IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2015

EEE PART III/IV: MEng, BEng and ACGI

Corrected copy

ELECTRICAL ENERGY SYSTEMS

Thursday, 10 December 9:00 am

Time allowed: 3:00 hours

There are SIX questions on this paper.

Answer 2 questions from Section A and 2 questions from Section B. Use a separate answer book for each section.

All questions carry equal marks.

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

Examiners responsible First Marker(s) : G. Strbac, B. Chaudhuri
Second Marker(s) : B. Chaudhuri, G. Strbac

Section A – Answer any 2 out of 3 questions in section A

Question 1

a) Contrast the operation and control of a synchronous generator when it supplies isolated load versus when it is connected to a large power system. [6]

b) Consider a three-phase synchronous generator connected to a very large system. Synchronous reactance of the generator is $X = 1.7241$ p.u., while armature resistance is negligible. The terminal voltage $V = 1.0$ p.u., and the generator is supplying the current $I = 0.8$ p.u. at 0.90 power-factor (reactive power is supplied to the system).

Find:

(i) The magnitude and angle of the internal voltage E [4]

(ii) Active (P) and reactive power (Q) delivered to the system [4]

(iii) The angle (δ) between internal (E) and terminal voltage (V) and the reactive power (Q) delivered to the system, if the real power output of the generator remains constant but excitation of the generator is increased by 20 % and then decreased by 20 %. [6]

Question 2

a) A 132/11kV 90MVA transformer has a per unit leakage reactance of X = 0.1 p.u. on rating:

(i) Calculate the magnitude of actual transformer impedances at both sides of the transformer; [2]

(ii) What would be the value of the per unit impedance of the transformer, for a power base of 150MVA, base value of voltage at 11kV voltage level of 11.5kV (while base value of voltage at 132kV voltage level is 132kV)? [3]

b) For a transmission circuit given in Figure 2.1 show:

(i) $$\overline{V}s = Vr + \left(\frac{RP_r + XQ_r}{Vr}\right) + j\left(\frac{XP_r - RQ_r}{Vr}\right)$$ [2]

(ii) Write an expression for the active and reactive power losses in the transmission circuit and then determine the active and reactive power generated by the source [3]

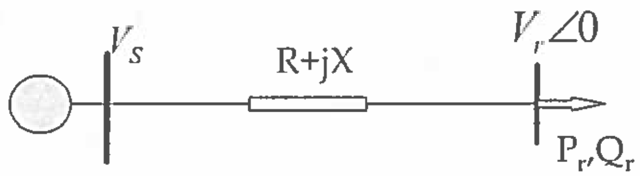

Figure 2.1 Transmission circuit with voltage and power specified at the receiving end

c) Consider a high voltage transmission circuit with negligible resistance, as the one shown in Figure 2.1, and assume that voltage magnitudes and phase angles are known at both sending and receiving ends.

(i) Write the expressions for sending end active and reactive powers as functions of voltage magnitudes and phase angles. [3]

(ii) Based on these expressions, show that active power flow will be mostly driven by the difference in the phase angles while that reactive power flow will be largely determine by the difference in the voltage magnitudes. [3]

(iii) What is the maximum amount of active power that can be transported via this transmission line? [2]

(iv) Explain why reactive power cannot be generally transported over long distances. [2]

Question 3

A generator supplies a load via 33 kV distribution line, as shown in Figure 3.1 below. The system is a balanced 50Hz 3-phase system. The circuit parameters are: R = 0.3267 Ω/km, X = 0.4356 Ω/km and the length of the line is 10 km.

Figure 3.1 Two-bus power system

(i) Using base power of S_b = 100 MVA, form the per-unit admittance matrix for this system. [4]

(ii) Using Gauss Seidel load flow algorithm, calculate the magnitude of the voltage at node 2 and active and reactive power generated at node 1. Perform 3 iterations. [10]

(iii) Compute the current, active and reactive power losses and voltage drop across the distribution line. [6]

Section B – Answer any 2 out of 3 questions in section B

Question 4

a) Explain the role of power-flow analysis, Thevenin theorem and superposition theorem in fault current calculation.

[5]

b) Show how the fault current and voltage at the faulted bus i can be calculated using the appropriate element of the bus impedance matrix. Consider a fault impedance Z_f.

[4]

c) Four identical 13 kV, 60 MVA three-phase generators, G1, G2, G3 and G4 are connected to a bus bar A and bus bar B as shown in Figure 4.1. The sub-transient reactance of each generator is 0.15 p.u. (with respect to their respective base). Bus bar A is connected to bus bar B through a reactor X. A feeder is supplied from bus bar A through a 240 MVA step-up transformer, T with 0.2 p.u. (with respect to its own base) leakage reactance. Choose 60 MVA base for the calculations. Neglect pre-fault loading and assume zero fault impedance.

(i) Determine the reactance X in ohms, if the fault level due to a three-phase fault at point F on the feeder side of the transformer, T is to be limited to 600 MVA.

[5]

(ii) Calculate the voltage (in kV) at bus bar A during the three-phase fault at point F in part (i) if the generator is operating at 13 kV (line).

[3]

(iii) For the three phase fault at point F, how much fault current (in kA) would be contributed by the generator G4?

[3]

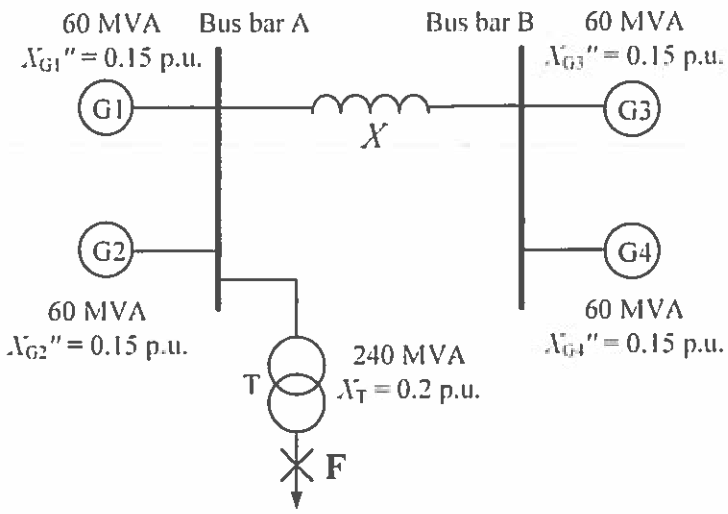

Figure 4.1: Single-line diagram of the generator arrangement for Question 4(c)

Question 5

a) Derive an expression for the minimum value of the neutral grounding reactor (X_n) of a star-connected generator so that the line-to-ground fault current at the generator terminal is limited to the corresponding three-phase fault current level. Assume identical values for positive (X_1) and negative (X_2) sequence reactance of the generator. Neglect resistance and derive the expression for X_n in terms of positive (X_1) and zero (X_0) sequence reactance of the generator.

[5]

b) A 3-phase line is supplying a star connected balanced 3-phase load with its neutral grounded. After a sudden disconnection of supply to phase B, the line currents in phase A and phase C are $I_A = 10\angle 0°$ A and $I_C = 10\angle 120°$ A. Calculate the magnitude and phase angles of the B-phase component of the positive, negative and zero sequence currents.

[5]

c) Two 30 MVA, 6.6 kV three-phase star-connected synchronous generators are connected in parallel to supply a 6.6 kV feeder. One generator has its star point grounded through a 0.4 Ω resistor and the other has its star point isolated. The sequence reactance for the generators are $X_{g1} = 0.2$ p.u.; $X_{g2} = 0.16$ p.u. and $X_{g0} = 0.06$ p.u. and for the feeder are $X_{f1} = X_{f2} = 0.6$ Ω per phase and $X_{f0} = 0.4$ Ω per phase. For a line-to-ground fault on phase A at the far end (opposite to the generator) of the feeder calculate the following considering 30 MVA base:

(i) the fault current in kA

[5]

(ii) the power dissipated (in MW) in the generator grounding resistor

[2]

(iii) what value of neutral grounding resistor (in ohms) would be required to limit the line-to-ground fault current to 2 kA

[3]

Question 6

a) Explain physically (not analytically) why the steady-state stability limit for a round rotor synchronous generator corresponds to a power angle of 90 degrees if resistances are neglected.

[4]

b) A 50 Hz, 4-pole synchronous generator is rated 500 MVA, 22 kV and has an inertia constant of 7.5 s. Assume that the generator is synchronized with a large power system and has a zero accelerating power while delivering a power of 400 MW. Suddenly its input power is increased to 500 MW. Calculate speed of the generator in revolutions per minute (rpm) after 10 cycles. Neglect rotational losses and any change in electrical power output of the generator during this period.

[5]

c) A round-rotor synchronous generator is connected to an infinite busbar via a generator transformer and a double-circuit overhead line. The leakage reactance of the transformer is 0.15 p.u. The reactance of each circuit of the double-circuit overhead line is 0.4 p.u. The generator has a transient reactance of 0.2 p.u and is supplying 0.8 p.u. active power at a terminal voltage of 1 p.u. All impedance values are based on the generator rating and the voltage of the infinite busbar is 1 p.u. Neglect generator resistance and assume constant mechanical input to the generator.

(i) Calculate the power angle (in degrees) between the generator terminal and the infinite busbar under the pre-fault condition.

[3]

(ii) A three-phase solid fault occurs at the sending (generator) end of one of the transmission line circuits and is cleared by disconnecting the faulted line. Calculate the maximum allowable power angle (in degrees) between the generator terminal and the infinite busbar under the post-fault condition without losing stability.

[3]

(iii) Use equal area criteria to determine the critical clearing angle (in degrees) for the three-phase fault mentioned in part 6(c)(ii). Assume zero power output from the generator during the fault.

[5]