EE 301P: Control Systems Laboratory Lab Exercise 5	
Lab session: September 15, 2023	*Report due*: September 22, 2023

1 Objective

To design a speed controller for a hybrid electric vehicle that ensures (i) stable operation, and (ii) that the steady-state error remains within a pre-defined threshold.

2 Pre-lab exercise

The block diagram of a possible cascade control scheme for a hybrid vehicle driven by a DC motor (with appropriate parameter values) is shown in Figure 1. Upon

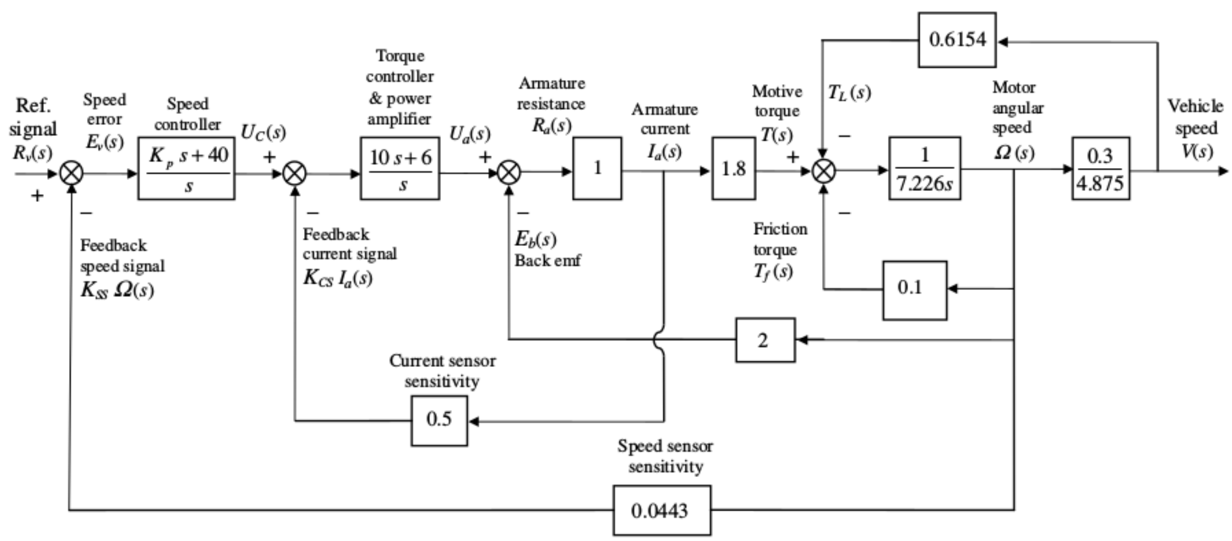

Figure 1: Block diagram of an HEV showing various components.

rearranging the above block diagram, we obtain the unity feedback system shown in Figure 2. Here the system output is, $C(s) = K_{SS}V(s)$, the output voltage of the speed sensor/transducer.

(a) Observe, from Figure 1, that the speed control has a proportional gain, K_p, that needs to be adjusted. Use the Routh-Hurwitz stability method to find the range of positive K_p for which the closed-loop system is stable.

(b) In the reduced block diagram shown in Figure 2, assume that the speed controller is given as $G_{SC}(s) = K_{P_{SC}}$. Find the gain $K_{P_{SC}}$, that yields a steady-state error, $e_{ss} = 1\%$ for a unit step input.

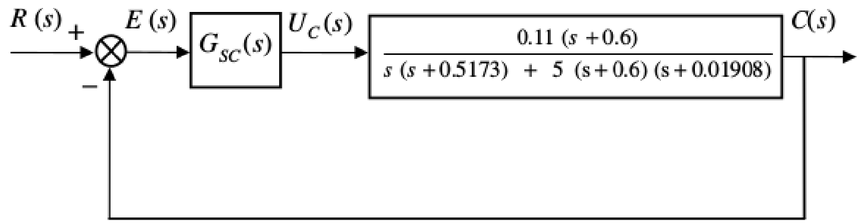

Figure 2: Reduced block diagram of an HEV showing showing output $C(s) = K_{SS}V(s)$, the output voltage of the speed sensor/transducer.

3 Lab exercise

(a) For an appropriate choice of input signal, simulate the response of the system shown in Figure 1 using MATLAB/Simulink. Tune K_p as per the limits calculated in in Pre-lab exercise (a) and verify the behaviour of the system as predicted by the Routh stability criterion.

(b) Simulate the simplified block diagram given in Figure 2 in MATLAB/Simulink. Verify that the derived value of $K_{P_{SC}}$ calculated in Pre-lab exercise (b) indeed yields an output with 1% steady-state error.

(c) Now assume that in order to reduce the steady-state error for step inputs, an integrator is added to the speed controller yielding

$$\begin{aligned} G_{SC}(s) &= K_{P_{SC}} + (K_{I_{SC}}/s) \\ &= 100 + (K_{I_{SC}}/s). \end{aligned}$$

Find the value of the integral gain $K_{I_{SC}}$, that results in a steady-state error $e_{ss} = 2.5\%$ for a ramp input. Verify using MATLAB/Simulink.

(d) In parts (a) and (b) the vehicle is assumed to be driven on a level ground. Consider the case when, after reaching a steady-state speed with a controller given by

$$G_{SC}(s) = 100 + \frac{40}{s},$$

the car starts climbing up a hill with a gradient angle $\alpha = 5°$. For small angles $\sin\alpha = \alpha$ (in radians) and, hence, when reflected to the motor shaft, the climbing torque turns out to be

$$T_{st} = \frac{mgr\alpha}{i_{tot}}.$$

For the parameter values considered, we get $T_{st} = 83.7$ Nm. Under this scenario, the block diagram of the vehicle can be re arranged as shown in Figure 3. In this diagram, the input is $T_{st}(t) = 83.7u(t)$, corresponding to $\alpha = 5°$, and the

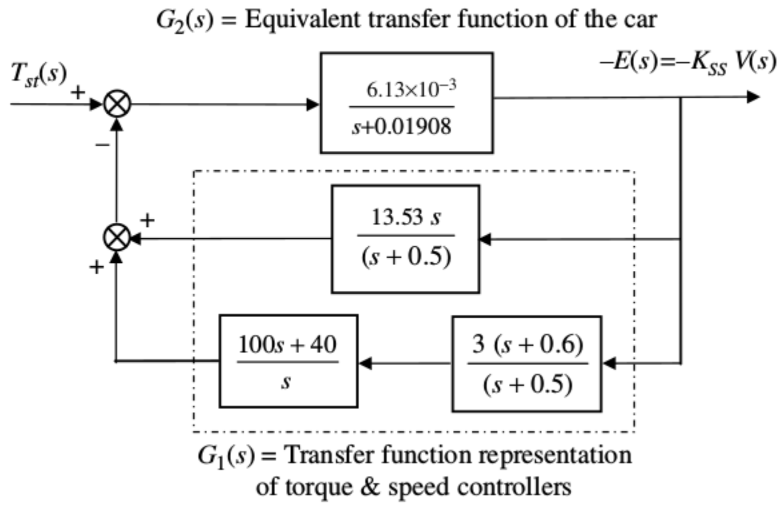

Figure 3: Block diagram of an HEV climbing up a hill with a gradient angle $\alpha = 5°$.

output is the negative error, $-e(t) = -c(t) = -K_{ss}v(t)$, proportional to the car speed $v(t)$. The parameter K_{ss} represents the sensitivity of the speed sensor, which you may take as 0.0433. Find the steady-state error due to unit step change in the climbing torque. Verify using MATLAB/Simulink.

4 Deliverables

1. Lab report, necessarily containing
   (a) All calculations required to obtain the values of $K_p, K_{P_{SC}}, K_{I_{SC}}, K_{SS}$.
   (b) Plots required to verify the predicted behaviour in each lab exercise (a–d).
2. MATLAB Code/ Simulink model.