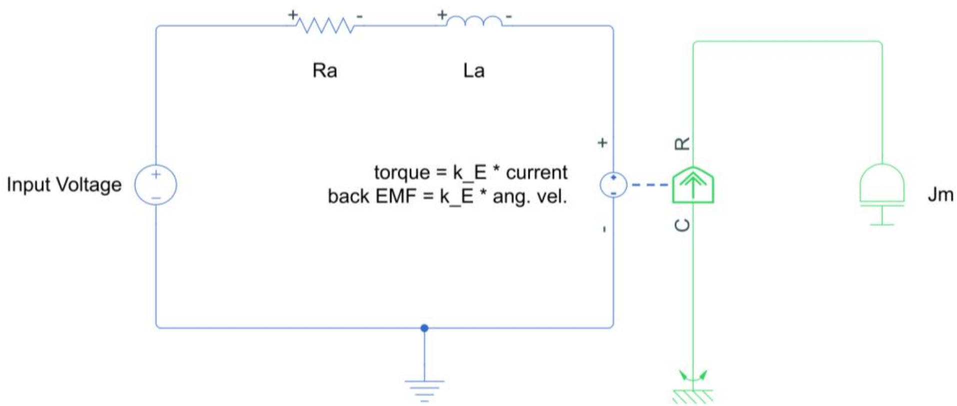
Questions

1. A permanent magnet DC motor such as the generator attached to the range extender can be represented using the electrical schematic shown in the diagram below.



   Assume that the electrical parameters of the motor are R_a = 0.12 ohms, L_a = 0.0012 H, k_E = 0.2 units, and the motor's rotor has a moment of inertia J_m = 0.25 kg m^2.

   a) Write down the differential equations describing the relationship between the rotor's angular velocity and angular displacement in response to a voltage input.

   b) By finding an expression for the angular acceleration in terms of other variables and then integrating this, implement a Simulink model of the motor. By considering step inputs of up to 48 V, use the model to illustrate the effects of 'back EMF' in the motor current. (You may need to read up on motors to do this.)

   c) Using Laplace transforms, convert your differential equation into a transfer function. Comment on the locations of any poles and zeros and explain how these relate to your observed simulation behaviour.

[20 marks]

2. You have been given a set of Simulink models representing the range extender rig. The main one is called 'm01_plant_model.slx'.

   a) Examine the model, and briefly answer the following questions:

      (i) Which (if any) blocks in the model represent nonlinearities? Is the overall model linear or nonlinear?

      (ii) How are noise and disturbances modelled?

      (iii) What are the model's states?

b) Write a MATLAB program to trim and linearize the version of the model in the file 'm02_linearization_model.slx' for a steady-state speed of 2500 rpm. (You can use the supplied trimming function to help you.) Include a listing for your program in your write-up, as well as the transfer function. Use Simulink to compare the linear model with the original nonlinear one.

If you can't solve this question, there is a MATLAB file containing the outputs you would have got, which you can use for the rest of the assignment.

[20 marks]

3. Use frequency domain loop-shaping to design a feedback controller for the range extender's speed. Aim for:

   A stable system, with phase margin >= 60 degrees.
   Steady-state disturbance rejection better than 25 rpm.
   Peak-peak noise in throttle signal < 0.025
   At least 450 rpm response to 500 rpm demand from a starting point of 2500 rpm in 2 sec.
   Peak overshoot < 2%.

   Your answer should include plots, code samples, etc., that illustrate your design process. You should ensure that you include a Bode plot showing your gain and phase margins, Bode magnitude plots showing $T(s)$, $S(s)$ and $C(s)$ $S(s)$ – if you use a prefilter, you should also include $R(s) = T(s)\,Q(s)$.

   You should test your controller in Simulink, showing a screenshot of your model's top level and relevant plots. Consider small speed demands (a few tens of rpm) and larger demands. How big can the angle be before you see significant effects from nonlinearities in your system?

[20 marks]

4. Repeat Question 3, but this time use a PID controller using the following controller structure:

$$C(s) = k_p e(t) + k_i \int_0^t e(\tau)\, d\tau + k_d \frac{de(t)}{dt}$$

   How does this relate to the 'PID weights' in the lecture notes? (Algebra is required here!)

   Design your controller in the frequency domain using proportional, PI and PD weights, as shown in lectures. Do not use a prefilter.

   In addition to answering the specifics asked for in Question 3, comment on and the advantages and disadvantages of the simplified PID method compared to the 'full' frequency-domain loop-shaping method.

   (Do not use the MathWorks PID Tuner – the resulting controllers are not 'pure' PID controllers.)

[20 marks]

5. Using the pole placement method, design an observer that can estimate the state variables. Implement this in Simulink and determine how effective it is.

   Your answer should include the following:

   a) The state space model you use, with the states clearly identified.

   b) Relevant code snippets showing how you found the observer gains.

   c) Your Simulink model with the observer added. (Don't forget to account for the operating point input u_0 in your implementation.)

   d) A comparison between your observer's state estimates and the state measurements from the model's measurement bus. Comment on how effective this is.

[20 marks]