

EE5351: CONTROL SYSTEM DESIGN
LABORATORY 01

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Table 1: Summative Laboratory Form

Semester	05
Module Code	EE5351
Module Name	Control System Design
Lab Number	01
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1 OBSERVATION

Table 1: Observations

Terminal Resistance (R_m)	8.4	Ω
Rotor inductance (L_m)	1.16	mH
Equivalent(J_{en})	2.09×10^{-5}	kgm ²
Torque constant (K_t)	0.042	Nm/A
Voltage constant (K_m)	0.042	Nm/A

2 CALCULATION

Q1.

i .

1. Voltage equation:

$$V_m = i_m R_m + L_m \frac{di_m}{dt} + e_b$$

2. Back EMF equation:

$$e_b = k_m \omega_m$$

3. Torque equation:

$$T_m = J_e q \frac{d\omega_m}{dt}$$

4. Motor torque relationship:

$$T_m = i_m k_t$$

ii From equations (1), (2), (3), and (4), the speed control transfer function is derived as:

$$\frac{\omega(s)}{V_m(s)} = \frac{k_t}{J_e q s [R_m + L_m s] + k_m k_t}$$

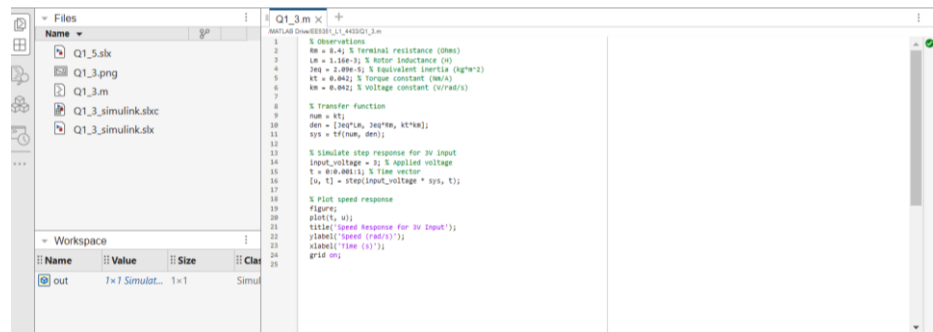
$$\frac{\omega(s)}{V_m(s)} = \frac{0.042}{2.09 \times 10^{-5} s [8.4 + 1.16 \times 10^{-3} s] + 0.042 \times 0.042}$$

$$\frac{\omega(s)}{V_m(s)} = \frac{0.042}{2.4244 \times 10^{-8} s^2 + 17.556 \times 10^{-5} s + 1.764 \times 10^{-3}}$$

From equations (1), (2), (3), and (4):

$$\frac{\theta_m(s)}{V_m(s)} = \frac{k_t}{s \{J_e q s [R_m + L_m s] + k_m k_t\}}$$

$$\frac{\theta_m(s)}{V_m(s)} = \frac{0.042}{2.4244 \times 10^{-8} s^3 + 17.556 \times 10^{-5} s^2 + 1.764 \times 10^{-3} s}$$



```

1 % Observations
2 Rm = 0.4; % terminal resistance (ohm)
3 Lm = 1.5e-3; % motor inductance (H)
4 Jm = 2.09e-3; % equivalent inertia (kg*m^2)
5 kt = 0.042; % torque constant (Nm/A)
6 km = 0.042; % voltage constant (V/rad/s)
7
8 % Transfer function
9 num = kt;
10 den = [Jm*Lm, Jm*Rm, kt*km];
11 sys = tf(num, den);
12
13 % Simulate step response for 3V input
14 input_voltage = 3; % Applied voltage
15 t = 0:0.001:1; % Time vector
16 [u, t] = step(input_voltage * sys, t);
17
18 % Plot speed response
19 figure;
20 plot(t, u);
21 title('Speed Response for 3V Input');
22 xlabel('Speed (rad/s)');
23 ylabel('Time (s)');
24 grid on;
25

```

Figure 1: MathLab code for the Speed Response

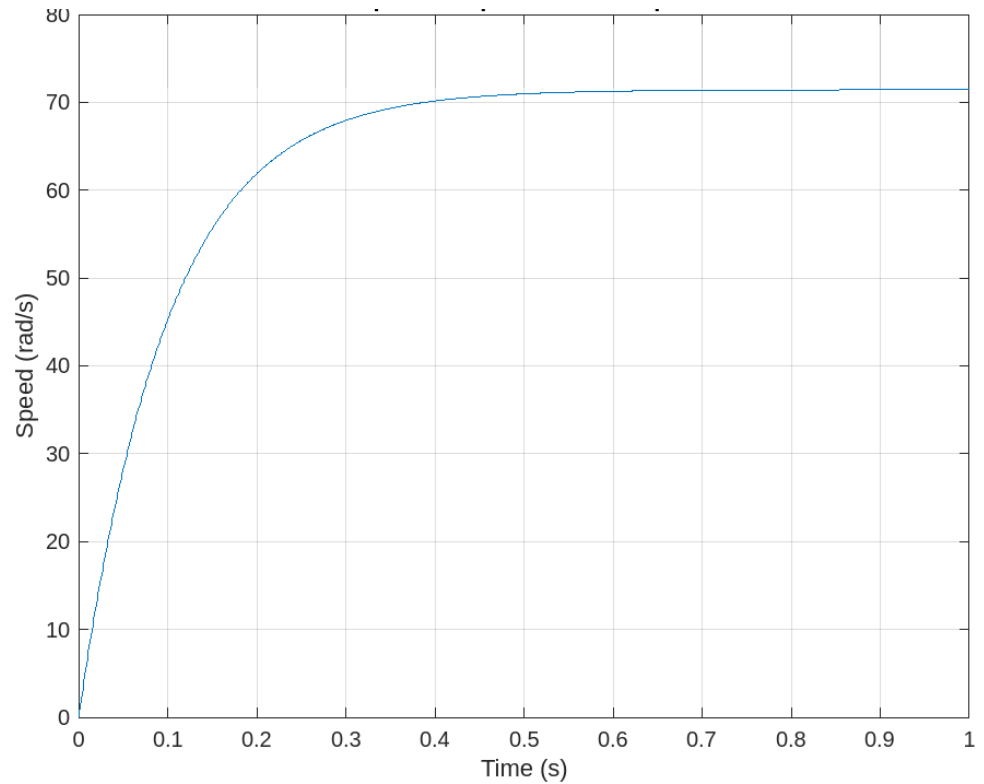


Figure 2: Speed Response Get by Mathlab

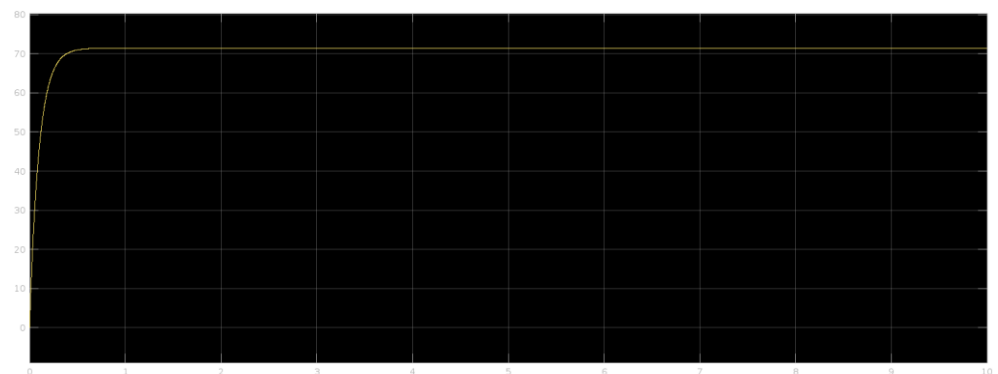


Figure 3: Speed Response Given by Simulink

Simplified Equations for Speed Control Transfer Function

$$\frac{\omega(s)}{V_m(s)} = \frac{k_t}{J_{eq}R_ms + k_mk_t}$$

$$\frac{\omega(s)}{V_m(s)} = \frac{0.042}{\{2.09 \times 10^{-5} \cdot 8.4s + 0.042 \times 0.042\}}$$

$$\frac{\omega(s)}{V_m(s)} = \frac{0.042}{\{1.7556 \times 10^{-4}s + 1.764 \times 10^{-3}\}}$$

Simplified Equations for Position Control Transfer Function

$$\frac{\theta_m(s)}{V_m(s)} = \frac{k_t}{s\{J_{eq}R_ms + k_mk_t\}}$$

$$\frac{\theta_m(s)}{V_m(s)} = \frac{0.042}{s\{1.7556 \times 10^{-4}s + 1.764 \times 10^{-3}\}}$$

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From the equations 1, 2, 3, 4;

$$\dot{i}_m = -\left(\frac{R_m}{L_m}\right)i_m - \left(\frac{k_m}{L_m}\right)\omega_m + \frac{V_m}{L_m}$$

$$\dot{\omega}_m = \left(\frac{k_t}{J_{eq}}\right)i_m + 0 \times \omega_m + 0 \times V_m$$

$$\begin{bmatrix} \dot{i}_m \\ \dot{\omega}_m \end{bmatrix} = \begin{bmatrix} -\left(\frac{R_m}{L_m}\right) & -\left(\frac{k_m}{L_m}\right) \\ \left(\frac{k_t}{J_{eq}}\right) & 0 \end{bmatrix} \begin{bmatrix} i_m \\ \omega_m \end{bmatrix} + \begin{bmatrix} \frac{1}{L_m} \\ 0 \end{bmatrix} V_m$$

$$\begin{bmatrix} \dot{i}_m \\ \dot{\omega}_m \end{bmatrix} = \begin{bmatrix} -7241.38 & -36.21 \\ 2009.57 & 0 \end{bmatrix} \begin{bmatrix} i_m \\ \omega_m \end{bmatrix} + \begin{bmatrix} 862.07 \\ 0 \end{bmatrix} V_m$$

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From the simplified equations

$$\dot{\theta}_m = 0 \cdot \theta_m + \omega_m + 0 \cdot V_m$$

$$\dot{\omega}_m = 0 \cdot \theta_m - \left(\frac{k_t k_m}{R_m J_{eq}}\right)\omega_m + \left(\frac{k_t}{J_{eq} R_m}\right)V_m$$

$$\begin{bmatrix} \dot{\theta}_m \\ \dot{\omega}_m \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & -\left(\frac{k_t k_m}{R_m J_{eq}}\right) \end{bmatrix} \begin{bmatrix} \theta_m \\ \omega_m \end{bmatrix} + \begin{bmatrix} 0 \\ \left(\frac{k_t}{J_{eq} R_m}\right) \end{bmatrix} V_m$$

$$\begin{bmatrix} \dot{\theta}_m \\ \dot{\omega}_m \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & -10.05 \end{bmatrix} \begin{bmatrix} \theta_m \\ \omega_m \end{bmatrix} + \begin{bmatrix} 0 \\ 239.23 \end{bmatrix} V_m$$

Q2.



Figure 4: Speed Response in the Model

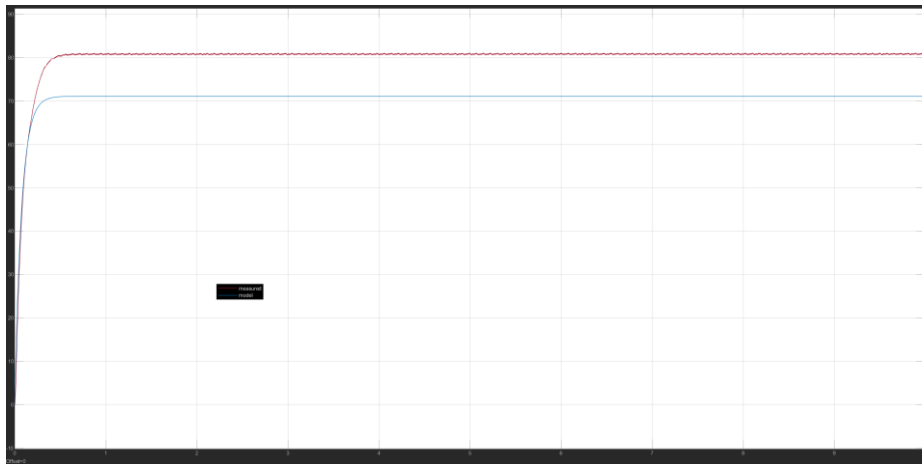


Figure 5: Comparing of the Speed Response with Model and State Vector

2. According to my knowledge I think the basic thing for happening those kind of the error is negligence of the resistance where having in the rotor and also matlab is the software which required the best performance of the computers so considering the computers which has been used there can be errors as the performance.

Q3)

1.

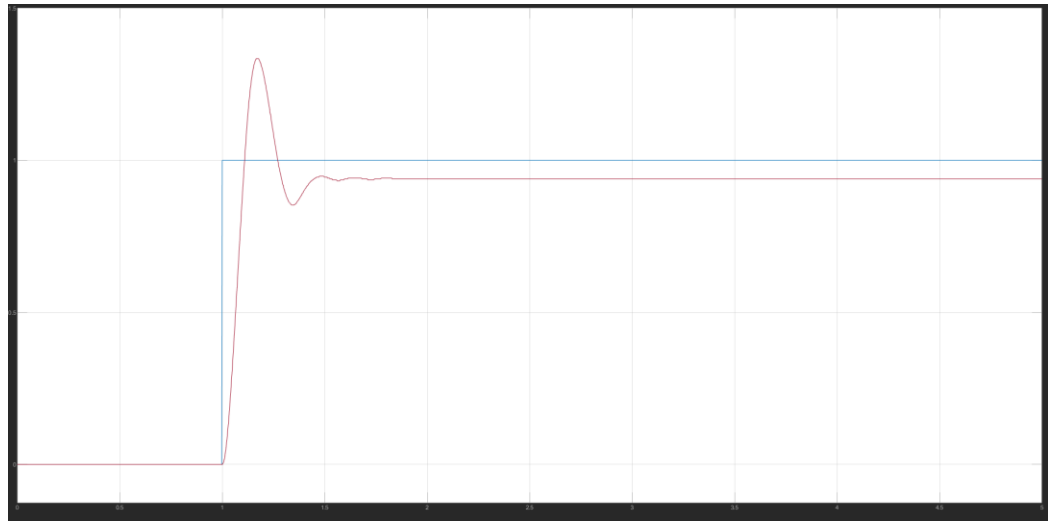


Figure 6: The Speed Response when KP=1

2.

Steady State Error: $1 - 0.938$: 0.062

$$\begin{aligned}\text{Overshoot} &= \frac{1.335 - 0.938}{0.938} \times 100\% \\ &= \underline{\underline{42.324\%}}\end{aligned}$$

3.

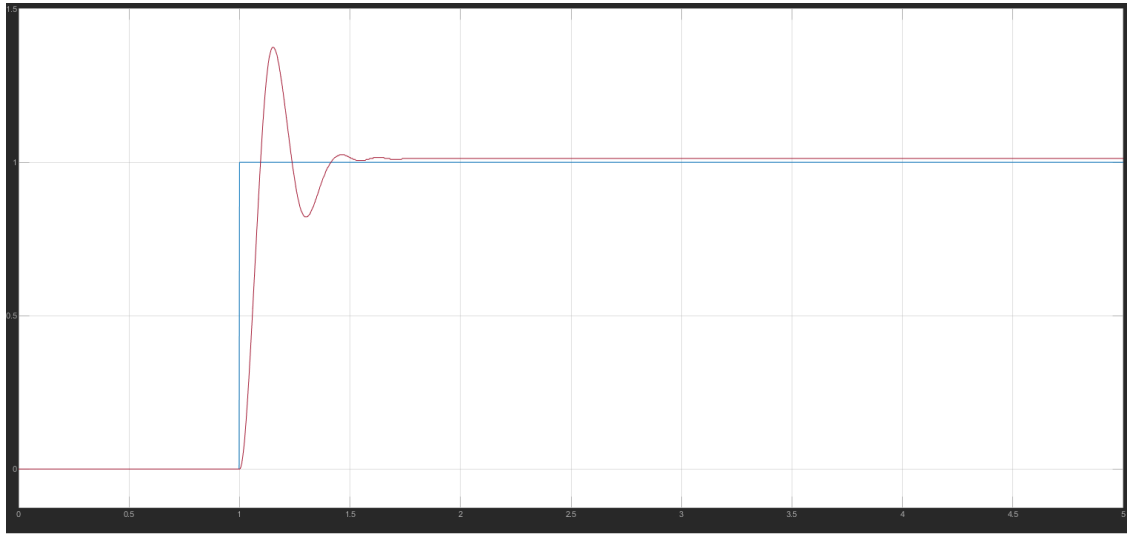


Figure 7: Speed Response from Simulink when $K_P=1.25$

According to the Figure 5 when $K_p = 1.25$,
Steady state error = $1 - 1.012 = 0.012$

$$\begin{aligned} \text{Overshoot} &= \frac{1.374 - 1.012}{1.012} \times 100\% \\ &\equiv \underline{\underline{35.770\%}} \end{aligned}$$

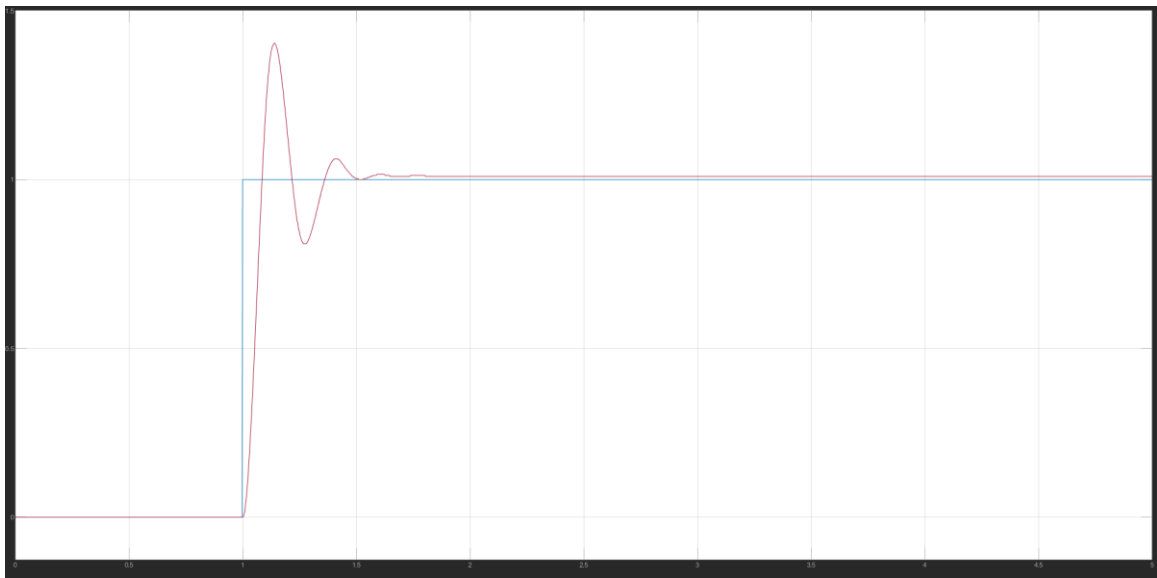


Figure 8: Speed Response from Simulink when $K_P=1.50$

According to the Figure 6 when $K_p = 1.5$,
Steady state error = $1 - 1.009 = 0.009$

$$\begin{aligned} \text{Overshoot} &= \frac{1.405 - 1.009}{1.009} \times 100\% \\ &\equiv \underline{\underline{39.25\%}} \end{aligned}$$

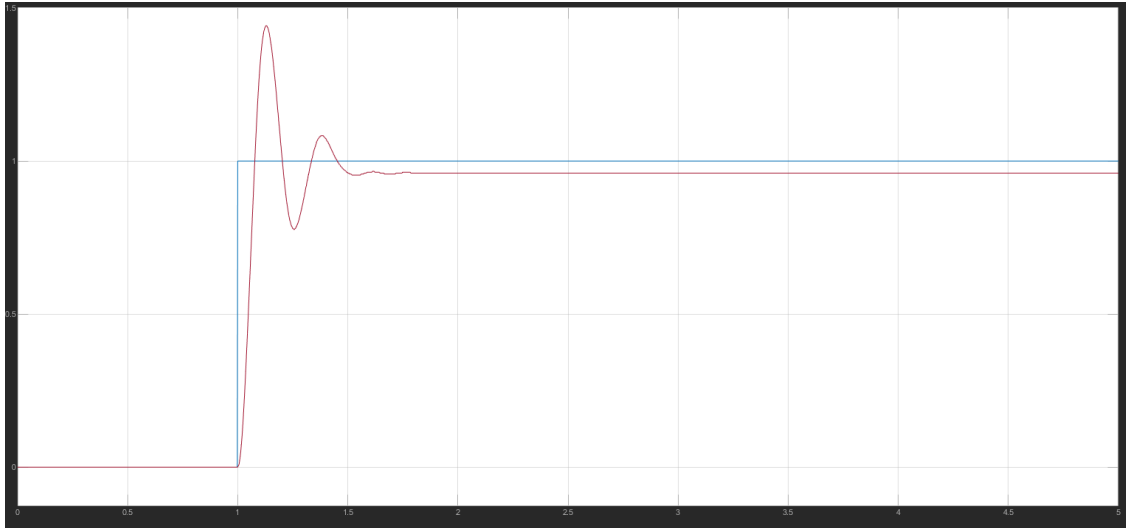


Figure 9: Speed Response from Simulink when $K_P=1.75$

According to the Figure 7 when $K_p = 1.75$,
 Steady state error = $1 - 0.96 = 0.04$

$$\text{Overshoot} = \frac{1.442 - 0.9603}{0.9603} \times 100\% \\ = \underline{\underline{50.161\%}}$$

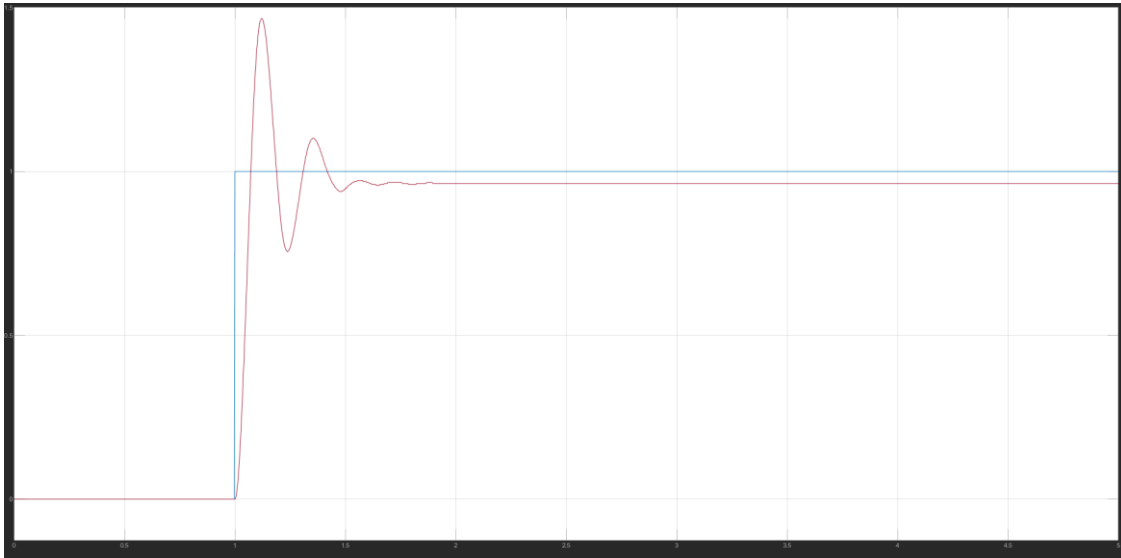


Figure 10: Speed Response from Simulink when $K_P=2.0$

According to the Figure 8 when $K_p = 2$,
 Steady state error = 3.35×10^{-2}

$$\begin{aligned}\text{Overshoot} &= \frac{1.466-0.9633}{0.9633} \times 100\% \\ &= \underline{\underline{52.19\%}}\end{aligned}$$