[ENG67]

UNIVERSITY OF GREATER MANCHESTER

SCHOOL OF ENGINEERING

MSc in ELECTRICAL AND ELECTRONIC ENGINEERING

EXAMINATION SEMESTER 2 - 2024/2025

ADVANCED POWER SYSTEMS CONTROL AND ELECTRICAL MACHINES

MODULE NO: EEE7006

Date: Monday 12 May 2025 **Time: 14:00 - 17:00**

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).**

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Question 1

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 1.0 kW and 1.5 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 2

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 $\Delta\delta = 10^o$.

I. Write 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

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Question 3

I. Briefly define dynamic stability of a power system.

[5 marks]

II. What are the general assumptions used in stability analysis?

[6 marks]

III. 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]

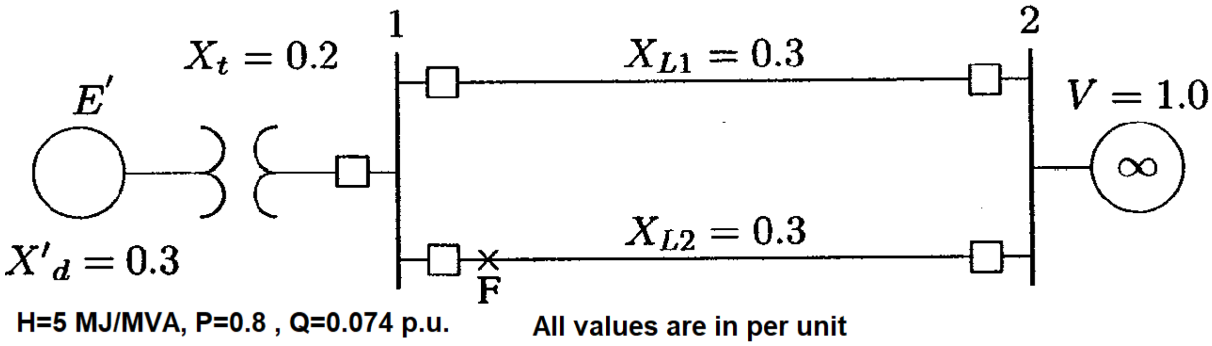

Figure Q4c

Total 25 marks

Please turn the page

Question 4

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

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

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

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]

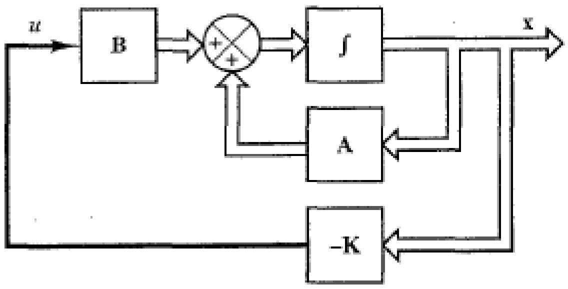

Figure Q5 Regulator system

IV. Find the new transfer function of the controlled plant and find the new dominant complex-pair poles.

[5 marks]

Total 25 marks

Please turn the page

Question 5

A 3-phase, 50 Hz, 220 kV power line is delivering load of 120 MW at 0.8 power factor lagging and has an impedance per phase of $150\angle 79^{o}\Omega$. find:

I. Explain with the aid of diagrams the benefit of using shunt reactor at the receiving end of a long power line when it is unloaded.

[8 marks]

II. The value of a series capacitance that compensates 70% of its inductive reactance.

[5 marks]

III. The new value of its receiving end voltage assuming its sending end voltage remains constant.

[12 marks]

Total 25 marks

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Question 6

I. Briefly define power system stability and classify it according to the nature of disturbance.

[5 marks]

II. 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 $\frac{dP}{dt}.P^{-1}$.

[12 marks]

$$=\omega\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix}$$

III. 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

End of Questions

Please turn the page for the Formula sheet

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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

End of Exam Paper