Prof. Dr. İbrahim EKSİN — **2015 - 2016 Fall Term**
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FEEDBACK CONTROL SYSTEMS (KON 313E)

HOMEWORK ASSIGNMENT - 2

Question 1: State space model of a synchronous generator connected to the infinite bus (Figure 1) is given below.

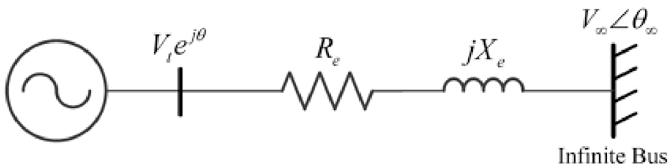

Figure 1. Single generator – infinite bus system.

$$\begin{bmatrix} \Delta \dot{E}'_q \\ \Delta \dot{\delta} \\ \Delta \dot{\omega} \\ \Delta \dot{E}_{fd} \end{bmatrix} = \begin{bmatrix} -\dfrac{1}{K_3 T'_{do}} & -\dfrac{K_4}{T'_{do}} & 0 & \dfrac{1}{T'_{do}} \\ 0 & 0 & \omega_s & 0 \\ -\dfrac{K_2}{2H} & -\dfrac{K_1}{2H} & -\dfrac{K_D}{2H} & 0 \\ -\dfrac{K_A\,K_6}{T_A} & -\dfrac{K_A\,K_5}{T_A} & 0 & -\dfrac{1}{T_A} \end{bmatrix} \begin{bmatrix} \Delta E'_q \\ \Delta \delta \\ \Delta \omega \\ \Delta E_{fd} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ \dfrac{K_A}{T_A} \end{bmatrix} \Delta V_{ref}$$

a. Obtain the open-loop transfer function $\left(T(s) = \frac{\Delta\delta(s)}{\Delta V_{ref}(s)}\right)$ with the help of state-space model by taking the system output as deviation of the rotor angle ($\Delta\delta$).

b. What is the type and order of this system? Show the poles (and zeros if exists) in s-plane. Is the open-loop system stable? Explain.

c. Calculate the approximate settling time, overshoot and final value of the closed-loop system. Plot the unit step response of system roughly.

d. It is desired to control the synchronous generator system using the block diagram given in Figure 2. Find the transfer functions of $T_y(s) = \frac{Y(s)}{R(s)}$, $T_{d1}(s) = \frac{Y(s)}{D_1(s)}$ and $T_{d2}(s) = \frac{Y(s)}{D_2(s)}$ (just in terms of $C(s)$ and $G(s)$).

e. Assume that there is not any disturbance effect (i.e. $D_1(s) = D_2(s) = 0$). In this case, if the controller is given as $C(s) = k$ calculate the steady state error for the unit step inputs. Solve the same problem by taking $C(s) = \frac{2k}{s}$.

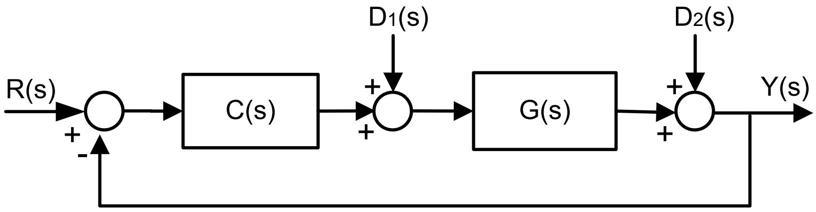

Figure 2. Closed-loop control system with unit feedback.

f. The controller is given as $C(s) = k\ (s+1)$. In case of a disturbance effect in the form of $D_1(s) = \frac{2}{s}$ calculate the steady state error for step type inputs ($D_2(s) = 0$). Similarly, in case of a disturbance effect in the form of $D_2(s) = \frac{2}{s}$ calculate the steady state error for step type inputs ($D_1(s) = 0$).

g. Use Routh–Hurwitz criteria to analyse the closed–loop system stability for $C(s) = {}^{1}/_{3}$.

h. Find the value range of k in which the closed-loop system remains stable by using Routh-Hurwitz stability analysis method for $C(s) = k\ (s+1)$.

i. Plot the variation curve of the roots of characteristic equation for the positive values of the parameter k ($C(s) = k$).

j. Is it possible to bring two of the closed-loop system poles to the points of $s_{1,2} = -2 \pm 2j$ by using positive k value? Interpret via the root-locus plot (do not perform any calculation).

Table 1. Parameters and their values.

Parameter	Value	Parameter	Value
K_1	0.925	K_D	0
K_2	1.075	T'_{do}	9.6
K_3	0.285	T_A	0.06
K_4	2.197	K_A	25
K_5	0.005	ω_s	377
K_6	0.355	H	3.2

Question 2:

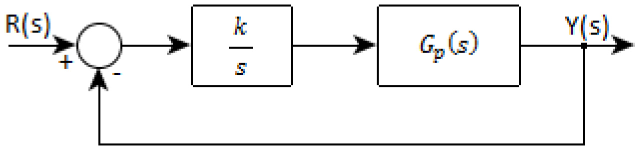

Figure 3. A closed-loop control system.

For the closed-loop control system given above, variation curve of the roots of characteristic equation for the positive and negative values of the parameter k is given in Figure 4.

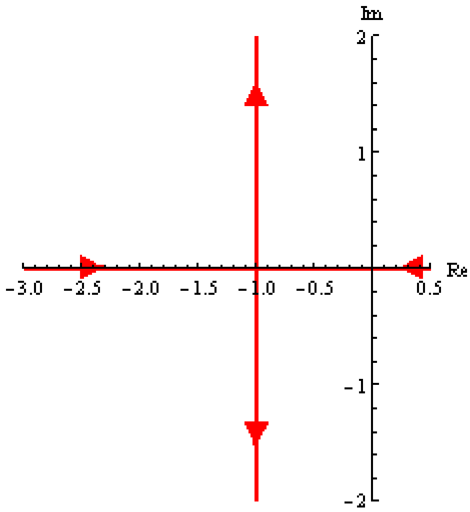

Figure 4. Root-locus plot of the system.

a. It is known that $G_p(s)$ is a first order system and value of its impulse response at the time of $t = 0$ is known to be 2. Find the open-loop transfer function $G_p(s)$ and plot the unit step response roughly.

b. Calculate the position, velocity and acceleration error constants for $k = {}^{3}/_{2}$.

c. Find the value range of the parameter k with the help of root-locus such that the lowest possible settling time in the closed-loop is achieved.

d. If one of the closed-loop system poles is located at the point of $s = -{}^{1}/_{3}$ calculate the location of the other closed-loop system pole.

e. Find the value range of the parameter k in which all closed-loop system poles are located on the left side of the line $s = -0.6$ using Routh-Hurwitz criteria (Note that Routh-Hurwitz checks whether the closed-loop poles are on the left side of the line $s = 0$ or not. In order to check the left side of the line $s = -0.6$ a minor modification is required).

Question 3: Answer the questions for the open-loop transfer function given below.

$$G(s) = \frac{K\,(s+4)}{(s^2+2s+2)(s+\varphi)}$$

a. What is the type and order of the given system? Plot the root-locus for the positive values of the parameter K by taking $\varphi = 1$.

b. Find the interval of parameter φ in which the closed-loop system is stable for $K = 1$ using Routh-Hurwitz stability test.

c. Plot the variation curve of the roots of characteristic equation for $\varphi < 0$ $(K = 1)$.

d. In case two of the closed-loop system poles are located on the imaginary axis, determine the location of 3rd pole for $K = 1$.

e. Calculate the approximate overshoot and delay-time of the closed-loop system for $K = {}^{3}/_{2}$ and $\varphi = 6$.