[ENG02]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

MSc in ELECTRICAL & ELECTRONIC ENGINEERING

SEMESTER TWO EXAMINATION 2021/2022

ADVANCED POWER SYSTEMS CONTROL AND ELECTRICAL MACHINES

MODULE NO: EEE7006

Date: Tuesday 17th May 2022 **Time: 10:00 – 13:00**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer ANY FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

Electronic calculators may be used provided that data and program storage memory is cleared prior to the examination.

CANDIDATES REQUIRE: **Formula Sheet (attached).**

Question 1

(a) Briefly define Park's transformation and give its benefit in modeling of power systems. **[5 marks]**

(b) Prove the following power equation and give definition for each term used:

$$P = v_a . i_a + v_b . i_b + v_c . i_c = v_o . i_o + v_d . i_d + v_q . i_q$$ **[10 marks]**

(c) Draw a pictorial representation of a 3-phase synchronous machine indicating the stator reference axis, the rotor reference axis, and the angular displacement θ . Define all stator and rotor windings shown on the diagram. Give the equation to calculate θ. **[10 marks]**

Total 25 marks

Question 2

A 480 V, 50 Hz, star-connected, 6-pole synchronous generator has a per-phase synchronous reactance of 1.0 Ohm. If it is working at full load of 60 A at 0.8 power factor lagging, its field current has been adjusted such that the no-load terminal voltage is 480 V , and has mechanical and core losses of 1.5 kW and 1.0 kW respectively. Calculate the following:

I. Terminal voltage and its voltage regulation at 0.8 pf lagging; [5 marks]
II. Terminal voltage and its voltage regulation at 0.8 pf leading; [5 marks]
III. Terminal voltage and its voltage regulation at unity pf; [5 marks]
IV. Efficiency when operating as in case I; and [5 marks]
V. Shaft torque for case I [5 marks]

Total 25 marks

PLEASE TURN THE PAGE….

Question 3

A 50 Hz synchronous generator having inertia constant H=10 MJ/MVA and a transient reactance $X_d' = 0.3$ per unit is connected to an infinite bus through a 3-phase transformer with reactance of X_t=0.2 per unit and a double-transmission line each having reactance of X_L=0.3 per unit. The infinite bus voltage is 1.0 per unit and the delivered generator real power is 0.65 per unit at 0.8 power factor lagging to the infinite bus. Assume the damping power coefficient is D=0.138 per unit and consider a small disturbance in load angle $\Delta\delta = 12^o$.

I. Derive the linearized force-free equation that describes the mode of oscillation of the system. **[15 marks]**
II. Obtain the equation describing the rotor angle $\delta(t)$. **[5 marks]**
III. Obtain the equation describing the frequency as a function of time. **[5 marks]**

Total 25 marks

Question 4

The excitation control system of a synchronous generator is shown in **Figure Q4.**

I. Define the function of each block with clear definition to each term. **[5 marks]**
II. Find the open-loop and closed loop transfer functions. **[10 marks]**
III. From the open-loop transfer function get the approximate second order characteristic equation then calculate the damping factor ζ and the damped frequency of oscillation. Comment on the time domain response of this system. Assuming all K's are equal to 1.0 and $\tau_A = 0.1\ , \tau_E = 10, \tau_G = 0.2, \tau_R = 0.05$. All in seconds.

Q4 continues over the page….

PLEASE TURN THE PAGE….

Q4 continued

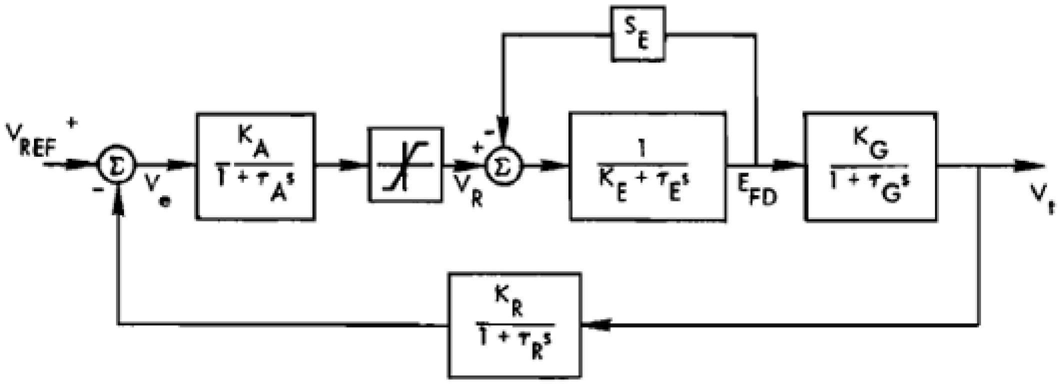

Figure Q4 The excitation control system

[10 marks]

Total 25 marks

Question 5

A power system is described by the following state-space equation

$$\dot{\boldsymbol{x}} = \boldsymbol{A}.\boldsymbol{x} + \boldsymbol{B}.\boldsymbol{u}$$

Where $\boldsymbol{A} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -3 & -2 & -5 \end{bmatrix}$, $\boldsymbol{B} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$, $\boldsymbol{C} = [1\ 0\ 0]$

i) Is the system controllable? **[5 marks]**

ii) Find the state feedback gain matrix K of the system shown in **Figure Q5** below if the desired closed-loop poles are:

$s = -2 \mp j0.5,\ s = -10$ **[15 marks]**

Q5 continues over the page….

PLEASE TURN THE PAGE….

Q5 continued

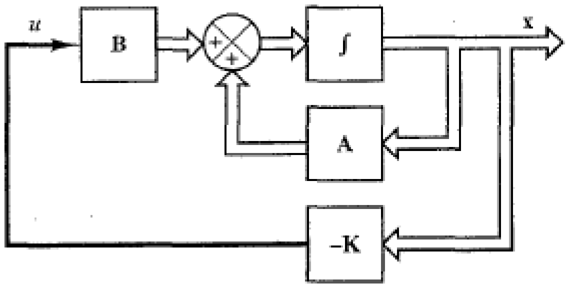

Figure Q5 Regulator system

iii) Find the new transfer function of the controlled plant and find the new dominant complex-pair poles. **[5 marks]**

Total 25 marks

Question 6

a) Define the per unit value of any variable **[3 marks]**
b) What is the importance of short circuit ratio of a synchronous machine? **[5 marks]**
c) Discuss briefly the effect of prime mover speed on a synchronous generator connected to a large power system (infinite bus bar) **[5 marks]**
d) Discuss briefly the benefit of using thyristor-controlled series capacitor in power lines **[5 marks]**
e) Find the state-space model of this system: $\ddot{x} + 3\dot{x} + 9x = 4u$ **[7 marks]**

Total 25 marks

END OF QUESTIONS

Formula sheet over the page….

PLEASE TURN THE PAGE….

School of Engineering
Msc Electrical and Electronic Engineering
Semester Two Examination 2021/2022
Advanced Power Systems, Control and Electrical Machines
Module no. EEE7006

Formula sheet

These equations are given to save short-term memorisation of details of derived equations and are given without any explanation or definition of symbols; the student is expected to know the meanings and usage.

$$\mathbf{P} = \sqrt{2/3}\begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ \sin\theta & \sin(\theta - 2\pi/3) & \sin(\theta + 2\pi/3) \end{bmatrix}$$

$$\mathbf{P}^{-1} = \sqrt{2/3}\begin{bmatrix} 1/\sqrt{2} & \cos\theta & \sin\theta \\ 1/\sqrt{2} & \cos(\theta - 2\pi/3) & \sin(\theta - 2\pi/3) \\ 1/\sqrt{2} & \cos(\theta + 2\pi/3) & \sin(\theta + 2\pi/3) \end{bmatrix}$$

$$\Delta\delta(s) = \frac{(s + 2\zeta\omega_n)\Delta\delta_0}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$$\Delta\omega(s) = \frac{\omega_n^2\Delta\delta_0}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$$\Delta\delta(t) = \frac{\Delta\delta_0}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t}\sin(\omega_d t + \theta), \quad \theta = \cos^{-1}\zeta$$

$$\Delta\omega(t) = -\frac{\omega_n\Delta\delta_0}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t}\sin(\omega_d t)$$

$$\delta(t) = \delta_0 + \Delta\delta(t), \quad \omega(t) = \omega_0 + \Delta\omega(t)$$

Per unit quantity=$\frac{Actual\ value\ of\ quantity}{Base\ value}$, $|S| = \sqrt{3}|V_L|.|I_L|$, $E = V + I.Z$

M=$[B \vdots AB \vdots A^2B]$, $G(s) = C[sI - (A - BK)]^{-1}B$, $s^2 + 2\zeta\omega_n s + \omega_n^2$=0

END OF PAPER