IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2016

EEE PART III/IV: MEng, BEng and ACGI

Corrected copy

ELECTRICAL ENERGY SYSTEMS

Thursday, 8 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

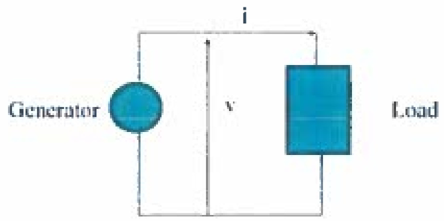
Question 1

a) What are the key objectives for operation and design of electrical energy systems? [3]

b) Explain how synchronous generators control flows in the transmission network and balance demand and supply in real time. [3]

c) Measurement demonstrates that diversified peak demand of 100 households is 400kW, while the peak demand of each individual household is 8kW. Estimate the diversified peak demand of 1000 households. Briefly explain the benefits of diversification. [4]

d) For the network presented in diagram below, derive the expression for the instantaneous active power and demonstrate that the power oscillates with double frequency. Sketch time diagrams of voltage, current and power. [4]



$v(t) = \sqrt{2}V\sin\omega t$ $\qquad$ $p(t) = v(t)\cdot i(t)$

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

Figure 1: Schematic diagram AC circuit composed of generator and load

e) A 3-phase synchronous generator (synchronous reactance X=1 pu and negligible armature resistance) feeds a strong network and maintains its output terminal voltage V=1pu while the supply current is I= 0.7pu at 0.9 power factor.

(i) Quantify the internal generator excitation voltage (E) in terms of magnitude and angle [2]

(ii) Compute the active and reactive output delivered by the generator [2]

(iii) Assuming that the active output of the generator remains constant, while excitation increases by 10%, compute the change in angle δ between internal and terminal voltages. [2]

Question 2

a) The diagram below shows phase voltage and current vectors of a three phase system

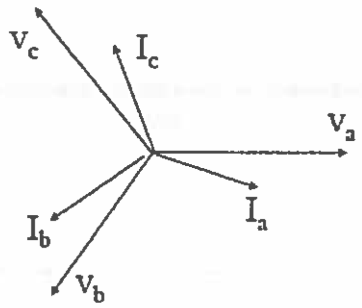


Figure 2: Schematic diagram of phase voltage and current vectors of a three phase system

(i) Write the time expressions for currents and voltages.

[2]

(ii) Demonstrate that the three-phase active power is time-independent.

[4]

(iii) Calculate the three-phase reactive power

[3]

b) Assume that12 tonnes of water need to be lifted on the roof of the Electrical and Electronic Engineering Department, total height 36 meters. Quantify the energy involved in carrying out this task in Joules and kWh, and estimate the cost if an electricity driven elevator is used.

[5]

c) Compute the probability that a system of 4 identical generating units, each of 50MW capacity and failure rate of 5%, will not meet peak demand of 140MW.

[6]

Question 3

A three-bus power network is presented in Figure below. Data relevant for the load flow analysis on this system are given in per unit values.

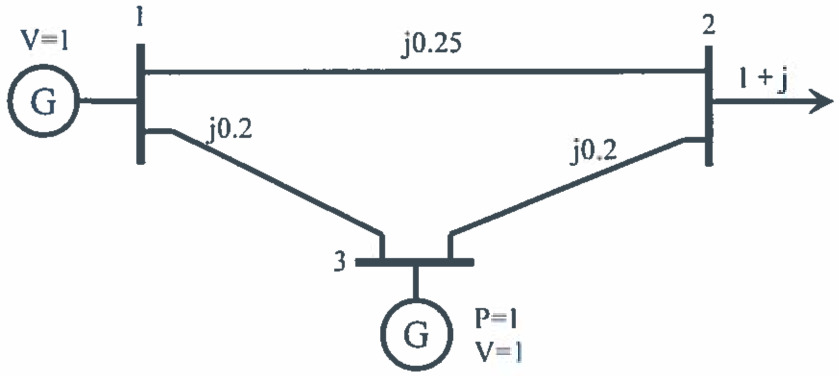


Figure 3. Three bus network showing per unit data for voltages, active and reactive loads and lines reactances

a) Explain the concept of the slack bus in the load flow calculations [2]

b) Form the Ybus matrix and explain why it is singular (i.e. not invertible) [3]

c) Perform 2 iterations of the Gauss-Seidel load flow method [9]

d) Using the results from c), calculate the power mismatch at the PQ bus [6]

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

Question 4

a) Explain how the system strength at a given busbar is related to the short circuit level there.

[4]

b) Explain how the short circuit level would be affected due to the following developments:

(i) An AC interconnection is set up between two different power systems.

[2]

(ii) Some of the conventional thermal power plants are replaced by non-synchronous generation such as wind power.

[2]

c) For a closed electric circuit with finite resistances, flux linkages due to any reason and sources of electromotive force but no series capacitance, state and prove the theorem of constant flux linkage.

[4]

d) Four 11 kV, 50 MVA three-phase generators designated as A, B, C, and D are connected as shown in Figure 4.1. The sub-transient reactance of each generator is 0.1 p.u. The generators are connected by means of three 100 MVA reactors which join A to B, B to C, and C to D as shown in Figure 4.1. The reactance of these reactors is 0.2 p.u., 0.4 p.u., and 0.2 p.u., respectively. Using a 50 MVA base calculate the following for a three-phase symmetrical fault on the terminals of generator B:

(i) Short circuit level (MVA).

[5]

(ii) Fault current (in kA).

[3]

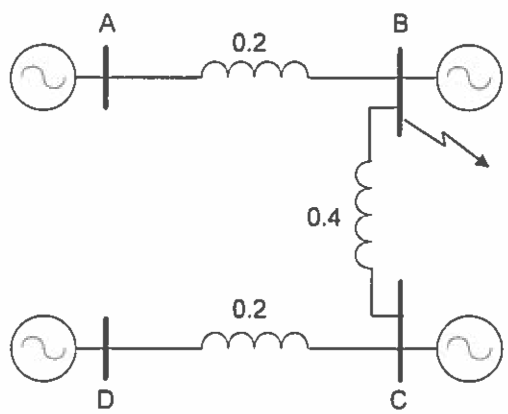


Figure 4.1: Single-line diagram of the generator arrangement for Question 4(d)

Question 5

a) For an unbalanced three-phase star connected load with a neutral connection, derive the following using the symmetrical component transformation:

(i) the neutral current has only got the zero sequence component.

[3]

(ii) there is no zero sequence component in the line voltages.

[2]

b) Explain with physical reasons (not mathematically) why a line to ground fault at the generator terminal is more severe than a three-phase fault while the opposite is true for such faults on the transmission line far from the generator.

[4]

c) An industrial customer is supplied from a three-phase 132kV system with a short circuit level of 4000 MVA at the supply point. Three 15 MVA transformers, connected in parallel, are used to step down the 132 kV supply to an 11 kV busbar from which six 5 MVA, 11 kV motors are fed. The transformers are delta-star connected with the star point of each 11 kV winding, solidly earthed. Each transformer has a reactance of 0.1 p.u. (based on their own rating). The fault contribution of each motor is equal to five times their rated current with 1.0 p.u. terminal voltage. Using a base of 100 MVA, calculate the following:

(i) the fault current (in kA) for a line-to-ground (LG) fault on the 11 kV busbar when no motors are connected

[6]

(ii) three-phase short circuit level (in MVA) at the 11 kV busbar if all the motors are operating and the voltage at the 11 kV busbar is 1.0 p.u.

[5]

Question 6

a) Describe with a diagram how the transmission capacity (or loadability) of uncompensated AC overhead transmission lines is limited by various considerations depending on the transmission distance.

[4]

b) Using the sinusoidal power-angle characteristics and the swing equation, derive an expression for the natural frequency of oscillation of a round-rotor synchronous generator in terms of the synchronising coefficient and inertia constant.

[5]

c) A 500 MVA, 50 Hz round-rotor synchronous generator has synchronous reactance of 0.2 p.u. and inertia constant of 4 MW-s/MVA. The generator is connected to a large power system through a transformer and overhead line which have a combined reactance of 0.3 p.u. on a base of 500 MVA. The magnitude of the voltage at both the generator terminals and at the connection point with the large power system is 1.0 p.u. The generator delivers 450 MW to the power system. Neglecting resistances, calculate the following:

(i) the internal voltage of the generator behind the synchronous reactance.

[3]

(ii) the natural frequency of oscillation (Hz) of the generator under the above condition.

[4]

(iii) the critical clearing angle for a three-phase fault at the generator terminals. Use equal area criterion and assume the generator power output to be zero during the fault.

[4]