[ENG06]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

MSc ELECTRICAL & ELECTRONIC ENGINEERING

EXAMINATION SEMESTER 2 - 2023/2024

ADVANCED POWER SYSTEMS CONTROL AND ELECTRICAL MACHINES

MODULE NO: EEE7006

Date: Tuesday 14th May 2024 **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).**

School of Engineering
Msc Electrical and Electronic Engineering
Examination Semester 2 - 2023/2024
Advanced Power Systems, Control and Electrical Machines
Module No. EEE7006

Question 1

A 208 V, 45 kVA, delta-connected , 50 Hz synchronous motor has a synchronous reactance of 2.5 Ω and a negligible armature resistance. Its friction and windage losses are 1.5 kW , and its core losses are 1.0 kW. Initially the shaft is supplying a 15 hp load, and the motor power factor is 0.8 leading. Answer the following:

I. Sketch the phasor diagram of this motor, and find the values of armature phase current, load line current and the internal back EMF; **[11 marks]**

II. Assume that the shaft load is increased to 30 hp with constant excitation; Sketch the behavior of the phasor diagram in response to this change;

[7 marks]

III. Find the armature phase current, load line current and the back EMF after the load change; and **[5 marks]**

IV. What is the new power factor? **[2 marks]**

Total 25 marks

Please turn the page

Question 2

A 100 MVA , 13.8 kV, 60 Hz, Y-connected , 3-phase synchronous generator is connected to a 13.8 kV/220 kV , 100 MVA, $\Delta - Y$ connected transformer. The reactances are in per unit to the machines's own base are

$X_d = 1.0, X_d' = 0.25 , X_d^{"} = 0.12$

And its time constants in seconds are

$\tau_a = 0.25 , \tau_d^{"} = 0.4 , \tau_d' = 1.1$

The transformer reactance is 0.2 per unit on the same base. The generator is operating at the rated voltage and no-load when a 3-phase fault occurs at the secondary terminals of the transformer. Answer the following:

I- Find the subtransient, transient, and the steady state short circuit currents in per unit and actual amperes on both sides of the transformer; **[12 marks]**

II- What is the maximum rms current (ac plus dc) at the beginning of the fault?; and **[3 marks]**

III- Obtain the instantaneous expression for the short circuit current including dc component. Assume load angle $\delta = \frac{\pi}{2}$ radians. **[10 marks]**

Total 25 marks

School of Engineering
Msc Electrical and Electronic Engineering
Examination Semester 2 - 2023/2024
Advanced Power Systems, Control and Electrical Machines
Module No. EEE7006

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 $\Delta\delta = 12^o$. Answer the following:

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 $\delta(t)$; and **[5 marks]**

III. Obtain the equation describing the frequency as a function of time. **[5 marks]**

Total 25 marks

School of Engineering
Msc Electrical and Electronic Engineering
Examination Semester 2 - 2023/2024
Advanced Power Systems, Control and Electrical Machines
Module No. EEE7006

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.

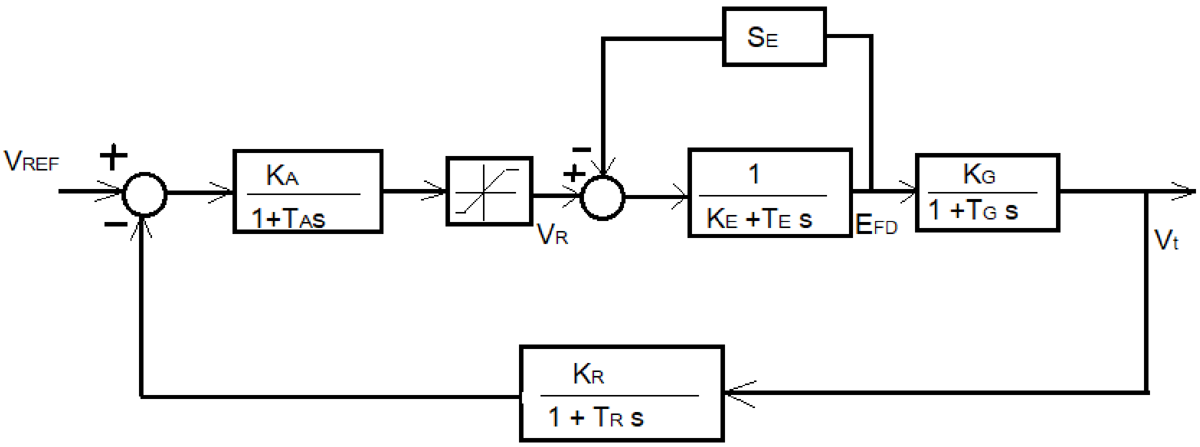

Figure Q4 The excitation control system

[10 marks]

Total 25 marks

School of Engineering
Msc Electrical and Electronic Engineering
Examination Semester 2 - 2023/2024
Advanced Power Systems, Control and Electrical Machines
Module No. EEE7006

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

The system uses the state feedback control law $\boldsymbol{u} = -\boldsymbol{K}\boldsymbol{x}$.

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

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

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

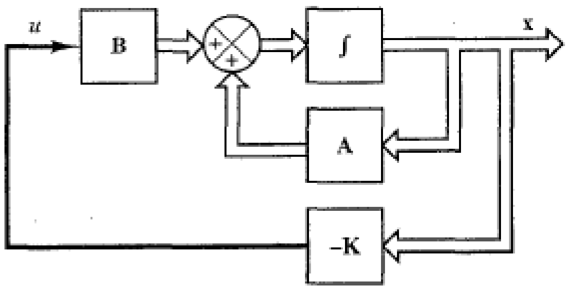

Figure Q5 Regulator system

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

Total 25 marks

Please turn the page

School of Engineering
Msc Electrical and Electronic Engineering
Examination Semester 2 - 2023/2024
Advanced Power Systems, Control and Electrical Machines
Module No. EEE7006

Question 6

I) Define the per unit value of any variable **[5 marks]**

II) What is the importance of short circuit ratio of synchronous machine?

[5 marks]

III) Discuss briefly the effect of prime mover speed on a synchronous generator connected to a large power system (infinite bus bar) **[5 marks]**

IV) Discuss briefly the benefit of using thyristor-controlled series capacitor in power lines **[5 marks]**

V) Find the state-space model of this system: $\ddot{z} + 3\dot{z} + 9z = 4u$ **[5 marks]**

Total 25 marks

END OF QUESTIONS

Please turn the page for Formula Sheets

School of Engineering
Msc Electrical and Electronic Engineering
Examination Semester 2 - 2023/2024
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.

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

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

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

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

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

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

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

$$i_{ac}(t) = \sqrt{2}E_0\left[\left(\frac{1}{X''_d} - \frac{1}{X'_d}\right)e^{-t/\tau''_d} + \left(\frac{1}{X'_d} - \frac{1}{X_d}\right)e^{-t/\tau'_d} + \frac{1}{X_d}\right]\sin(\omega t + \delta)$$

$$I_d = \frac{E_0}{X_d}$$

$$\tau_a = \frac{X''_d + X''_q}{2R_a} \qquad I'_d = \frac{E_0}{X'_d}$$

$$I_{dc} = \sqrt{2}\frac{E_0}{X''_d}\sin\delta\, e^{-t/\tau_a} \qquad I_{asy} = \sqrt{I''^2_d + I^2_{dc}} \qquad I''_d = \frac{E_0}{X''_d}$$

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