EE4-48
EE9-CS6-2
EE9-FPN1-03

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2016

MSc and EEE PART IV: MEng and ACGI

Corrected copy

POWER SYSTEM DYNAMICS, STABILITY AND CONTROL

Tuesday, 17 May 10:00 am

Time allowed: 3:00 hours

There are FOUR questions on this paper.

Answer ALL questions.

All questions carry equal marks.

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible First Marker(s) : B.C. Pal
Second Marker(s) : B. Chaudhuri

The Questions

1.

a) Why are the steam turbine generators of two-pole constructions? [3]

b) Why are furnace and boiler dynamics not represented in electromechanical stability study? [2]

c)

i) Why is the transfer function of a hydro-turbine a non-minimum phase type? [4]

ii) How is such turbine dynamics controlled in practice? [3]

d)

i) Synchronous generators have large synchronous reactance (usually greater than 2.0 p.u.) - Explain the reason(s). [3]

ii) Why, despite having such a large reactance, the fault current fed by a synchronous machine is large (about 4.0 p.u)? [5]

e) Two synchronous generators (Gen A and Gen B) of similar capacity are made by two manufactures. The clearance (air gap) between the stator and rotor of Gen A is 1.25 times that of Gen B. Both generators are loaded equally. Following a temporary disturbance the rotors of the generators started swinging. Which generator will offer higher margin of stability and why? [5]

[Total = 25 marks]

2. a) A 3-phase, star connected, 20 kV (line); 600 MVA alternator is connected to the grid operating at 50 Hz. The resistance is negligible and synchronous reactance is 1.25 Ohm.

i) Find out the excitation voltage (line-line) (magnitude and angle) when the generator is delivering full load at 0.85 power factor lagging. [6]

ii) The excitation voltage is now increased by 20% keeping the prime mover power fixed. How will the power output (both MW and MVAR) will be affected by way of this change? [6]

iii) Keeping the excitation voltage at the value obtained in (i), if the prime mover power is gradually increased the generator will continue to deliver increased MW before steady state stability limit is reached; Compute the stability limit (in terms of MW). [5]

b) A synchronous generator produces a terminal voltage of 9 kV (phase). This is connected to a network which has many other machines. The power flow solution obtains a 15 degree phase angle (θ) with respect to some reference angle. The load angle delta (δ) is 25 degree with respect to the same reference angle. The output current is 10 kA and 0.85 pf lagging with respect to the terminal voltage. Find the following quantities.

i) direct and quadrature axis voltages in the machine reference frame [4]

ii) direct and quadrature axis currents in the machine reference frame [4]

Assume d axis is leading q axis (IEEE convention)

[Total = 25 marks]

3.

a) The terminal voltage of a synchronous generator is suddenly dropped by 20% because of a temporary remote fault in the network. This resulted in temporary drop in power produced by the generator. The input mechanical power remained at the pre-fault value. This resulted in a dynamic response of the generator which is characterised very approximately by the following equations:

$$\frac{d\delta}{dt} = \omega_r - \omega_s \quad (3.1)$$

$$\frac{d\omega_r}{dt} = \frac{\omega_s}{2H}\left[P_{mech} - \frac{E'V_t}{X_d'}\sin\delta - D(\omega_r - \omega_s)\right] \quad (3.2)$$

δ: load angle, ω_r : rotor speed, ω_s: synchronous speed (314 rad/sec), P_{mech} : mechanical input power, E' transient speed voltage , V_t : terminal voltage, X_d': direct axis transient reactance, H: H constant, D: damping coefficient (pu/rad).

i) What are the roles of P_{mech} and E' in influencing the dynamics characterised by the above two equations? [5]

ii) Treating P_{mech} and E' as inputs develop the linearised state space equations in the form:

$$\dot{x} = Ax + Bu$$

$$x = [\Delta\delta, \Delta\omega_r], u = [\Delta P_{mech}, \Delta E']$$

[7]

iii) Obtain the element of matrix A, B for the following values of the parameters and operating variables:

δ= 40 degree, ωs= 314 rad/sec), P_{mech} : E'= 1.5 p.u. Vt =1.05 p.u. Xd'= 0.3 p.u. H= 6.0 s, D=0.04 (pu/rad)

[5]

iv) Obtain the eigenvalues of the system matrix [4]

v) Frequency of oscillations (imaginary part of the eigenvalue pair in Hz) [2]

vi) Comment on the stability of the system. [2]

[Total = 25 marks]

4.

a) What is the performance co-efficient (C_p) in a wind turbine? [2]

b) Show that the theoretical maximum value of C_p is 16/27 or 59.3 %. [8]

c) This part relates to gear box in a wind turbine generator (WTG):

i) What is the function of the gear box in a WTG? [2]

ii) Why is the gear box optional in Type-4 (Full converter machine)? [3]

d) This part relates to stall control in WTG:

i) What is meant by stall control in wind energy conversion system? [3]

(ii) Why is stall control not effective below the rated wind speed? [3]

(iii) How does active stall control differ from passive stall control? [4]

[total = 25 marks]