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(*University of Choice*)
MASINDE MULIRO UNIVERSITY OF SCIENCE AND TECHNOLOGY (MMUST)

MAIN CAMPUS

UNIVERSITY EXAMINATIONS
2021/2022 ACADEMIC YEAR

FIRST YEAR SECOND SEMESTER EXAMINATIONS

FOR THE DEGREE
OF
MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

COURSE CODE: EPE 820

COURSE TITLE: POWER SYSTEM DYNAMICS AND STABILITY

DATE: 29th April, 2022 **TIME:12.00 noon-02.00 p.m.**

INSTRUCTIONS TO CANDIDATES

Question ONE (1) is compulsory
Answer Any Other TWO (2) questions

TIME: 2 Hours

MMUST observes ZERO tolerance to examination cheating

Question 1 (20 Marks)

(a) Briefly explain why we lump synchronous machine circuits for purposes of analysis and derivation of their mathematical models. (4 marks)

(b) A 50 Hz synchronous generator is connected to an infinite bus through a line. The p.u. reactances of generator and the line are j0.3 p.u. and j0.2 p.u. respectively. The generator no load (terminal) voltage is 1.1 p.u. and that of infinite bus is 1.0 p.u. The inertia constant of the generator is 3 MW-sec/MVA and the machine's initial power angle $\cos\delta_0 = 0.8$. A small perturbation in power will make the rotor oscillate. The natural frequency of oscillation is given by eq. 1.

$$f_n = \left\{ \left(\frac{\partial P_e}{\partial \delta} \right) \delta_0 \frac{1}{M} \right\}^{\frac{1}{2}} \text{ rad/sec} \tag{1}$$

Where the generator moment of inertia M is given in MJ-s/electrical radians in eq. 2

$$M = \frac{GH}{\pi f} \text{ MJ-s/electrical radians} \tag{2}$$

The oscillatory power expressed in terms of eq.1 is given by eq. 3

$$\frac{\partial P_e}{\partial \delta} = \frac{V_1 V_2}{X} \cos\delta_0 \tag{3}$$

i. Determine the total reactance X (2 marks)

ii. Determine the oscillatory power $\frac{\partial P_e}{\partial \delta}$. (5 marks)

iii. Determine natural frequency of oscillation f_n in Hz. (7 marks)

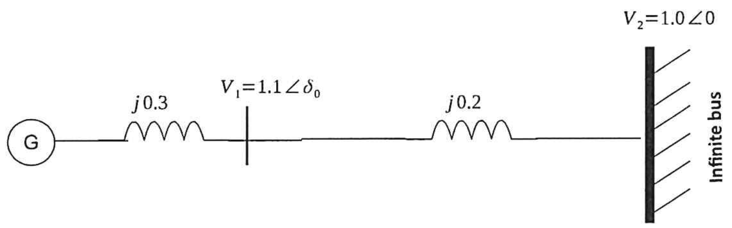

Figure 1: Single machine infinite bus

(c) Explain the per unit system. (2 marks)

Question 2 (20 Marks)

(a) Explain the fundamental difference between the notion of system stability in *continuous time* coordinates and *discrete time* coordinates. (6 marks)

(b) Differentiate between a steady state and transient analyses of synchronous machines. (3 marks)

(c) Which of the following eigenvalues are stable? explain. (i).$\lambda_1 = -3 + j0.08$ (ii) $\lambda_2 = 3 + j0.08$. (3 marks)

(d) Sketch a labelled 4 pole two -axis model of a salient pole synchronous machine. (6 marks)

(e) An 80 MVA, 69.3 kV, three phase synchronous generator has a synchronous reactance of 10 Ω per phase and stator winding resistance $r_a \approx 0$. The generator is delivering rated power at 0.8 p.f lagging at the rated terminal voltage to an infinite bus bar. Determine

i. Real power 'P' and reactive power 'Q' (1 mark)

ii. Rated voltage per-phase. (1 mark)

Question 3 (20 Marks)

(a) A set of three phase stator currents i_a, i_b, i_c are given by the vector of eq. (4)

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} \cos(\omega_s t) \\ \cos(\omega_s t - 120°) \\ \cos(\omega_s t + 120°) \end{bmatrix} \quad (4)$$

Transform the eq. (4) currents to the two-phase α, β,
(Clarke's) orthogonal coordinate system, eq. (4) by multiplication with transformation matrix of eq. (5). (5 marks)

$$\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (5)$$

(b) The three phase balanced stator voltage equations for a salient pole synchronous machine in the *a,b,c* reference frame are given in eqs. 6-8

$$V_a = -Ri_a - \frac{d\lambda_a}{dt} \quad (6)$$

$$V_b = -Ri_b - \frac{d\lambda_b}{dt} \quad (7)$$

$$V_c = -Ri_c - \frac{d\lambda_c}{dt} \quad (8)$$

After applying Park's d-q transformation we get the following voltages:

$$V_d = -Ri_d - \frac{d\lambda_d}{dt} - \omega\lambda_q \quad (9)$$

$$V_q = -Ri_q - \frac{d\lambda_q}{dt} + \omega\lambda_d \quad (10)$$

Answer the following questions in relation to the equations 6-10

i. Explain how the d-q transformation makes the solutions to the derivatives in the a,b,c frame simpler. (7 marks)

ii. Identify the *speed voltage* terms in the Park transformed equations and explain their significance (8 marks)

Question 4

(a) The significant penetration of wind and solar power into the grid has resulted in reduction of system inertia. Read the following text and answer the questions following
" Many generators producing electricity for the grid have spinning parts - they rotate at the right frequency to help balance supply and demand and can spin faster or slower if needed. The kinetic energy 'stored' in these spinning parts is our system inertia. If there's a sudden change in system frequency (a transient), these parts will carry on spinning - even if the generator itself has lost power - and slow down that change (what we call the rate of change of frequency) while the control room restores balance. Inertia behaves a bit like the shock absorbers in a car's suspension, which dampen the effect of a sudden bump in the road and keep the car stable and moving forward."

i. Explain how you understand grid inertia in terms of solar, wind power and the traditional synchronous generators. (6 marks)

ii. If a sudden short circuit (transient) occurred in the system that self cleared after a few seconds as often happens, give an explanation of the effect on grid frequency for a system with high penetration of solar and wind power. (4 marks)

iii. For the same transient in

iv. (b) above, give an explanation of the effect on grid frequency for a system with no presence of solar and wind power, i.e a system with only large synchronous generators. (4 marks)

(b) Describe transient inductance $L_d^{"}$ of a synchronous machine. (6 marks)

Question 5

(a) With the aid of a suitable diagram (with a unit circle), explain the notion of eigenvalues in discrete plane coordinates, include indication of stable and unstable regions. (8 marks)

(b) Without going into too much detail, explain how three phase alternating quantities appear as d.c. quantities after transformation from $a, b, c \rightarrow \alpha - \beta \rightarrow d - q$ (6 marks)

(c) A generator of 250 MVA rating has an inertia constant of 6MJ/MVA, find its inertia constant on a 100 MVA base. (6 marks)