EE4-51
EE9-FPN2-11

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2017

EEE PART IV: MEng and ACGI

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POWER SYSTEM ECONOMICS

Tuesday, 9 May 10:00 am

Time allowed: 3:00 hours

There are FOUR questions on this paper.

Answer ALL 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.C. Pal

Question 1

(a) Describe the significance of the concept of system marginal price and explain why it varies with time in the case of electricity.

[4]

(b) Four generators are available to supply a demand of $D = 472.5\ [MW]$. The cost of generating power $C_i(P_i)$ corresponding to each of the generators i is:

$$C_1(P_1) = 500 + 3 * P_1 + 0.06 * P_1^2\ [\frac{£}{h}]$$

$$C_2(P_2) = 300 + 17 * P_2 + 0.10 * P_2^2\ [\frac{£}{h}]$$

$$C_3(P_3) = 1300 + 12 * P_3 + 0.15 * P_3^2\ [\frac{£}{h}]$$

$$C_4(P_4) = 150 + 15 * P_4 + 0.22 * P_4^2\ [\frac{£}{h}]$$

Calculate the optimal production of each generator, the system marginal cost, the system average cost, and the profits of each generator.

[6]

(c) Assume that the maximum output limit of each generator is:

$$P_1^{max} = 230\ [MW]$$

$$P_2^{max} = 120\ [MW]$$

$$P_3^{max} = 160\ [MW]$$

$$P_4^{max} = 80\ [MW]$$

Determine the optimal production of each generator, the system marginal cost, the system average cost and the profits of each generator. Based on the results, briefly explain the impact of considering these maximum output limits on the total cost of operating the system and the profits of the four generators.

[6]

(d) In the solution of **(b)** and **(c)**, the profit of one of the generators is negative. Explain why this happens, what this means for this generator, as well as why and how it should be avoided in practice.

[4]

Question 2

(a) Consider a market for electrical energy that is supplied by two generating companies with the two corresponding cost functions:

$$C_A = P_A^2 \ [\frac{£}{h}]$$

$$C_B = P_B^2 + 15 * P_B \ [\frac{£}{h}]$$

The inverse demand curve for this market is estimated to be:

$$\pi = 60 - D \ [\frac{£}{MWh}]$$

Assuming perfect competition, calculate the electricity price, level of demand, production levels and the profits made by the generating companies.

[6]

(b) Assuming a Cournot model of competition:

(i) Write the optimality conditions for the evaluation of the exact equilibrium point of this market

[5]

(ii) Calculate the equilibrium price, level of demand, production levels and profit of each generating company.

[5]

(iii) Based on the results, briefly explain the impacts of imperfect competition on the market outcome.

[4]

Question 3

(a) Consider a two area system, with demand in Area A $D_A = 1500\ [MW]$ while demand in Area B is $D_B = 400[MW]$. Generator A is in Area A and generator B is located in Area B, with their respective cost functions given by:

$$C_A(P_A) = 1000 + 10 * P_A + 0.01 * P_A^2\ [\frac{£}{h}]$$

$$C_B(P_B) = 500 + 5 * P_B + 0.005 * P_B^2\ [\frac{£}{h}]$$

Determine the optimal generation dispatch, locational marginal prices, total cost of operating the system, cost of constraints and congestion surplus for:

i) The case where the capacity of the transmission link between the two areas is not binding

ii) The case where no transmission link exists between the two areas

[7]

(b) If the annuitized cost of building the transmission line is given by $C_{inv} = k * L * F$, where F is the capacity of the line, $L = 750km$ (length of the line) and $k = 120\ [£/(MW.km.year)]$, calculate:

i) The transmission demand function

ii) The transmission supply function

iii) The congestion surplus as a function of F

[7]

(c) Determine the optimal capacity that should be built if i) the transmission is a regulated activity and ii) the transmission is operated as a merchant company

[6]

Question 4

(a) For the system shown in Figure Q4, and the data given in Tables Q4-1 and Q4-2, calculate the unconstrained economic dispatch as well as the resulting nodal prices and power flows in each line.

[6]

(b) Demonstrate that line 1-3 is overloaded if the capacity limits of the lines are considered and the dispatch calculated in (a) is implemented. Show how this overload can be eliminated by:

i) increasing the output of generator A.

ii) increasing the output of generator B.

Calculate the hourly cost of options i) and ii) above. Which of the two options is preferable and why?

[7]

(c) Calculate the nodal prices when the more preferable of the two options compared in (b) is implemented.

[7]

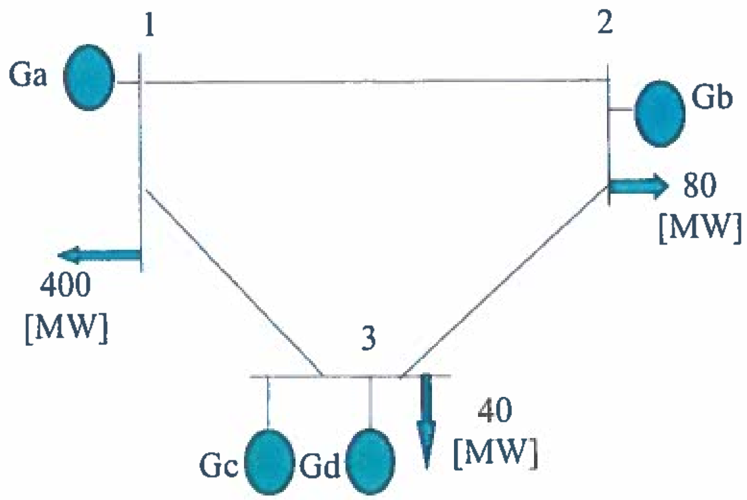

Figure Q4: System layout

Table Q4-1 Generator data

Generator	Capacity (MW)	Marginal cost (£/MWh)
Ga	200	15
Gb	150	12
Gc	150	10
Gd	400	8

Table Q4-2 Line data

Line	Per unit reactance	Capacity (MW)
1-2	0.2	250
1-3	0.3	250
2-3	0.3	250