IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2014-15

EEE PART III/IV: MEng, BEng and ACGI

Corrected Copy

ELECTRICAL ENERGY SYSTEMS

Friday, 12 December 2:00 pm

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

© Imperial College London

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

1. Structure of the conventional power system is presented in Figure 1.

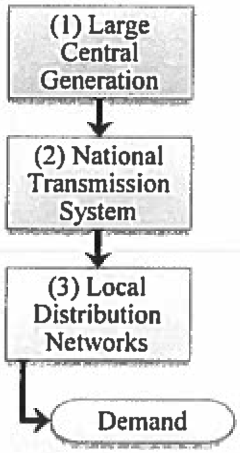

Figure 1

a) List key functions of the three sectors of the electricity system.

[3]

b) Describe briefly how demand-supply balance is maintained in real time.

[2.5]

c) Describe briefly how power flows on the transmission network are controlled.

[2.5]

d) Describe the importance of the effect of diversity of demand in planning of power systems. What is the coincidence factor and how does it change with the number of consumers?

[4]

e) Describe briefly how security of supply, as one of the key requirements of the electricity system, is delivered. Briefly state the rationale behind the power system design standards.

[4]

f) Calculate the probability that a system of 4 generators, each of 100MW with failure rates of 6%, will not meet a demand of 280MW.

[4]

2.

a) Considering a simplified equivalent circuit of a high voltage transmission line presented in Figure 2.1,

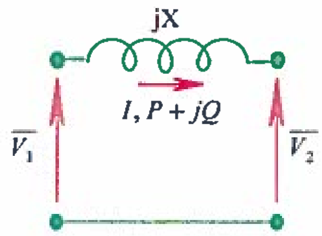

Figure 2.1

(i) show that the expressions of active and reactive power flow over the transmission line are given by:

$$P = \frac{V_1 V_2}{X} \sin(\delta_1 - \delta_2)$$

$$Q = \frac{V_1^2 - V_1 V_2 \cos(\delta_1 - \delta_2)}{X}$$

[4]

(ii) Discuss the limits of transporting active and reactive power over transmission lines.

[4]

b) Consider the transformer model in Figure . below:

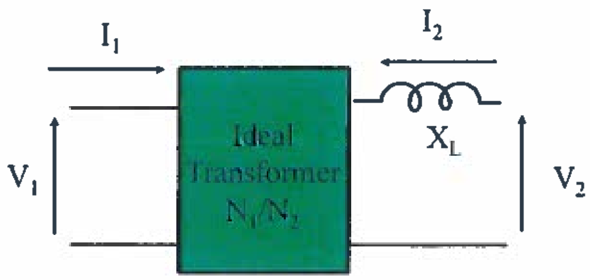

Figure 2.2

Starting from $Z_1 = \left(\frac{N_1}{N_2}\right)^2 Z_2$ derive the expression for per unit value of the transformer impedance and show that $Z_{1pu} = Z_{2pu}$

[5]

c) Circuit diagram of a three phase system is shown in Figure below.

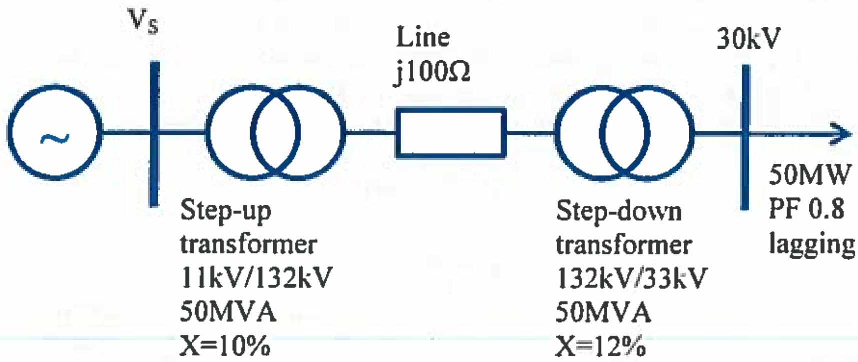

Figure 2.3

(i) Calculate the corresponding per unit impedances and sketch the per-unit circuit. [3.5]

(ii) Calculate the magnitude of the sending voltage Vs. [3.5]

3. A 132 kV network, supplied from a remote generator connected to busbar 1 (Figure below) supplies an industrial site at busbar 3 and a town supplied from busbar 2. Network voltage is controlled by the generator (G) and Static-Var-Compensator (SVC) and is kept at 1 p.u. at busbars 1 and busbar 2. Lengths of the circuits are shown in Figure 3. Individual circuits all have the same unit reactance of x = 0.2 Ω/km, while active power losses can be ignored.

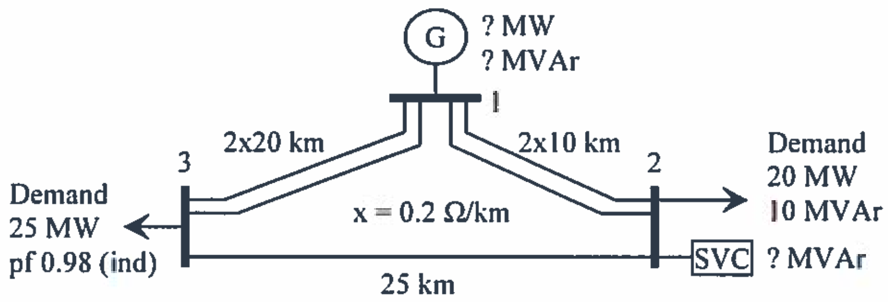

Figure 3

a) Identify the type of busbars for nodes 1, 2 and 3 (Slack, PV or PQ) [3]

b) Assuming a 100MVA base, calculate the per unit values of all system parameters [2]

c) Form the Ybus matrix for this system [2]

d) Perform two iterations of the Gauss-Seidel power flow and calculate:

(i) Voltages (p.u.) and angles at all three busbars [8]

(ii) Generator G active and reactive power output [2]

(iii) Reactive power delivered by the Static Var Compensator (SVC) [3]

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

4.

a) Explain why sub-transient reactance of synchronous generators is considered for fault calculations.

[5]

b) The bus bar arrangement within a 33 kV substation is shown in Figure 4.1. The two sections of the 33 kV bus bar (AB and CD) is separated by a reactor L. Section AB is fed from four identical 10 MVA generators each having 0.2 p.u. sub-transient reactance. Section CD is fed from the power grid through a 50 MVA transformer with a reactance of 0.1 p.u. Each of the circuit breakers M and N has a short circuit capacity of 600 MVA. Consider 50 MVA base for your calculations. For a 3-phase fault at location P,

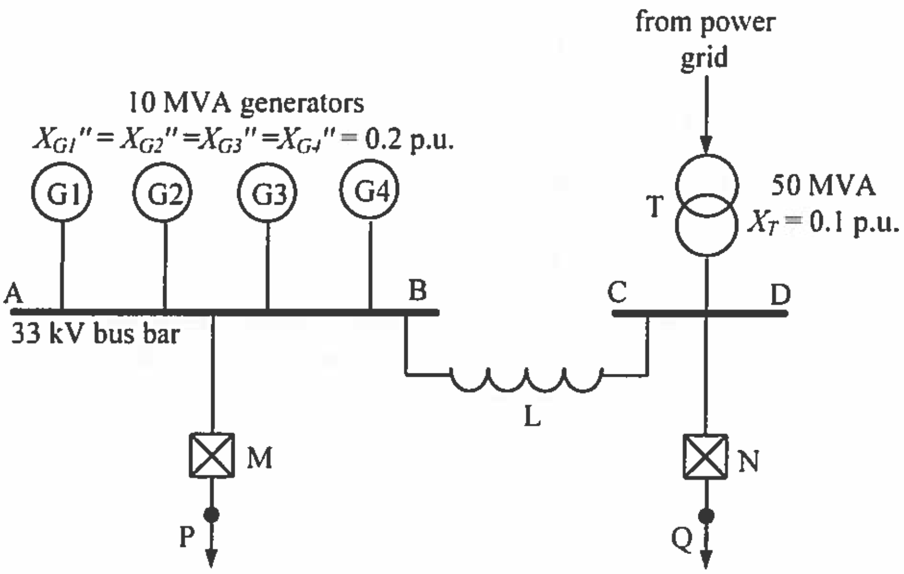

Figure 4.1: Single-line diagram of the 33 kV substation in Question 4(b) and 4(c)

(i) Draw the single line circuit arrangement of the reactances looking into the fault point P. Label the reactance values (except the unknown value of the reactor L) in p.u. with respect to your chosen 50 MVA base.

[3]

(ii) Calculate the reactance of the reactor L in p.u. (with respect to 50 MVA base) which would ensure that the circuit breaker M is not overloaded.

[4]

(iii) Determine the reactance of the reactor L in ohms.

[3]

c) For the same sub-station arrangement as shown in Figure 4.1 and described in part (b) of this question, determine the reactance (in ohms) of the reactor L if the circuit breaker N is not be overloaded due to a 3-phase fault at location Q. Consider 50 MVA base for your calculations.

[5]

5.

a) Derive the expression for fault current (in phase domain) due to a line-to-line (LL) fault between phases B and C. The final expression should be in terms of pre-fault voltage and sequence impedances. Neglect fault impedance.

[5]

b) An unbalanced delta-connected load draws the following line currents: $I_B = 5\angle 30°$ A, $I_C = 3.5\angle 90°$ A. Calculate the magnitude and phase angle of the following:

(i) negative-sequence component of the unbalanced line current drawn by the load.

[4]

(ii) zero-sequence component of the line current drawn by the delta-connected load.

[1]

c) A 50 MVA, 11 kV 3-phase synchronous generator is subjected to three different types of faults at its terminal. Each fault is a solid fault with zero fault impedance. The recorded fault currents for each fault type are as follows:

3-phase fault – 2000 A
LG fault on phase A – 4200 A
LL fault between phases B and C – 2600 A

Assuming 1.0 p.u. pre-fault voltage calculate the positive-, negative- and zero-sequence reactances (in p.u. on 50 MVA base) of the synchronous generator for the following generator neutral grounding arrangements:

(i) Generator neutral is grounded through a reactance of 0.05 ohms

[6]

(ii) Generator neutral is solidly grounded

[4]

6.

a) Using the power-angle curve for a round rotor synchronous generator, explain the sequence of events that follows if the mechanical input to the generator is suddenly increased. Label the different positions of mechanical power inputs, rotor angles clearly on the power-angle curve and identify the accelerating and decelerating areas.

[5]

b) The rotor of a 50 MVA, 11 kV, 4-pole, 50 Hz 3-phase synchronous generator has a moment of inertia $J = 10 \times 10^3$ kg-m^2.

(i) Calculate the kinetic energy stored (in MJ) in the generator rotor at rated speed.

[2]

(ii) Determine the inertia constant H (in MJ/MVA) of the generator.

[1]

(iii) If the mechanical input power to the generator is suddenly increased by 25 MW, calculate the acceleration of the rotor (in elect-rad/sec^2) using the swing equation. Neglect any instantaneous change in electrical power output of the generator.

[3]

c) The generator in part (b) of the question is a round-rotor machine which maintains 1.05 p.u. voltage at its terminal while producing 60 MW power output in steady state. The generator is connected to a large power system (infinite bus) through two transmission routes whose equivalent reactance is 0.3 p.u. The voltage of the infinite bus is 0.98 p.u. Neglect the resistance of the generator and the transmission line. Assume a constant the mechanical power input.

(i) Calculate the steady state rotor angle δ_0 (in rads).

[2]

(ii) During a 3-phase short circuit at the sending end of one of the transmission routes the power output of the generator drops to zero. The short circuit is cleared by disconnecting the affected transmission line which increases the equivalent reactance between the generator and the infinite bus to 0.45 p.u. Calculate the maximum allowable rotor angle δ_m (in rads) to preserve stability.

[3]

(iii) Use equal area criterion to determine the critical clearing angle corresponding to the 3-phase short circuit condition described in part (ii).

[4]

 © Imperial College London