ENG16

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

MSc in ELECTRICAL & ELECTRONIC ENGINEERING

EXAMINATION SEMESTER 2 - 2022/2023

ADVANCED POWER SYSTEMS CONTROL AND ELECTRICAL MACHINES

MODULE NO: EEE7006

Date: Tuesday 9th May 2023 **Time: 10:00am – 1:00pm**

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).**

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Question 1

(a) Briefly define power system stability and classify it according to the nature of disturbance. **[5 marks]**

(b) Calculate showing the steps of solution, the derivative with respect to time and the inverse of park transformation matrix P. Then calculate the product of $\frac{dP}{dt}.P^{-1}$. Explain the meaning of this product. **[12 marks]**

(c) Derive a formula for the critical clearing angle of a power system composed of single synchronous generator connected to a large power system using equal area criterion. **[8 marks]**

Total 25 marks

Question 2

A 500 V, 50 Hz, star-connected, 6-pole synchronous generator has a per-phase synchronous reactance of 1.2 Ohm. If it is working at full load of 65 A at 0.8 power factor lagging, its field current has been adjusted such that the no-load terminal voltage is 500 V , and has mechanical and core losses of 1.25 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

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Question 3

A 50 Hz synchronous generator having inertia constant H=8 MJ/MVA and a transient reactance $X_d' = 0.2$ per unit is connected to an infinite bus through a 3-phase transformer with reactance of X_t=0.1 per unit and a double-transmission line each having reactance of X_L=0.25 per unit. The infinite bus voltage is 1.0 per unit and the delivered generator real power is 0.8 per unit at 0.8 power factor lagging to the infinite bus. Assume the damping power coefficient is D=0.12 per unit and consider a small disturbance in load angle $\Delta\delta = 10^o$.

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

Total 25 marks

Question 4

a) Briefly define dynamic stability of a power system. **[5 marks]**

b) What are the general assumptions used in stability analysis? **[6 marks]**

c) For the given power system shown in **figure Q4c** calculate the critical clearing angle and critical clearing time if a 3-phase fault occurs at point F assuming when the fault is cleared both lines are intact. System frequency is f=50 Hz.

[14 marks]

Question 4 continues over the page

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Question 4 continued

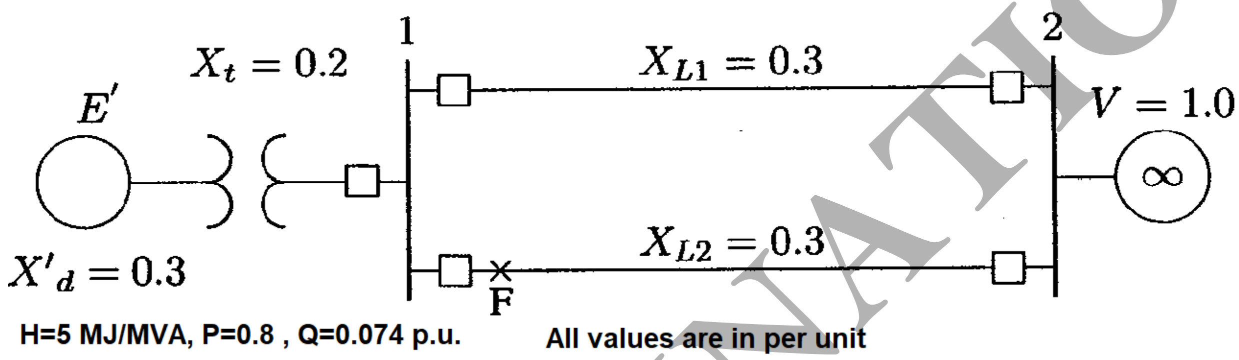

Figure Q4c

Total 25 marks

Question 5

A power system is described by the following third-order differential equation:

$$\boldsymbol{\dddot{y} + 5\ddot{y} + 2\dot{y} + 3y = u}$$

Assuming the output is the first state, and the system uses the state feedback control law $\boldsymbol{u = -Kx}$.

i) Find the A, B, and C matrices of the state space model. **[5 marks]**

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

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

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

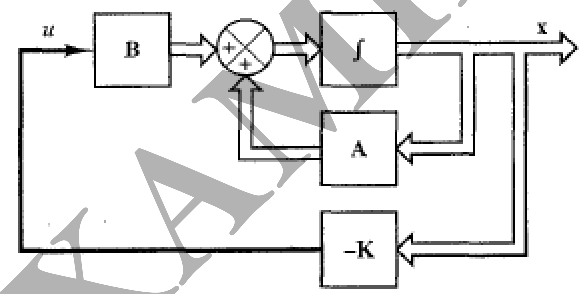

Figure Q5 Regulator system

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

Total 25 marks

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Question 6

a) Define the per unit value of any variable **[3 marks]**

b) What is the importance of short circuit ratio of synchronous machine? **[5 marks]**

c) Briefly discuss the effect of prime mover speed on a synchronous generator connected to a large power system (infinite bus bar) assuming constant excitation. You may aid your answer with diagrams. **[7 marks]**

d) Discuss briefly the benefit of using thyristor-controlled series capacitor in power lines **[3 marks]**

e) Explain the effect of excitation system control on the transient stability of a power system. You may aid your answer with diagrams. **[7 marks]**

Total 25 marks

END OF QUESTIONS

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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.

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

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

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

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

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

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

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

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