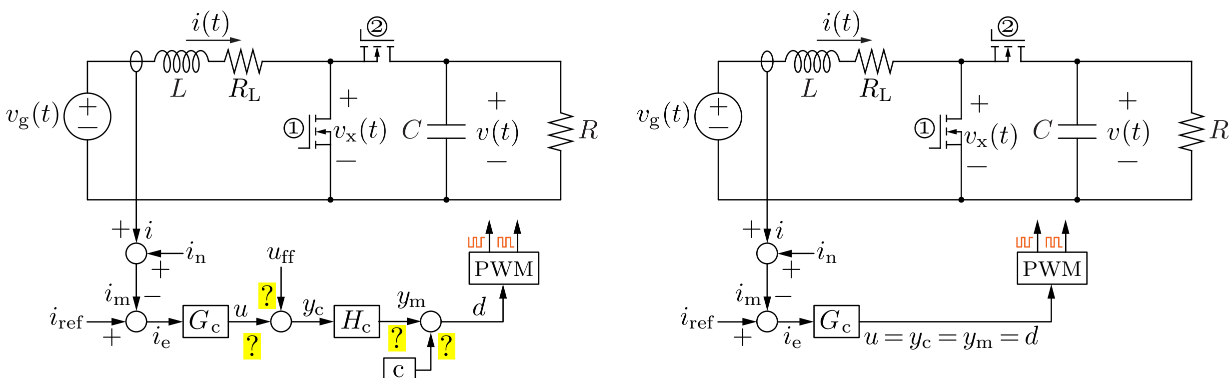
EE 458/533 – Power Electronics Controls, Winter 2022

Homework 5

Due Date: Friday March 3rd 2022, 4:30pm PT

Problem 1: Consider a boost converter where the winding and MOSFET on resistances are lumped into R_L. The diagrams in Figs. 1(a) represents the version used in lab and 1(b) represent the improved control structure that implements feed-forward. Below, you will model the improved controller and then compare it to the lab implementation. Assume all sensing path gains are equal to 1 and that a PI controller is used.



(a) Improved current controller

(b) Existing current controller in lab

Figure 1: Boost converter with current control.

Perform the following:

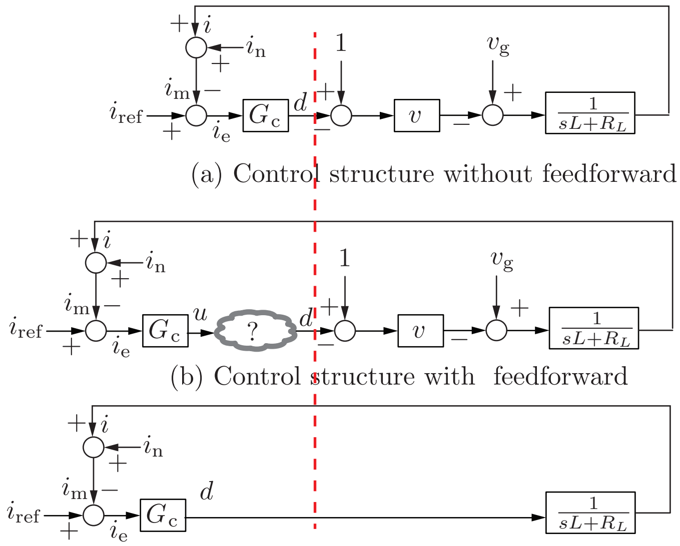
(a) Derive the voltage $\langle v_\mathrm{x}(t)\rangle$(average value of $v_\mathrm{x}(t)$ over one switching period) in terms of duty, d and output voltage, $\langle v(t)\rangle$

(b) Derive the KVL in the input loop to obtain a relationship between $v_\mathrm{g}(t)(=\langle v_\mathrm{g}(t)\rangle)$, L, R_L,$\langle v_\mathrm{x}(t)\rangle$ and $\langle i(t)\rangle$.

(c) Assume the controller, G_c produces an output, d, verify that Fig. 2 (a) shows the correct implementation of your KVL derived in the preceding question.

(d) We want to implement feed-forward to simplify our plant transfer function to be only $1/(sL + R_L)$ so that the controller design becomes simplified as in Fig. 2 (c). To achieve this, sketch or provide a numerical relationship between the controller output,u, and the actual duty ratio, d, that goes into the PWM block. (Note under all circumstances, $0 < d < 1$). Compare the relationship you have derived with Fig. 1 (a) to identify H_c, c, u_{ff} and the signs of the sum blocks shown with ?.

(e) Design your controller, G_c by plant-inversion formulae to achieve a bandwidth of 1/10-th of your switching frequency.



(a) Control structure without feedforward

(b) Control structure with feedforward

(c) Simplified plant with feedforward

Figure 2: Control simplification with feed-forward. On the right side of the red-dashed line is your plant and on the left is your controller.

Problem 2: Simulate the improved implementation in Problem 1 where $V_{\mathrm{g}} = 24\,\mathrm{V}$, $f_s = 10\,\mathrm{kHz}$, $L = 1.3\,\mathrm{mH}$, $R_{\mathrm{L}} = 60\,\mathrm{m\Omega}$, $C = 250\,\mu\mathrm{F}$, and $R = 10\,\Omega$. Use the white noise block[1] to simulate the current sensor noise. Initialize your simulation with a reference of $i_{\mathrm{ref}} = 3\,\mathrm{A}$ such that the states are all in steady-state and the error, i_{e}, is zero. Perform the following:

(a) Create a switched simulation for improved implementation in Fig. 1 with and without feedforward where the following events below occur. Use your control gains from 2(a). Overlay the $i(t)$ waveforms for with and without feedforward (for without feedforward, use the controller you developed in lab) on the same plot to facilitate comparison. Comment on how they differ.

- At $t = 5\,\mathrm{ms}$, i_{ref} changes from $3\,\mathrm{A} \to 5\,\mathrm{A}$.
- At $t = 10\,\mathrm{ms}$, v_{g} changes from $24\,\mathrm{V} \to 28\,\mathrm{V}$.
- At $t = 15\,\mathrm{ms}$, R changes from $10\,\Omega \to 15\,\Omega$.

[1]Configure the white noise block with zero mean, 50 mA standard deviation, and sample time T_{s}.

Problem 3: We will build on the results from Homework 4, Using Faraday's Law, give the expressions for the induced back EMF voltages, e_{a}, e_{b}, e_{c}, within the a, b, and c phase windings, respectively. In addition, draw the equivalent circuits looking into the a, b, and c windings where the back EMFs, e_{a}, e_{b}, e_{c}, are clearly labeled along with the speed-dependent voltages $\mathcal{E}_{\mathrm{a}}$, $\mathcal{E}_{\mathrm{b}}$, $\mathcal{E}_{\mathrm{c}}$ and inductive voltage drops. Be careful with all circuit element polarities.