ECE 141 - Project
Winter 2025

Due Friday, March 14, at 5pm on Gradescope

100 points

(a) The project covers state-space modeling, linearization, stability, and controller tuning. Controller tuning is a trial and error design process to meet the required time domain specifications, and is a classical control systems engineering.

(b) You will need a PC with access to Matlab, and specifically Simulink, to assist you with the tuning process, which also happens to be the industry standard software tool;

(c) As your read through the project description, please note that lower case variables in bold e.g. $\mathbf{x}$ are vector valued and capitalized variables in bold e.g. $\mathbf{A}$ are matrix valued. Moreover, notice the notational difference between the equilibrium point, when 0 used as a subscript e.g. $\mathbf{x}_0$, and the initial conditions/states, with 0 as a function argument e.g. $\delta\mathbf{x}(0)$;

(d) Submit your project report as a single .pdf file. There are no specific formatting requirements except that it has to be typed. Please try to keep your answers concise and short;

(e) Include the clear snapshots of your closed-loop Simulink models (if you have subsystems, please show us the inside as well) and plots of the output against time obtained from the scope readings in Simulink.

The figure below illustrates a common application in railway signaling systems industry, where an outdoor DC-DC switched-mode converter, energizing some rail-side equipment, is supplied by an indoor DC voltage source through a shielded twisted pair of wires. As shown, the resistance and inductance of the connecting wires are modeled by R and L respectively. Furthermore, the outdoor DC-DC converter together with the equipment it's connected to (everything to the right of the dashed vertical line in Fig. 1), are modeled as a constant power load (CPL) since the converter keeps the power supplied to the load at the constant value of P. The CPL terminals are connected in parallel with an electrolytic capacitor C.

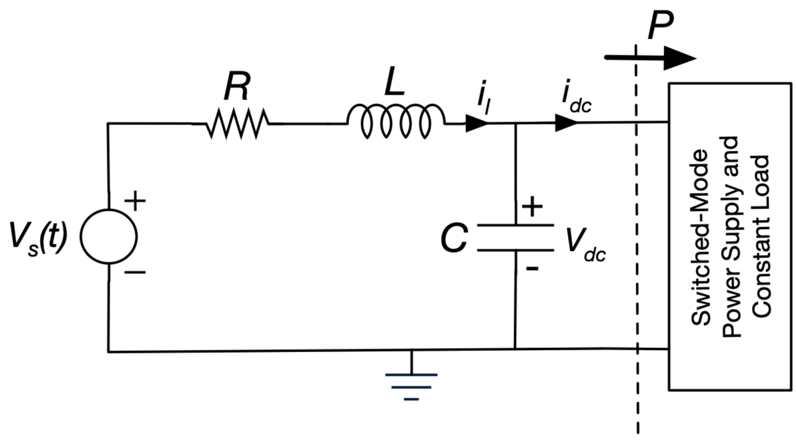

Figure 1: Circuit schematics of the system described above

1. (10 points) Considering the inductor current and the capacitor voltage as your two states (i.e., $x_1(t) = i_l(t)$ and $x_2(t) = v_{dc}(t)$), obtain the state-space representation for this system in the form of $\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}, u)$ where $u(t) = v_s(t)$. Recall that power supplied to the load is the product of the current through and the voltage across it.

2. (10 points) Assume that the system has an equilibrium point at $(i_{l_0}, v_{dc_0}, v_{s_0})$. Obtain the linearized dynamics of this system in the form of $\delta\dot{\mathbf{x}} = \mathbf{A}\delta\mathbf{x} + \mathbf{B}\delta u$ where $\delta\mathbf{x} \triangleq [i_l - i_{l_0} \quad v_{dc} - v_{dc_0}]^T$ and $\delta u \triangleq v_s - v_{s_0}$. Find matrices $\mathbf{A}$ and $\mathbf{B}$.

3. (10 points) Find the open-loop transfer function $H(s)$ from input δv_s to output δv_{dc} in s-domain, assuming zero initial conditions. Find the relationship between R, L, C, and P that would ensure the linearized system would remain stable.

4. (10 points) Assume the wire resistance of $R = 60\Omega$, the CPL power constant of $P =$ 20W and, input equilibrium DC voltage of $v_{s_0} = 80$V. Find all possible corresponding equilibrium values for the current through the wire and the voltage across the outdoor converter (i.e., i_{l_0} and v_{dc_0} respectively).

5. (10 points) Consider the system linearized around the equilibrium point with the *lowest* possible value you obtained for v_{dc_0} in Part 4. Assume the same values for R and P as in Part 4 with the addition of $C = 100\mu F$ and $L = 100\mu H$. Is this linearized system BIBO stable? Recall Part 3.

6. (20 points) Consider the same linearized system as in Part 5, with all the same values. Let $y = \delta x_2$. Recall the open-loop transfer function H. Build the linearized model in Simulink. Use a solver for stiff differential equations (e.g., ode23s) when using Simulink. Design a controller such that the closed-loop system's output decays to 0 in no more than 0.1s with no overshoot and the initial conditions of $\delta \mathbf{x}(0) = \begin{bmatrix} 8 & -8 \end{bmatrix}$.

7. (30 points) Implement the original nonlinear model in Simulink, assuming the initial states of $\mathbf{x}(0) = \mathbf{x}_0 + \delta \mathbf{x}(0)$ and with the same parameters as Part 6. Keep in mind that the input v_s and the states i_l and v_{dc} need to be non-negative at all times, with the additional safety requirement that they shall not exceed 120V, 10A and 40V respectively. *Hint:* you can use a saturation block in Simulink and set its lower and upper limits to the corresponding safety bounds. Apply the controller found in Part 6 by placing it in the closed-loop with the nonlinear model in Simulink. Since we are translating the system back to the original system, adjust the control input appropriately, and the output's settling value. If needed, redesign your controller. Comment on the differences you observe as you implement the controller in the linearized vs the nonlinear model.