IMPERIAL COLLEGE LONDON

EE4-51
EE9-FPN2-11

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2018

EEE PART IV: MEng and ACGI

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POWER SYSTEM ECONOMICS

Tuesday, 15 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 differences between electricity and other market commodities.

[4]

(b) Three generators are available to supply a two-hour demand of $D_1 = 300\ [MW]$ and $D_2 = 1000\ [MW]$. The cost of generating power $C_{i,t}(P_{i,t})$ corresponding to each of the generators i in hour t is:

$$C_{1,t}(P_{1,t}) = 600 + 1 * P_{1,t} + 0.045 * P_{1,t}^2\ [\frac{£}{h}]$$

$$C_{2,t}(P_{2,t}) = 150 + 5 * P_{2,t} + 0.15 * P_{2,t}^2\ [\frac{£}{h}]$$

$$C_{3,t}(P_{3,t}) = 300 + 16 * P_{3,t} + 0.5 * P_{3,t}^2\ [\frac{£}{h}]$$

Calculate:
- the optimal production of each generator at each hour,
- the system marginal cost at each hour,
- the total cost of operating the system, and
- the total profit for each of the generators.

Which hour is characterised by the highest system marginal cost and why?

[6]

(c) Modify the dispatch found in **(b)** that respects the constraints on the minimum and maximum outputs of each of the generators:

$P_1^{min} = 50\ [MW]$ and $P_1^{max} = 850\ [MW]$
$P_2^{min} = 20\ [MW]$ and $P_2^{max} = 160\ [MW]$
$P_3^{min} = 50\ [MW]$ and $P_3^{max} = 120\ [MW]$

Calculate:
- the optimal production of each generator at each hour,
- the system marginal cost at each hour,
- the total cost of operating the system, and
- the total profit for each of the generators.

[8]

(d) The total profit of generator 3 in **(c)** is negative. Explain why this is the case. If the generators are free to participate in the market based on their profitability, discuss how that generator can avoid the economic losses.

[2]

Question 2

(a) How can generation companies exercise market power in electricity markets? What factors favour the exercise of market power in electricity markets?

[6]

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

$$C_A(P_A) = 25 \cdot P_A + 0.40 \cdot P_A^2 \ [\frac{£}{h}]$$

$$C_B(P_B) = 27 \cdot P_B + 0.30 \cdot P_B^2 \ [\frac{£}{h}]$$

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

$$\pi = 210 - 1.3 \cdot D \ [\frac{£}{MWh}]$$

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

[4]

(c) Assuming a Cournot model of competition:

(i) Form a table to calculate the Nash equilibrium point of this market, i.e. market price, demand quantity and profit of each company for different levels of productions for each of the companies. Consider range of productions of company A at 37MW, 39MW and 41MW and of company B at 37MW, 39MW and 41MW.

[8]

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

[2]

Question 3

(a) Answer the following questions with brief statements:

- What are the benefits of having a transmission system?
- What are the main characteristics of the transmission as a business?
- Explain why transmission business is regulated.

[4]

(b) Consider two-area system, with demand in Area 1 of $D_1 = 1950\ [MW]$ and demand in Area 2 of $D_2 = 450\ [MW]$. Generator 1 is located in Area 1 and generator 2 is located in Area 2, with their respective cost functions given by:

$$C_1(P_1) = 158 + 19.17 \cdot P_1 + 0.033 \cdot P_1^2\ [\frac{£}{h}]$$

$$C_2(P_2) = 201 + 16.43 \cdot P_2 + 0.021 \cdot P_2^2\ [\frac{£}{h}]$$

Given that the existing capacity of the transmission line connecting the two Areas is $F^{max} = 800\ [MW]$, calculate the constraint costs and locational marginal prices for this system.

[4]

(c) The regulators are considering reinforcing the transmission link. Write the expression for network constraint costs as a function of transmission capacity added (ΔF).

[4]

(d) The annuitized cost of reinforcing the transmission line is given by $C_{inv} = k \cdot L \cdot \Delta F$ where $k = 205.67\ [£/(MW \cdot km \cdot year)]$ (the annuitized cost of reinforcing 1 km of the transmission line for 1 MW), $L = 460km$ and ΔF [MW] represents the network capacity added. Plot the cost of network constraints, the cost of network investment and the total system cost as a function of network capacity added (ΔF). Calculate the optimal capacity of the line that should be added between the two areas

[5]

(e) What would be the revenue and profit of investing and operating this transmission link on a merchant basis?

[3]

Question 4

For the system shown in Figure 1, and the accompanied data given in Tables 1, 2 and 3, answer the following questions:

a) Ignoring the impact of transmission constraints, calculate the minimum cost dispatch of the generators, the corresponding network flows and show that branch 1-2 would be overloaded.

[5]

b) Change the dispatch by increasing generation at 3 to eliminate this overload and calculate the marginal price at 2.

[5]

c) In order to manage the exposure to price fluctuations Load at 2 has (i) made a contract for difference with generation at 1 at a strike price of 26.5£/MWh and (ii) purchased a transmission congestion contract that gives the right to transport 90MW from bus 1 to bus 2. Calculate the income from the transmission congestion contract received by the Load at 2 and calculate the unit price that demand will pay for the energy consumed under this condition.

[5]

d) Because of the maintenance on one of the lines of the transmission circuit between nodes 2 and 3, the flow through this circuit has to be restricted to 67MW. Calculate the new price at node 2. How much the demand at bus 2 will now pay for the electricity consumed, given the new conditions and its contract portfolio?

[5]

Figure 1: The system layout

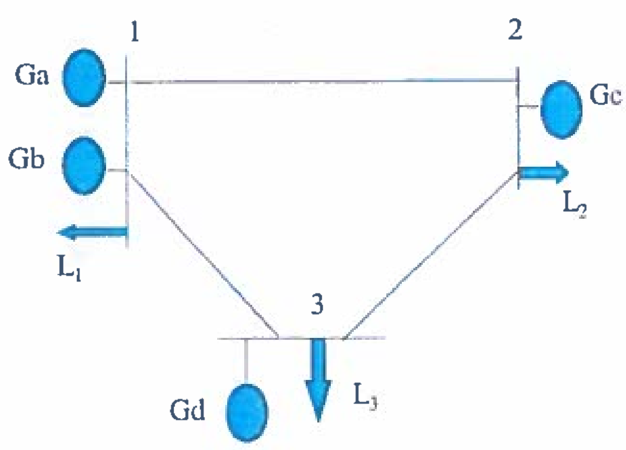

Table 1 Load data

Node	Load (MW)
1	80
2	90
3	330

Table 2 Generator data

Generator	Capacity (MW)	Marginal cost (£/MWh)
Ga	170	19
Gb	345	15
Gc	110	35
Gd	105	25

Table 3 Line data

Line	Per unit reactance	Capacity (MW)
1-2	0.3	160
1-3	0.3	260
2-3	0.2	110