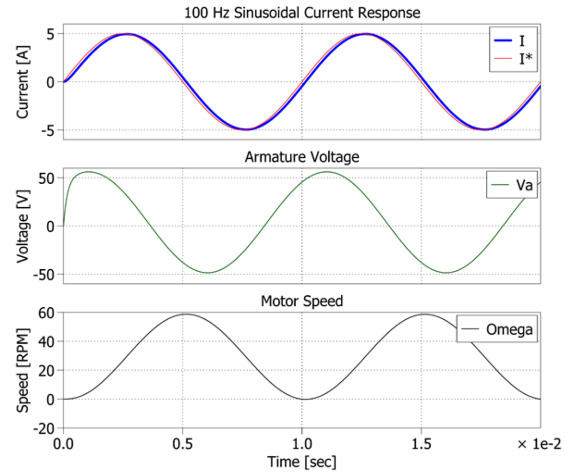


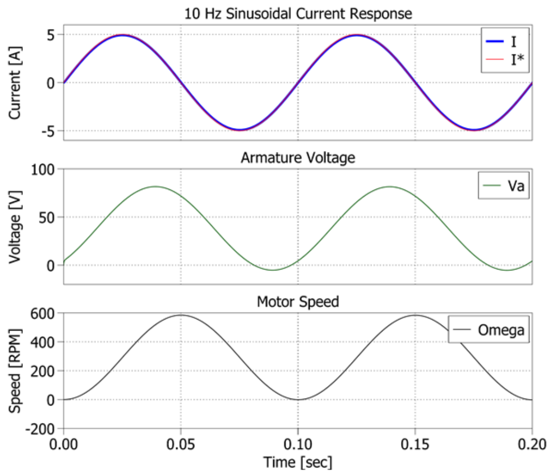
e. Evaluate the performance of the system when the rotor is free to rotate. What improvements can be made to enhance this performance?

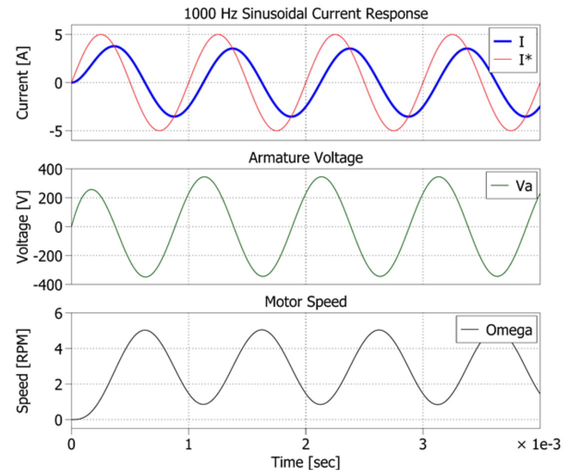
can use back EMF decoupling, can increase gains (but doesn't help if saturated) (note: either one of these or other responses possible)

Motor 1

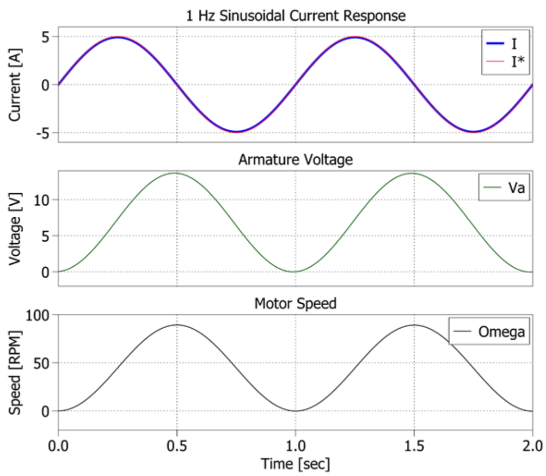


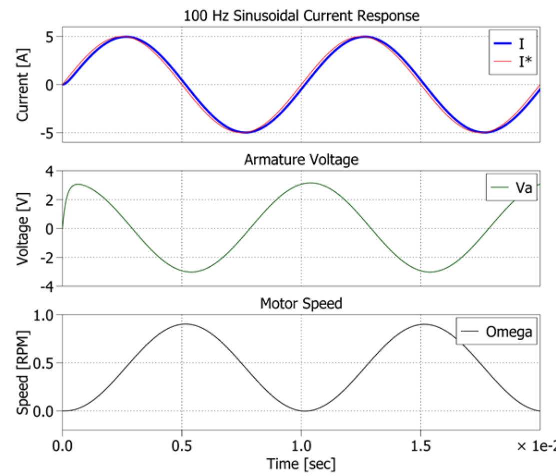


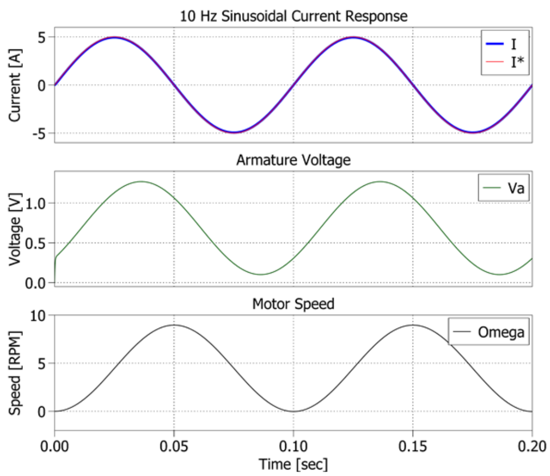


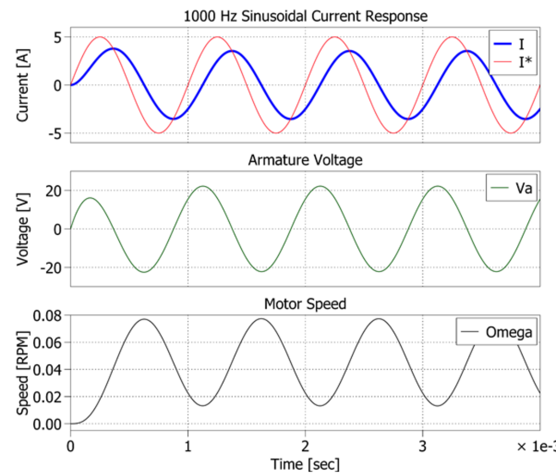


Motor 2





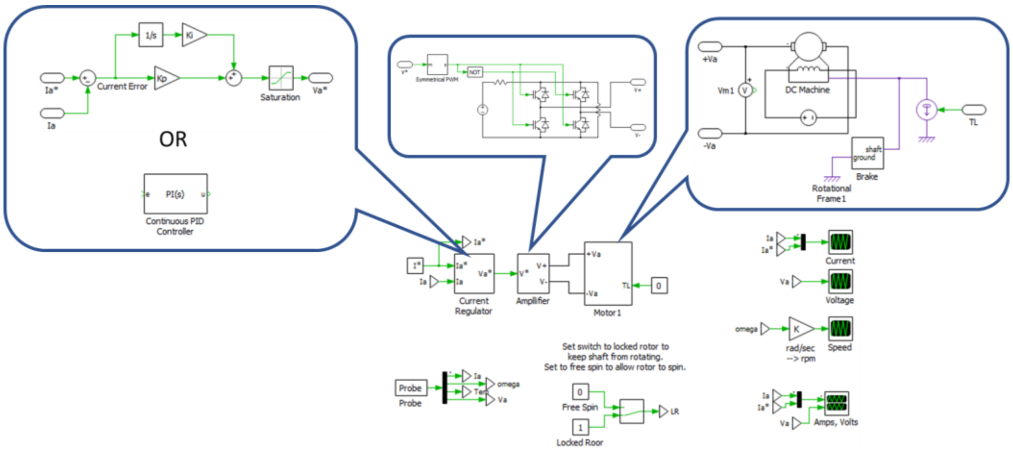




Notice that the speed amplitude increases at lower frequencies, this is because there is more time for the rotor to accelerate. Also notice that motor 1 has a higher speed amplitude, this is because there is lower inertia (and note that motor 1 at 1 Hz saturates the armature voltage).

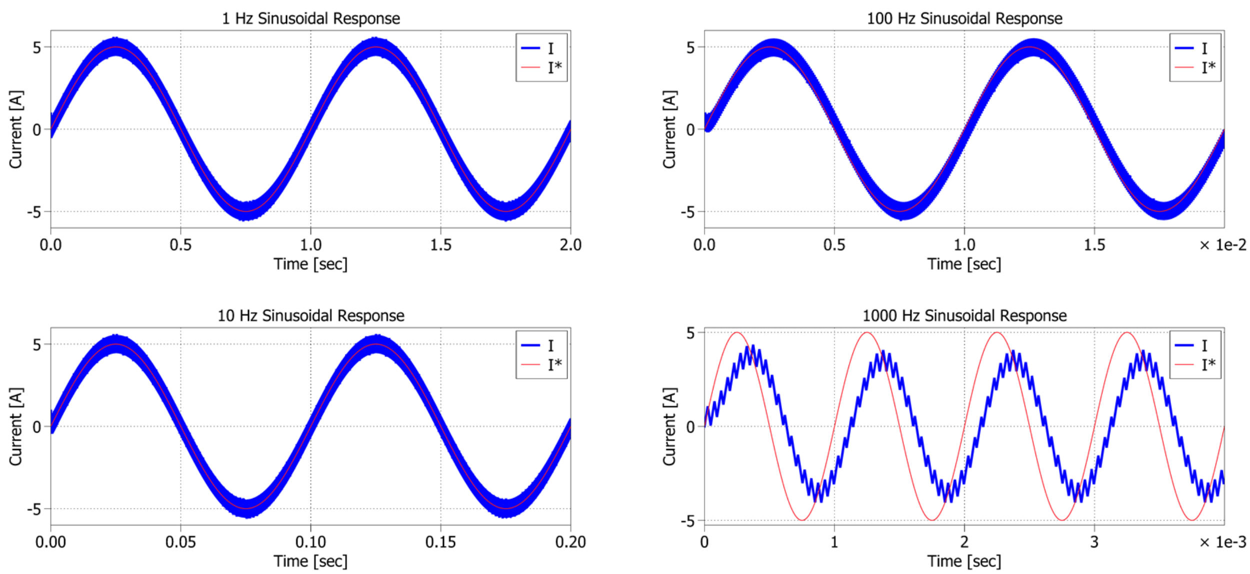
f. Repeat steps c-e with an H-bridge inverter with a 680V bus.

Part c. with H-bridge

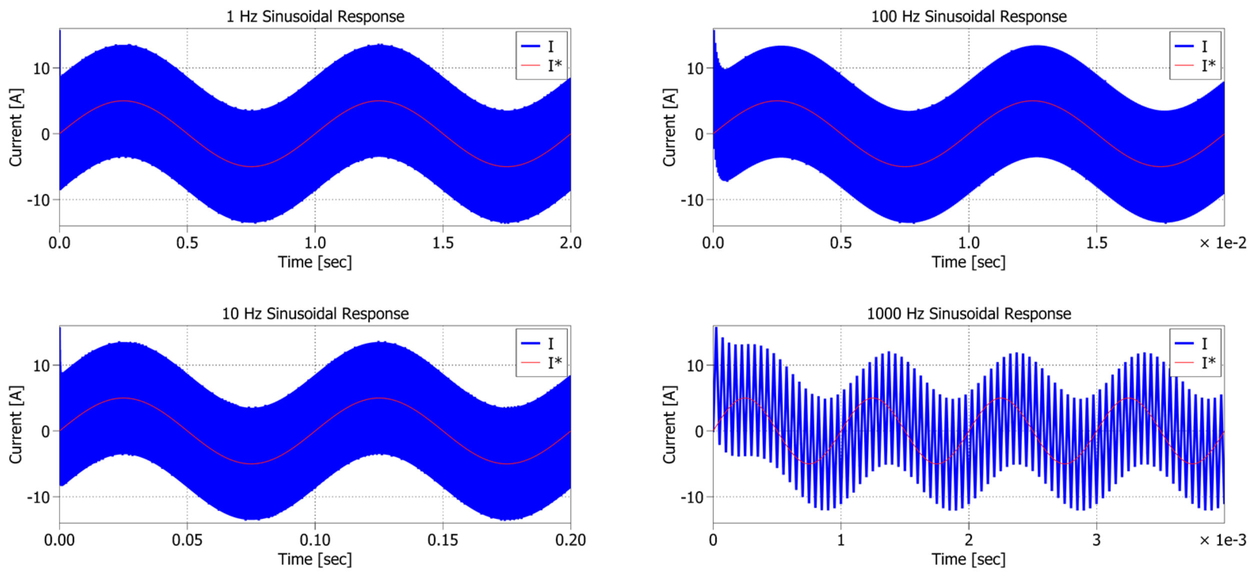


Part d. with H-bridge

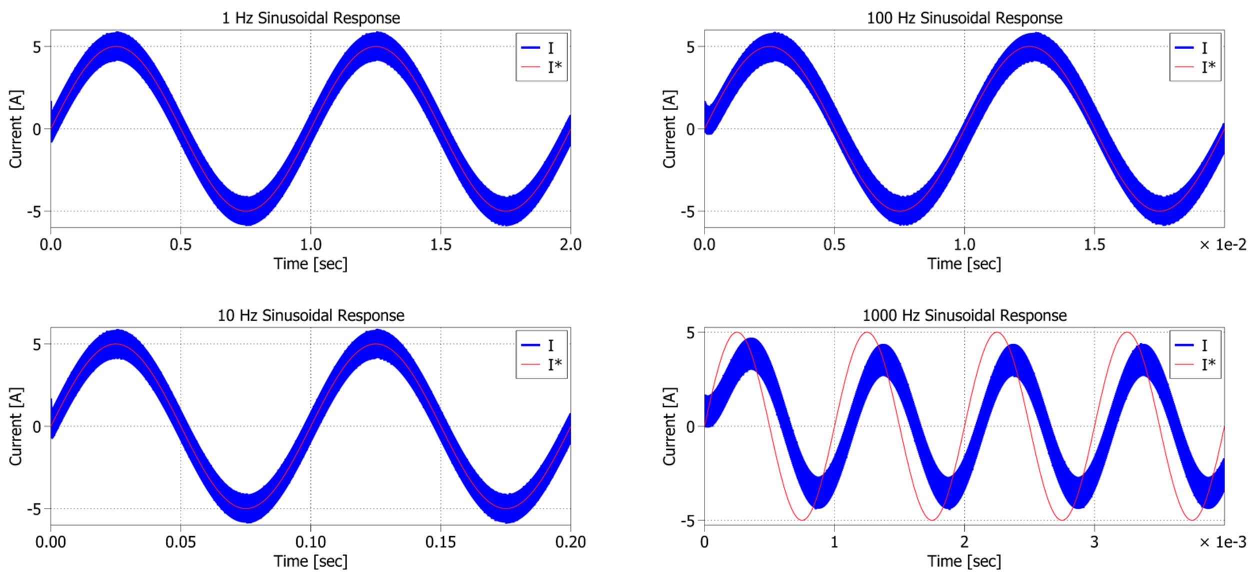
Motor 1 – 20kHz switching frequency



Motor 2 – 20kHz switching frequency

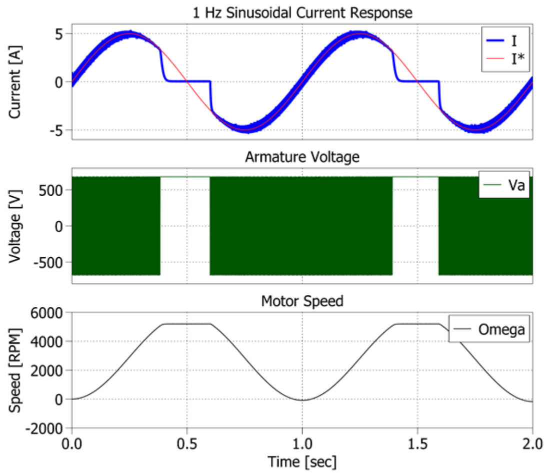


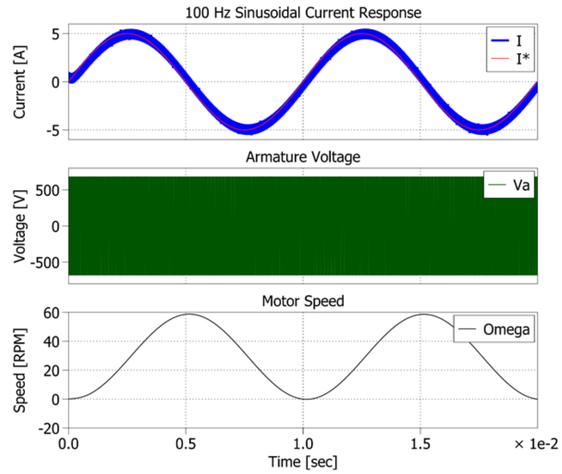
Motor 2 – 200kHz switching frequency (for comparison, not required)

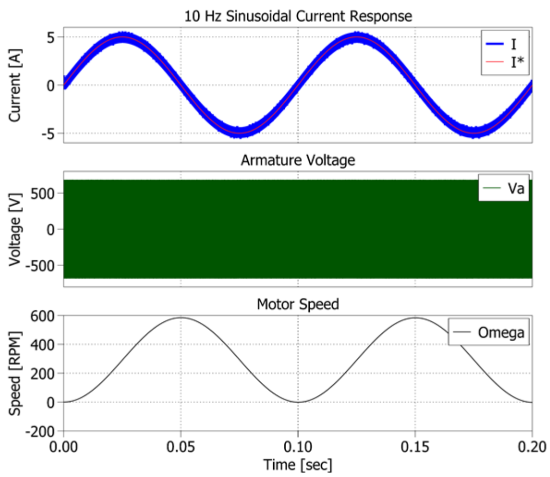


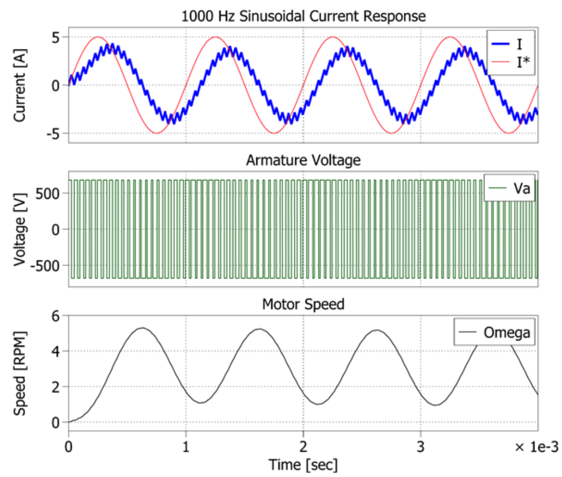
Part e. with H-bridge

Motor 1 – 20kHz switching frequency

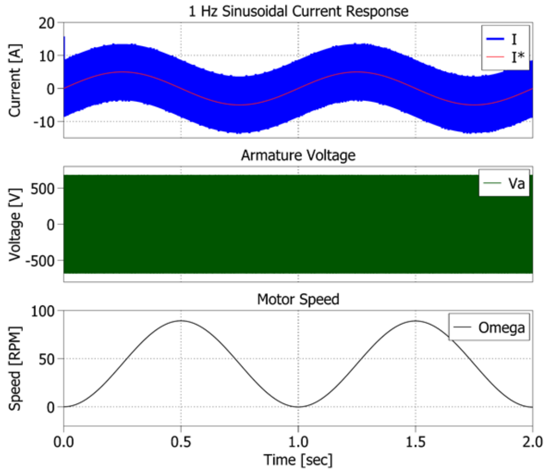


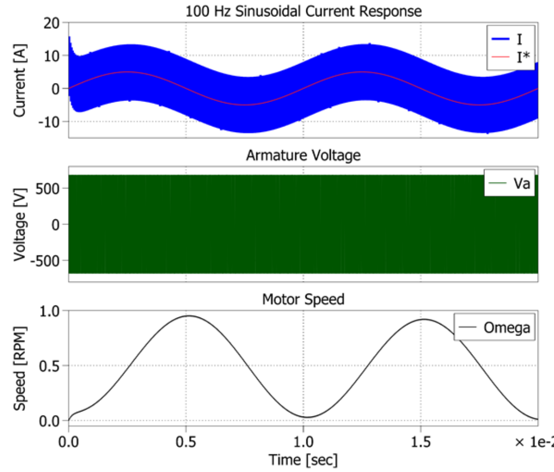


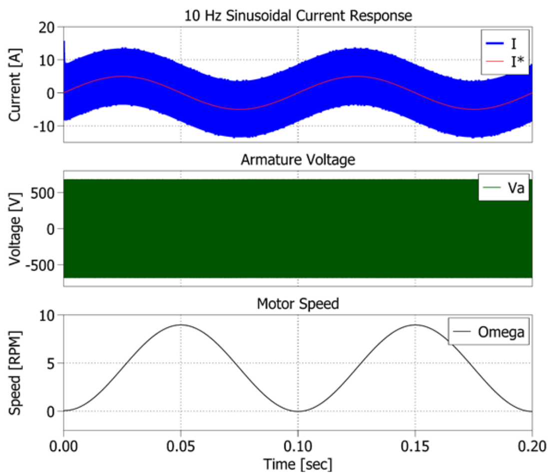


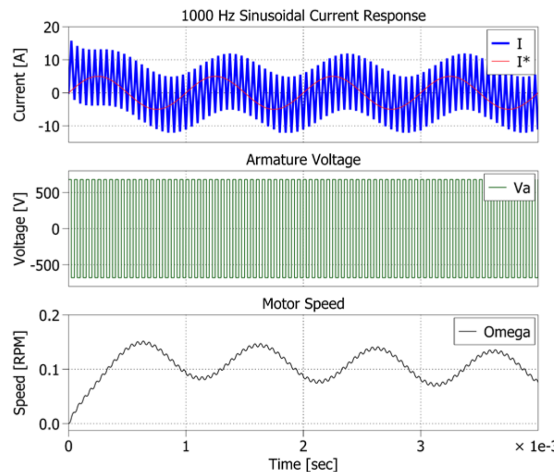


Motor 2 – 20kHz switching frequency









Notice that the speed response looks about thee same as the ideal amplifier case. You can clearly note the switching frequency induced speed ripple at 20 kHz on top of the 1000 Hz ripple in motor 2.

g. Provide a highly organized report with very clear figures and equations. The report should detail the design and analysis of the current regulator and list observations. (Keep main body of report to four pages or less.)

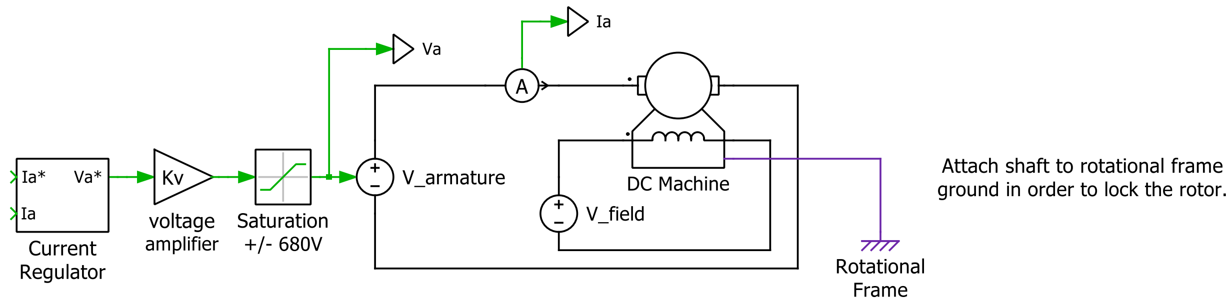


Figure 1: Implementation of Locked Rotor DC Motor in PLECS