IMPERIAL COLLEGE LONDON

EE4-48 ✓
EE9-CS6-2

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2014

MSc and EEE PART IV: MEng and ACGI

Corrected Copy

POWER SYSTEM CONTROL, MEASUREMENT AND PROTECTION

Wednesday, 14 May 10:00 am

Time allowed: 3:00 hours

There are SIX questions on this paper.

Answer FOUR 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

L

The Questions

1.

a) A synchronous generator has suddenly lost its excitation power. Nevertheless the generator stayed connected with the network and continued to produce power at a reduced capacity for few minutes before the excitation was restored back. Explain how this is possible.

[4]

b) The rotor of a synchronous generator is a solid iron structure- where as its stator is made of laminated steel. Why is it constructed in this way?

[4]

c) 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 1.5 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?

[4]

d) A synchronous generator produces a terminal voltage at 9 kV (phase). This is connected to a network which has many other machines. The power flow solution obtains a 12 degree phase angle (θ) with respect to some reference angle. The load angle delta (δ) is 35 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 machine reference frame

[4]

ii) direct and quadrature axis currents in machine reference frame

[4]

Assume d axis is leading q axis (IEEE convention)

2.

a) The terminal voltage of a synchronous generator is suddenly dropped by 10% 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:

$$\frac{d\delta}{dt} = \omega_r - \omega_s \quad (2.1)$$

$$\frac{d\omega_r}{dt} = \frac{\omega_s}{2H}\left[P_{mech} - \frac{E'V_t}{X_d'}\sin\delta + D(\omega_r - \omega_s)\right] \quad (2.2)$$

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?

[4]

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

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

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

[6]

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)

[4]

iv) Obtain the eigenvalues of the system and frequency of oscillations (imaginary part of the complex eigenvalue pair in Hz) and comment on the stability of the system.

[4+1+1]

3.

a)

i) Why is it necessary to control the voltage in the power network? [2]

ii) What is *'field flashing'* in the context of excitation system control? [3]

iii) Why modern synchronous generators are mostly equipped with high gain fast acting voltage regulators? [3]

iv) Briefly describe the function of a power system stabiliser (PSS). [3]

b) Synchronous generators and shunt capacitor banks are both used to produce reactive power to support the system voltage. During appreciably low voltage situation in the network why are the capacitors not as effective as synchronous generators? [3]

c) Following is a block diagram of an excitation system controller

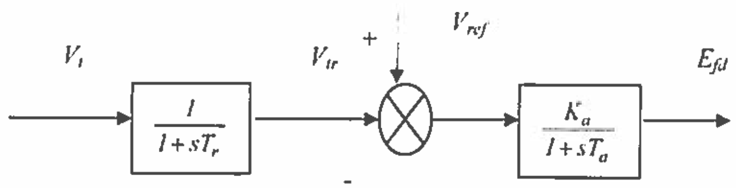

Fig 3.1 Block Diagram of a Fast Excitation System

i) Write the relevant differential equations describing the voltage control dynamics. [3]

ii) It is required to produce 3.5 p.u. of E_{fd} to maintain a terminal voltage of 1.05 p.u. Find suitable V_{ref} to meet such condition in steady state with a voltage regulator gain (K_a) = 300. [3]

4.

a)

i) Why is droop introduced in speed governing?

[3]

ii) Why is droop control not enough to restore the frequency to its pre-disturbed steady state value?

[3]

b) An interconnected power system has two commercial areas. The composite droop and load frequency sensitivity of Area 1 are R_1 and D_1 respectively and the same for Area 2 are R_2 and D_2. For a change in Area 1 load by ΔP_{L1} the change in the generation in Area 1 and 2 are ΔP_{m1} , ΔP_{m2} respectively. The associated change in the tie line flow is ΔP_{12}. Derive that the associated frequency deviation Δf is related as:

$$\Delta f = -\frac{\Delta P_{L1}}{D_1 + \frac{1}{R_1} + D_2 + \frac{1}{R_2}}$$

[6]

c) Area 1 has Gen 18,000 MW, Load 18,500 MW; Area 2 has Gen 30,500 MW and Load 30,000 MW. The load in each area varies by 1% with 1% change in the frequency. The composite droop is 5% for both areas. Area 1 is importing 500 MW from Area 2. For the loss of 1000 MW load in Area 1, find the change in the system frequency when there is no tie-line supplementary control. Assume the nominal system frequency to be 50 Hz.

[8]

5.

a)

i) What is the difference between apparatus protection and system protection?

[3]

ii) Why is current inrush observed during power transformer switching?

[3]

iii) Describe the principle that is adopted to prevent the relay to operate during current inrush in a power transformer.

[3]

iv) Draw a conceptual block diagram of a relay and briefly describe the role of various inputs/outputs and other elements.

[5]

b) The performance of an over current relay was monitored for a period of three years. It was found that the relay operated 14 times, out of which 12 were correct trips. If the relay failed to issue trip decisions on 2 occasions, compute dependability, security and reliability of the relay as percentages.

[3x2=6]

6

a)

i) What are the functions of a current transformer?

[2]

ii) What are the basic differences between a measurement CT and a protection CT ?

[3]

iii) How are the accuracies of CTs and VTs specified?

[3]

iv) Why is it necessary to have a tuning inductor in capacitive voltage transformer (CVT)?

[5]

b) A 1200/5 C400 CT is connected on the 1000/5 tap. At 20 times the rated secondary current with this setting, the secondary resistance of the CT is 0.5 Ω. How many relays having burden of 0.5 Ω. each can be connected in order for the CT to supply relay currents without reaching saturation?

[7]