EE4-51
EE9-FPN2-11

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2016

EEE PART IV: MEng and ACGI

Corrected copy

POWER SYSTEM ECONOMICS

Monday, 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

Power System Economics 2016

Question 1:

(i) List and discuss key objectives of unbundling and liberalisation of electricity markets.

[3.5]

(ii) Explain the notion of supply curve, demand curve, market clearing price and social welfare.

[3.5]

(iii) Explain why electricity prices may vary with location. What is constraint cost and congestion surplus?

[3.5]

(iv) Demand function of a transmission interconnector is given in the form of: $\pi_T = 7.2 - 0.015F$ (π_T is expressed in £/MWh and F is the capacity of the line in MW). Determine the capacity that would maximise the revenue to the transmission operator.

[3]

(v) If the annuitised investment cost of building the interconnector in (v) can be expressed as a linear function of its capacity: $C = 13{,}140F$ [£], estimate the capacity that should be built to maximise the benefit for the entire system.

changed to (iv) prior to exam.

[3]

(vi) Define Financial Transmission Rights and explain how these are used.

[3.5]

Question 2

The electricity demand curve for a particular price-sensitive customer is given by the following expression: $\pi = -0.02Q + 6$, where Q is the quantity in kWh bought by the consumer in a given period, and π is the electricity price in p/kWh. The electricity producer's generation cost in the same period is given by $C = 0.015Q^2 + 0.8Q$ [p/h].

(i) Determine the expression for marginal production cost, and sketch the demand and supply functions. Then find the equilibrium price and demand at which the social welfare is maximised.

[4]

(ii) For the situation in (i) determine the total production cost, average production cost, supplier's revenue and supplier's profit. Calculate the demand charges, gross demand benefit and consumer's surplus.

[4]

(iii) If the price level is for some reason artificially fixed at $\pi = 4.5$ p/kWh, calculate the level of consumption, consumer surplus, demand charges and revenue received by suppliers. What would be the percentage change in quantity bought if the price increased by 1%?

[3]

(iv) For the price level in (iii), calculate the producer's surplus, and the overall social welfare.

[2]

(v) If the government administratively decides to reduce the price to 3.6 p/kWh, determine the change in producer's generation output and the new revenue received by the producer. Find the producer's and consumer's surpluses. What is the social welfare?

[4]

(vi) Calculate the social welfare at the equilibrium point (i), and welfare losses for cases (iii) and (v). Discuss the differences between the social welfare in the two cases and the welfare at the equilibrium point.

[3]

Question 3

Consider the three-bus power system shown in Figure Q5. Demands at buses 2 and 3 and line reactance values are indicated in the figure.

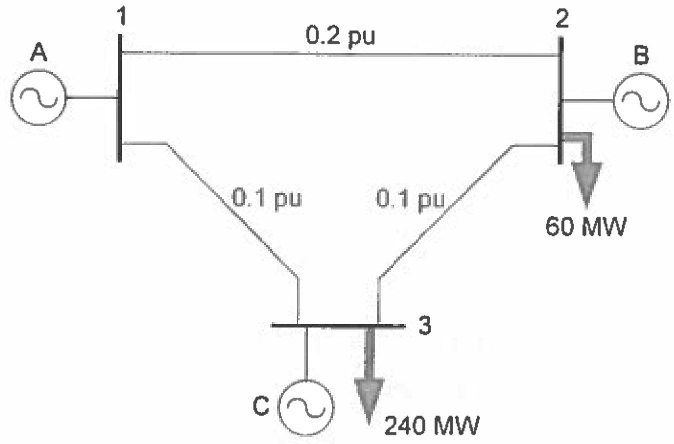

Figure Q3. A simple three-bus system

Assume that generating units A, B and C have the following marginal production costs:

$$MC_A = 12 + 0.1P_A \text{ [£/MWh]}$$
$$MC_B = 18 + 0.2P_B \text{ [£/MWh]}$$
$$MC_C = 45 \text{ [£/MWh]}$$

a. Calculate the optimal unconstrained dispatch for these conditions, and the nodal prices. What is the hourly cost of this dispatch?

[3]

b. Calculate the power flows in each line of the network if this dispatch was implemented.

[4]

c. Assume that the flow in line 1-3 is limited to 160 MW for security reasons. How should the generators be re-dispatched in order to supply the demand at minimum cost without violating line 1-3 flow limit?

[5]

d. Calculate the hourly cost of this constrained dispatch and the hourly cost of security.

[3]

e. Calculate the marginal cost of energy at each node after the constraint on the flow on line 1-3 is taken into consideration. What is the total congestion surplus?

[5]

Question 4

a. Consider two regions, A and B, of a small power system that are not connected. Marginal cost of generation in areas A and B can be modelled by the following expressions:

$MC_A = 10 + 0.02P_A$ [£/MWh]
$MC_B = 11 + 0.04P_B$ [£/MWh]

The load in regions A and B varies depending on the season, as specified in the following table.

	Winter	*Summer*
Demand A (MW)	100	70
Demand B (MW)	400	250
Duration (hours)	2500	6260

For both winter and summer, calculate the marginal costs in both regions and the corresponding generator outputs, hourly generator revenues and demand charges. What are the seasonal marginal values of transmission?

[4]

b. If the capacity of the transmission link between the regions is never binding (exceeds the need), calculate the optimal generator dispatch, marginal costs in regions A and B, and generator revenues in both seasons. What is the marginal value of transmission?

[4]

c. A well-paid consultant has proposed two schemes to be considered for construction of the 300 km long transmission line connecting regions A and B: (i) 80 MW and (ii) 160 MW link. The annuitised investment cost of transmission (including the allowable profit) is 37 £/MW.km.year. For each of the schemes calculate:

- Marginal prices in regions A and B for both seasons;
- Hourly generator payments, demand charges and congestion surpluses in both seasons;
- Annual network revenues (assuming that the transmission company charges for the use of link on the basis of short-run marginal cost) and the transmission company's annual profit.

[7]

d. Explain which of the two schemes would be preferable from the viewpoint of:

(i) A regulated transmission company that maximises the benefit of transmission for the entire country;

(ii) A merchant transmission company that makes profit from buying electricity in region A and selling it in region B.

[5]