E3.13

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2008

EEE PART III/IV: MEng, BEng and ACGI

Corrected Copy

ELECTRICAL ENERGY SYSTEMS

Thursday, 15 May 10:00 am

Time allowed: 3:00 hours

There are SIX questions on this paper.

Answer Question ONE and THREE other questions.

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
Second Marker(s) : B. Chaudhuri

Special instructions for invigilators

This section may be omitted.

Special instructions for students

If both sections here are omitted (the normal case) the whole page may be deleted.

@12 pm

the following base values:
power base : 150MVA
Voltage base : 11.5kV (for the 11kV side)
132kV (for the 132kV side)

Questions

Question 1: Compulsory question

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

(i) Calculate the actual impedances as seen at the HV and LV side of the transformer. [2]

(ii) What would be the value of the per unit impedance of the transformer, for ~~a power base of 150 MVA, base value of voltage at 11 kV voltage level of 11.5 kV (while base value of voltage at 132 kV voltage level is 132 kV).~~ [2]

(b) For a transmission circuit given in Figure 1.1 and the corresponding phasor diagram below, show:

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

(ii) Write an expression for active and reactive power losses in the transmission circuit and then determine the active and reactive power generated by the source. [2]

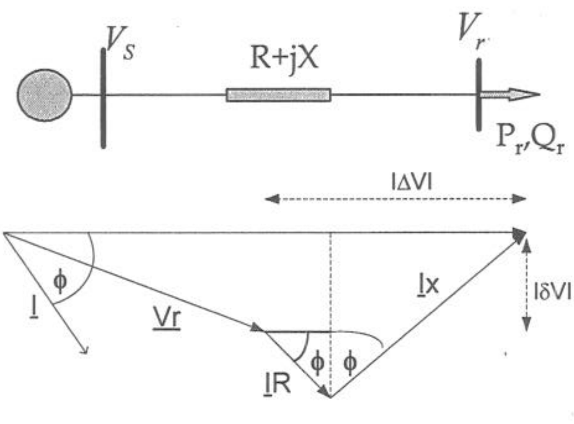


Figure 1.1 Transmission circuit and the corresponding phasor diagram with voltage and power specified at the receiving end

(c) Consider a high voltage transmission circuit with negligible resistance, shown in Figure 1.1. Assume that voltages (magnitudes and phase angles) are known at both sending and receiving ends.

(i) Write down the expressions for sending end active and reactive powers as functions of voltage magnitudes and phase angles. [2]

(ii) Based on these expressions, show that active power flow requires a difference in phase angle and that reactive power flow requires a difference in voltage magnitude. [2]

(iii) What is the maximum amount of active power that can be transported via this transmission line? [1]

(d)

(i) Any set of three-phase voltages can be decomposed into the sum of three components: a positive sequence component (set of three voltages of equal magnitude, separated by 120°

in the positive phase sequence), a negative sequence component (set of three voltages of equal magnitude, separated by 120° in the negative phase sequence) and a zero sequence component (set of three voltages of equal magnitude and phase).

Show that the positive and negative sequence components of a set of identical phasors are equal to zero. [2]

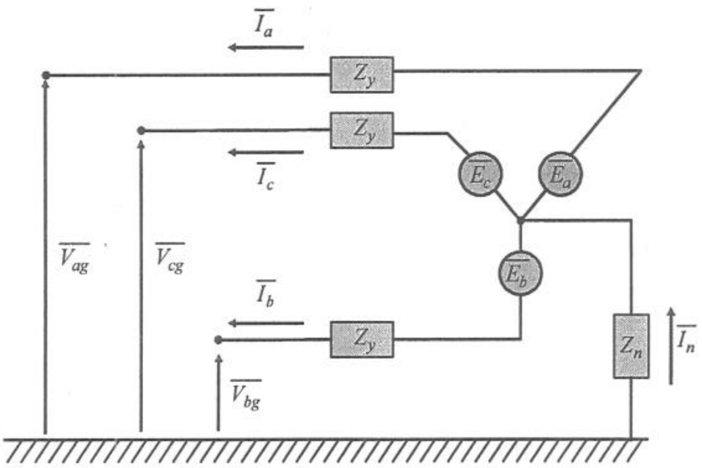


Figure 1.2. Generic unbalanced circuit

(ii) For the unbalanced circuit shown in Figure 1.2, show that positive and negative sequence currents do not flow in the neutral circuit and if there is no neutral connection, there will be no zero sequence current. [2]

(iii) For a circuit in Figure 1.3 (100 MVA base) and data presented in Table 1.1, sketch positive, negative and zero sequence circuits and place appropriate sequence impedances in these circuits. [3]

Table 1.1

	Positive	Negative	Zero
Generator	0.5	0.666	0.8
Transformer	0.3	0.3	0.3
Line	0.115	0.115	0.172

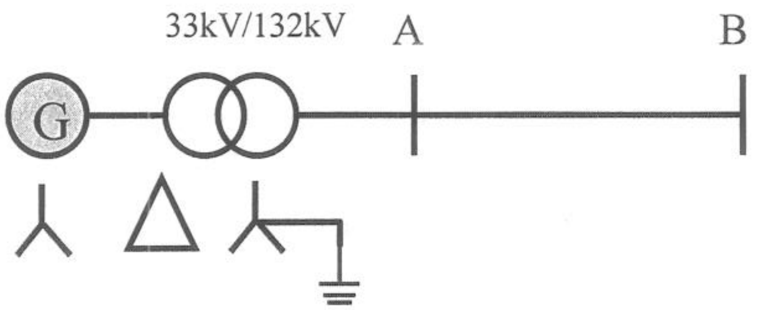


Figure 1.3. A simple power system composed of a generator, transformer and transmission line

Question 2

(a) Consider a system supplied with three generators with given capacities and availabilities as in Figure 2.1.

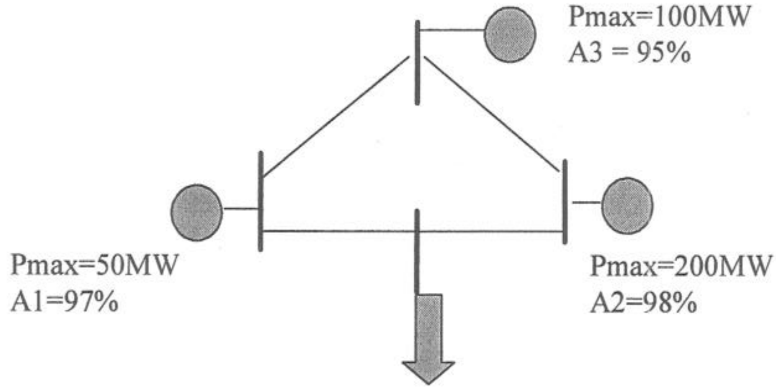


Figure 2.1. A simple power system

The states in which this generation system can find itself are given in Table 2.1.

Table 2.1. 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. [5]

(ii) If the system peak load is 260 MW, find the probability that generation will not be able to meet it. [2]

(b) What would be the energy cost of lifting 25 tonnes of water onto the roof of the Electrical and Electronic Engineering Department that is 36 meters high, assuming that electricity price is about 8p/kWh? [3]

(c) Consider a turbo-generating unit rated at 635 MVA, 24 kV, 0.9 power factor, X_d = 172.41%.

What is the maximum reactive power that this generator can absorb? [3]

What is the active power export in this case? [2]

(d) Find the peak load of an 11/0.4 kV substation supplying 400 households not using electricity for heating purposes (Type A), and 100 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. [5]

Question 3

a) Explain briefly why it is more difficult to transport reactive power than active power over high-voltage AC transmission systems. [3]

b) A three bus power network is presented in Figure 3.1. Data relevant for the load flow analysis on this system are given in per unit.

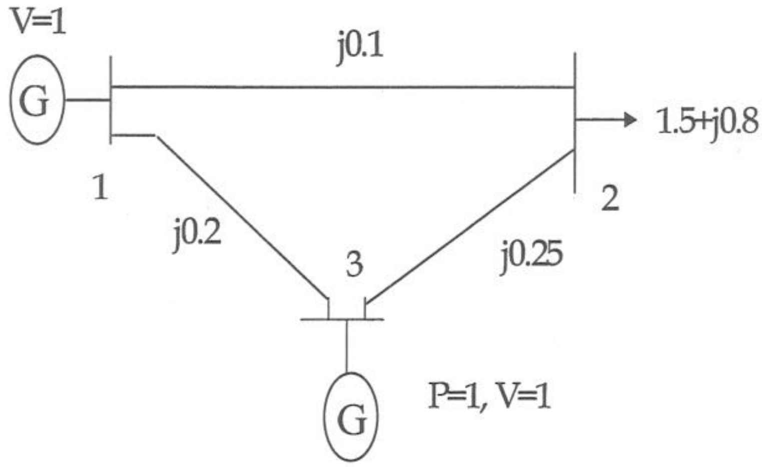


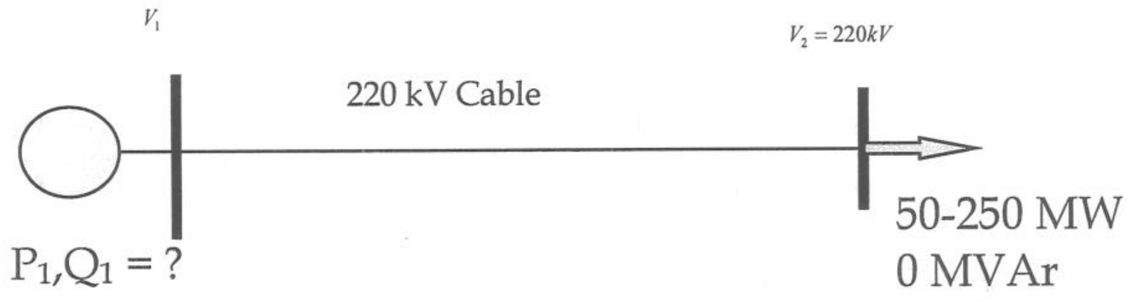
Figure 3.1 Three bus network showing per unit data for voltages, active and reactive load, and lines reactance

(i) Form the Y_{bus} matrix for this system. [3]

(ii) Perform two iterations of the Gauss-Seidel load flow. [14]

Question 4

A generator is supplying a load over a 220 kV cable circuit, with parameters given in Table below. Load varies between minimum value of 50 MW and maximum value of 250 MW.



Length of line 1-2	Series resistance r′ [Ω/km]	Series reactance x′ [Ω/km]	Shunt susceptance b′ [μS/km]
100km	0.1	0.1	30

Assuming that the voltage at the load end is kept at its nominal value of 220 kV, calculate for minimum and maximum loading condition:

(a) Voltage at the sending end, [8]

(b) Active and reactive power generated, [8]

(c) Why is the reactive power absorbed by the generator larger in low demand conditions. [4]

Question 5

A three-phase synchronous generator with negligible armature resistance has synchronous reactance $X_d = 1.7241$ p.u. and is connected to a very large system. The terminal voltage is 1.0 p.u. and the generator is supplying to the system a current of 0.8 p.u. at 0.90 power-factor (reactive power is supplied to the system).

Find:

(a) The magnitude and angle of the internal voltage E_i; [4]

(b) P and Q delivered to the system; [4]

(c) The angle between E_i and terminal voltage, and the Q delivered to the system, if the real power output of the generator remains constant, but excitation of the generator is:

(i) increased by 20%, and [4]

(ii) decreased by 20%; [4]

(d) Sketch the capability chart and place these values on the chart. [4]

Question 6

(a) Why is the method of symmetrical component analysis so useful in fault analysis? [4]

(b) A Y-connected unbalanced load draws currents in abc sequence as $I_a = 10\underline{/10°}$, $I_b = 10\underline{/100°}$, $I_c = 20\underline{/150°}$. Evaluate the positive, negative and zero sequence component of these currents. [7]

(c) Consider the one-line diagram of a simple power system shown in Figure 6.1. System data in per-unit (p.u.) on appropriate MVA base are given as follows:

Synchronous generators:

G1:	500 MVA	16 kV	$X_1 = X_2 = 0.15$	$X_0 = 0.05$
G2:	500 MVA	16 kV	$X_1 = X_2 = 0.15$	$X_0 = 0.05$

Transformers:

T1:	500 MVA	16/400 kV	$X_1 = X_2 = X_0 = 0.08$
T2:	500 MVA	16/400 kV	$X_1 = X_2 = X_0 = 0.08$

Transmission lines:

TL12:	100 MVA	400 kV	$X_1 = X_2 = 0.05$ $X_0 = 0.15$
TL13:	100 MVA	400 kV	$X_1 = X_2 = 0.025$ $X_0 = 0.075$
TL23:	100 MVA	400 kV	$X_1 = X_2 = 0.025$ $X_0 = 0.075$

The neutral of each generator is grounded through a current limiting reactor of 0.03 p.u. on 100 MVA base. All transformer neutrals are solidly grounded. The generators are operating at no-load with a voltage of 1.05 p.u. Draw the positive, negative and zero sequence networks after expressing all the parameters in 100 MVA base. [9]

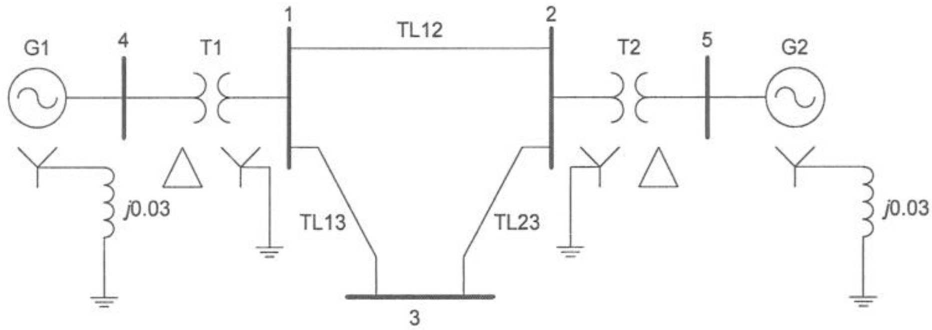


Figure 6.1. A simple power system