IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2014

EEE PART III/IV: MEng, BEng and ACGI

Corrected Copy

ELECTRICAL ENERGY SYSTEMS

Friday, 24 January 10:00 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

Part A – Answer any 2 out of 3 questions in Part A

1. a) Consider a single phase AC circuit shown in Figure 1.1. Expressions for generator voltage and current are given by:

$$v(t) = \sqrt{2}V \sin \omega t$$

$$i(t) = \sqrt{2}I \sin(\omega t - \phi)$$

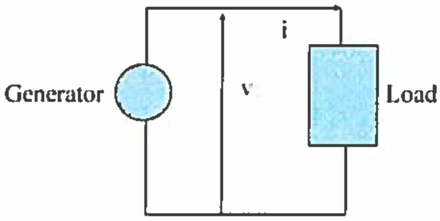

Figure 1.1: Single phase AC circuit

(i) Show that the expression for the instantaneous power can be written in the following form:

$$p(t) = \underbrace{P(1 - \cos 2\omega t)}_{A(t)} - \underbrace{Q \sin 2\omega t}_{R(t)}$$

and write the expressions for P and Q

[4]

(ii) Sketch functions p (t) and its components A(t) and R(t) on the same diagram.

[3]

(iii) Write the expression for A(t) and R(t) for a three phase system (no need for a formal derivation). Explain R(t).

[3]

b) Find the peak load of an 11/0.4 kV substation supplying 370 households not using electricity for heating purposes (Type A), and 80 households with electric heating (Type B). Peak demands of individual households are 10 kW and 20 kW, respectively. Coincidence coefficient for Type A households is $j_{A\infty} = 0.2$, and for Type B $j_{B\infty} = 0.5$. Assume that peaks of both groups of consumers coincide.

[4]

c) Consider a system supplied with three generators with given capacities and availabilities as in Figure 1.2.

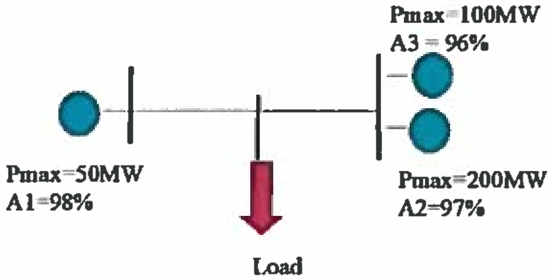

Figure 1.2: A system with 3 generators

The states in which this generation system can find itself are given in Table 1.1.

Table 1.1: System state probabilities

STATE	State Probability	Probability that Generation is equal to or greater than State
350 MW		
300 MW		
250 MW		
200 MW		
150 MW		
100 MW		
50 MW		
0 MW		

(i) Calculate state probabilities for this system and the probability that the generation will be greater than the given state.

[3]

(ii) If the system peak load is 260 MW, find the probability that generation will not be able to meet it.

[3]

2. a) A 33/11kV 15MVA transformer has a leakage reactance of 4Ω as seen from the HV side

(i) Calculate the leakage reactance as seen from the LV side [2]

(ii) Calculate the p.u. impedance at the HV side and show that this is the same as the pu impedance as seen from the LV side [3]

(iii) What is the significance of per-unit system in the analysis of power systems? [2]

b) A turbo-generator feeds into a very strong network that maintains the terminal voltage $V_t = 1$ p.u (Figure 2.1).

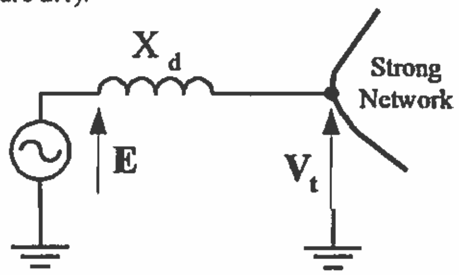

Figure 2.1: A generator connected to a very strong system

The synchronous reactance of the generator is equal to 1 p.u. Initially, the generator runs overexcited with E = 1.5 p.u. with real power output of 0.25 p.u. Calculate:

(i) The power angle and reactive power output for this initial operating condition. [4]

(ii) The active and reactive power delivered to the system when the turbine torque doubles. [3]

(iii) The active and reactive power delivered to the system for an increase in the internal voltage E by 20% (from the initial condition). [3]

(iv) Explain how the active and reactive power outputs of a synchronous generator are controlled. [3]

3. a) List 3 objectives of power flow calculations.

[3]

b) Explain briefly why an iterative method is required to determine nodal voltages in power networks.

[4]

c) Explain briefly why reactive power cannot be transported over long distances across transmission networks.

[4]

d) In Figure 3.1, the reactances of transmission circuits and bus bar loads are given in per unit using a common base

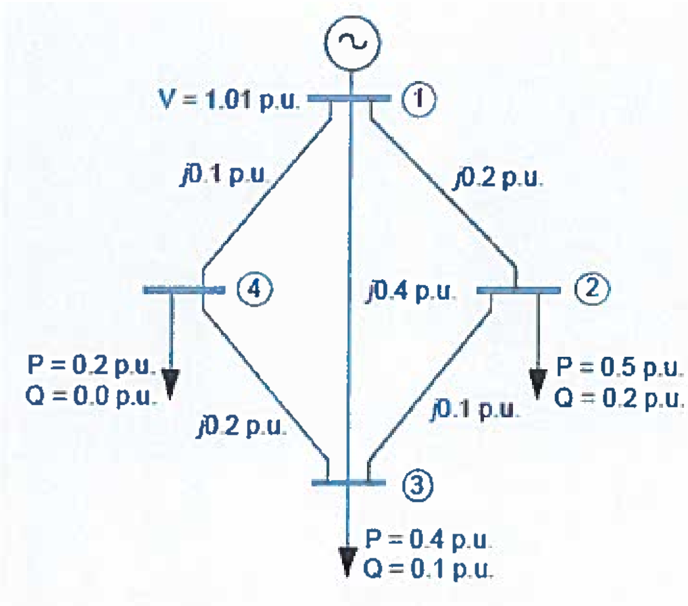

Figure 3.1: Network diagram and data

(i) Form the bus admittance matrix Y_{BUS} for this network.

[4]

(ii) Using bus bar 1 as the slack (reference) bus bar, carry out the first iteration of a Gauss-Seidel load-flow algorithm to determine the voltage at all bus bars. Assume the initial voltages of all bus bars to be 1.01 p.u.

[5]

Part B – Answer any 2 out of 3 questions in part B

4. a) For short-circuit analysis, why is it reasonable to assume 1.0 p.u. pre-fault voltages and zero pre-fault currents?

[5]

b) Explain with the help of constant flux linkage theorem why there is a decaying AC component in the stator current which flows as a result of a three-phase short circuit on the terminal of a synchronous generator.

[5]

c) Four identical generators are connected to two bus bars, A and B as shown in Figure 4.1. The rating of each generator is 13 kV, 60 MVA and their sub-transient and transient reactance is 0.15 pu and 0.3 pu, respectively. A feeder is supplied from bus bar A through a step-up transformer rated at 30 MVA with 10% leakage reactance. Bus bars A and B are connected through a reactor with reactance X. Neglect the pre-fault current and fault impedance and assume the pre-fault voltage to be 1.0 pu. Choose 60 MVA as the system base. Consider fault current contribution from the generators only.

(i) Calculate the value of the reactance X in pu if the three-phase short-circuit level at the feeder side of the transformer (marked by point C in Figure 4.1) is to be limited to 240 MVA

[6]

(ii) Using the value of X from part (i) calculate the voltage at bus bar A during a three-phase fault at the feeder side of the transformer (marked by point C in Figure 4.1)

[4]

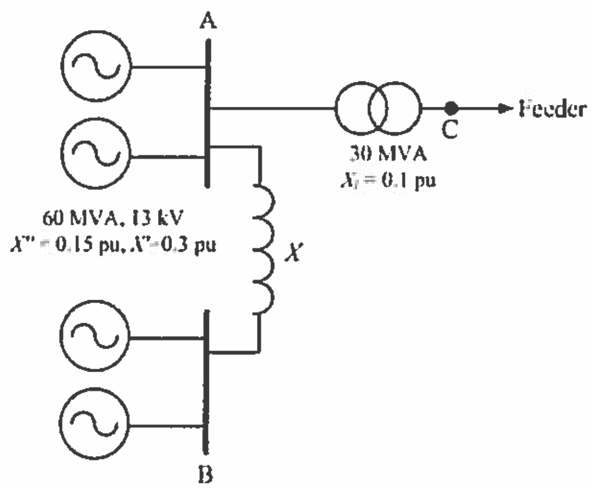

Figure 4.1: Single line diagram for the system in Problem 4(c)

5. a) Starting from the voltages and currents in the phase domain during a fault condition show how the positive, negative and zero sequence networks would be connected for a line-to-line (LL) fault between phases B and C.

[5]

b) A 20 kV, 500 MVA three-phase generator has a star connected stator winding with the neutral point grounded through a 1Ω resistor. The positive, negative and zero sequence sub-transient reactance for the generator are 0.2 pu, 0.16 pu and 0.14 pu, respectively based on the rating of the generator. The generator supplies a delta-star connected 20 kV/275 kV, 550 MVA step-up transformer with its neutral point solidly grounded as shown in Figure 5.1. The leakage reactance of the transformer is 0.15 pu. Neglect the pre-fault current and fault impedance and assume the pre-fault voltage to be 1.0 pu. Choose 60 MVA as the system base. Consider fault current contribution from the generator only and assume zero contribution from the system on the 275 kV side of the transformer.

(i) Calculate the fault current (in kA) due to a three-phase fault on the 275 kV side of the transformer.

[4]

(ii) Calculate the fault current (in kA) due to a line-to-ground (LG) fault on the 275 kV side of the transformer.

[6]

(iii) Compare the fault currents for a three-phase and line-to-ground (LG) fault on the 275 kV side of the transformer if the transformer connection is changed to star-star with the neutral points solidly connected on both sides.

[5]

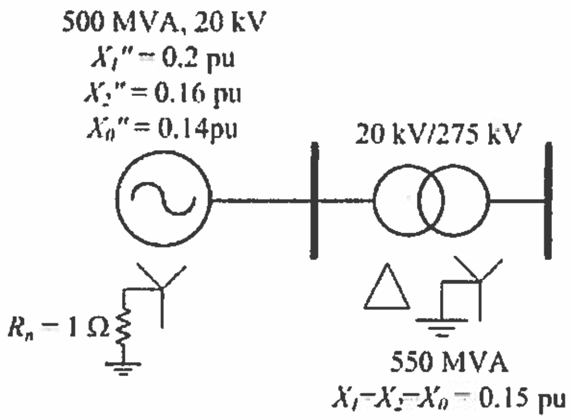

Figure 5.1: Single line diagram for the system in Problem 5(b)

6. a) What is transient stability in the context of power systems?

[2]

b) Mention two main factors that influence the transient stability of power systems along with an example of each of the two factors in the context of a short-circuit in a simple system comprising a single generator connected to an infinite bus bar.

[3]

c) A round-rotor synchronous generator is connected to an infinite bus bar via a generator transformer and two parallel overhead lines. The transformer has a leakage reactance of 0.15 p.u. and each transmission line has a reactance of 0.4 p.u. Under normal operating condition the generator is supplying 0.8 p.u. active power at a terminal voltage of 1.0 p.u. The generator has a transient reactance of 0.2 p.u. All impedance values are based on the generator rating and the voltage of the infinite bus bar is 1 p.u. Calculate the critical clearing angle (in degrees) if a three-phase solid fault occurs on the sending (generator) end of one of the transmission line circuits and is cleared by disconnecting the faulted line. Assume the electrical power output of the generator to be zero during the fault. Neglect resistances.

[8]

d) A round-rotor generator connected to an infinite bus bar through two parallel 132 kV lines in parallel, each having a reactance of 70 Ω/phase. The rating of the generator is 60 MW at power factor 0.9 lagging and has a transient reactance of 0.3 p.u. and an inertia constant 3 kWs/kVA. The generator is delivering 1.0 pu active power to the infinite bus bar. A three-phase symmetrical fault occurs halfway along one line and is cleared by disconnecting the faulted line. The generator internal voltage is 1.05 p.u. and the infinite bus bar voltage is 1.0 p.u. From steady state stability considerations, determine maximum allowable power transfer during the i) pre-fault, and ii) post-fault conditions. Neglect resistances.

[4+3]