KTH Electrical Engineering

Supplementary test in 2C1118 System Planning, 26 June 2007, 18:00–20:00, the seminar room

Instructions

Write your answers on the enclosed answer sheet. Motivations and calculations do not have to be presented.

The maximal score of the test is 40 points. You are guaranteed to pass if you get at least 35 points.

Allowed aids

In this test you are allowed to use the following aids:

- Calculator without information relevant to the course.
- One **handwritten**, **single-sided** A4-page with **your own** notes (original, not a copy), which should be handed in together with the answer sheet.

Problem 1 (4 p)

Answer the following theoretical questions by choosing *one* alternative, which you find correct.

a) (2 p) In a modern, restructured ("deregulated") electricity market, the system operator is responsible for the short-term balance between generation and consumption. This means that I) The system operator has to ensure that the frequency is kept within given limits, II) If the system operator does not ensure that the system in every moment is supplied as much power as is consumed, then the system operator will have to pay a penalty fee to the balance responsible players, III) If the system operator does not ensure that the system in every trading period (for example an hour) is supplied as much energy as is consumed, then the system operator will have to pay a penalty fee to the balance responsible players.

1. None of the statements is true.
2. Only I is true.
3. Only II is true.
4. Only III is true.
5. I and II are true but not III.

b) (1 p) What does a take-and-pay contract mean?

1. The customer buys the same amount of energy in each trading period as long as the contract is valid.
2. During the time the contract is valid, the customer is allowed to consume as much energy they want each trading period, provided that the maximal power is not exceeded.
3. The customer buys energy at the power exchange. If the price of the power exchange exceeds a specified maximal price, the customer is receives a compensation corresponding to the difference between the power exchange price and the contracted maximal price.

c) (1 p) What does a down-regulation bid mean?

1. A power company is selling electricity to a customer and the customer must in advance notify the power company about how much the customer will consume during each trading period.
2. A player offers to increase the generation (alternatively decrease the consumption) at the request of the system operator.
3. A player offers to decrease the generation (alternatively increase the consumption) at the request of the system operator.

Problem 2 (6 p)

The electricity market in Land has perfect competition, all players have perfect information and there are neither capacity, transmission nor reservoir limitations in the system. Data for the electricity producers of Land are given in table 1. The variable costs of the coal condensing are assumed to be linear in the given interval, i.e., the production is zero if the price is on the lower price level and the production is maximal at the higher price level.

Table 1 Data for the electricity producers in Land.

Power source	Production capability [TWh/year]	Variable costs [¤/MWh]
Hydro	75	10
Nuclear	75	100
Coal condensing	50	300–500

a) (2 p) Assume that the consumers in the electricity market of Land are not price sensitive. What will the electricity price be if the consumption is 175 TWh/year?

b) (2 p) Assume that the electricity price in Land is 380 ¤/MWh. The power company Strålinge owns a nuclear power plant with a production capability of 10 TWh per year. The fixed costs of the power plant are 2 000 M¤/year. How large is the profit of the company?

c) (2 p) Assume that the consumers in the electricity market will consume 175 TWh/year if the electricity price is 300 ¤/MWh or lower, and that the consumption will decrease by 0.25 TWh/year for each ¤/MWh the price exceeds 300 ¤/MWh. Which electricity price will there be in Land?

Problem 3 (6 p)

Riksnät is the system operator of Rike. As Riksnät does not have any power plants on their own, they have purchased gain from different players in the electricity market, as shown in table 2. It can be assumed that if a power plant is supplying gain down to a certain frequency, then the power plant will not be able to increase its generation if the frequency continues to drop; hence, the power plant will not contribute any more to the gain of the system if the frequency is less than the frequency stated in table 2.

Table 2 Primary control in Rike.

Category	Number of units	Gain in each unit [MW/Hz]	Lowest frequency where the gain is available [Hz]
I	20	100	49.9
II	10	50	49.9
III	50	50	49.5

a) (2 p) How large is the total reserve to increase the generation in the power plants belonging to categories I and II when the frequency is 49.92 Hz?

b) (1 p) How large is the total gain of the system when the frequency is 49.75 Hz?

c) (3 p) At a certain occasion the frequency of the system is stable at 49.92 Hz, when a nuclear power plant must be stopped immediately. The nuclear power plant produced 1 050 MW before the stop. What will the frequency be once it has been stabilised after the stop?

Problem 4 (12 p)

Stads energi AB owns a thermal power plant with three blocks. Moreover, the company owns a wind farm. Assume that the company has formulated their short-term planning problem as a MILP problem and that the following symbols have been introduced:

Indices for the power plants: Block I - 1, Block II - 2, Block III - 3.

C_g^+ = start-up cost in power plant g, g = 1, 2, 3,
D_t = contracted load during hour t, t = 1, …, 24,
$G_{g,t}$ = generation in power plant g, hour t, g = 1, 2, 3, t = 1, …, 24,
$\overline{G}_g$ = installed capacity in power plant g, g = 1, 2, 3,
$\underline{G}_g$ = minimal generation when power plant g is committed, g = 1, 2, 3,
$s_{g,t}^+$ = start-up variable for power plant g, hour t, g = 1, 2, 3, t = 1, …, 24,
$u_{g,0}$ = unit commitment of power plant g at the beginning of the planning period, g = 1, 2, 3,
$u_{g,t}$ = unit commitment of power plant g, hour t, g = 1, 2, 3, t = 1, …, 24,
W_t = expected wind power generation in hour t, t = 1, …, 24,
β_{Gg} = variable operation cost in power plant g.

a) (4 p) Stads energi AB wants to minimise the operation cost for the coming 24 hours. Formulate the objective function of the short-term planning problem of the company. Use the symbols defined above.

b) (2 p) How should a linear constraint be formulated in order to describe the relation between $\underline{G}_g$, $G_{g,t}$ och $u_{g,t}$ for power plant g, hour t in the short-term planning problem of Stads energi AB?

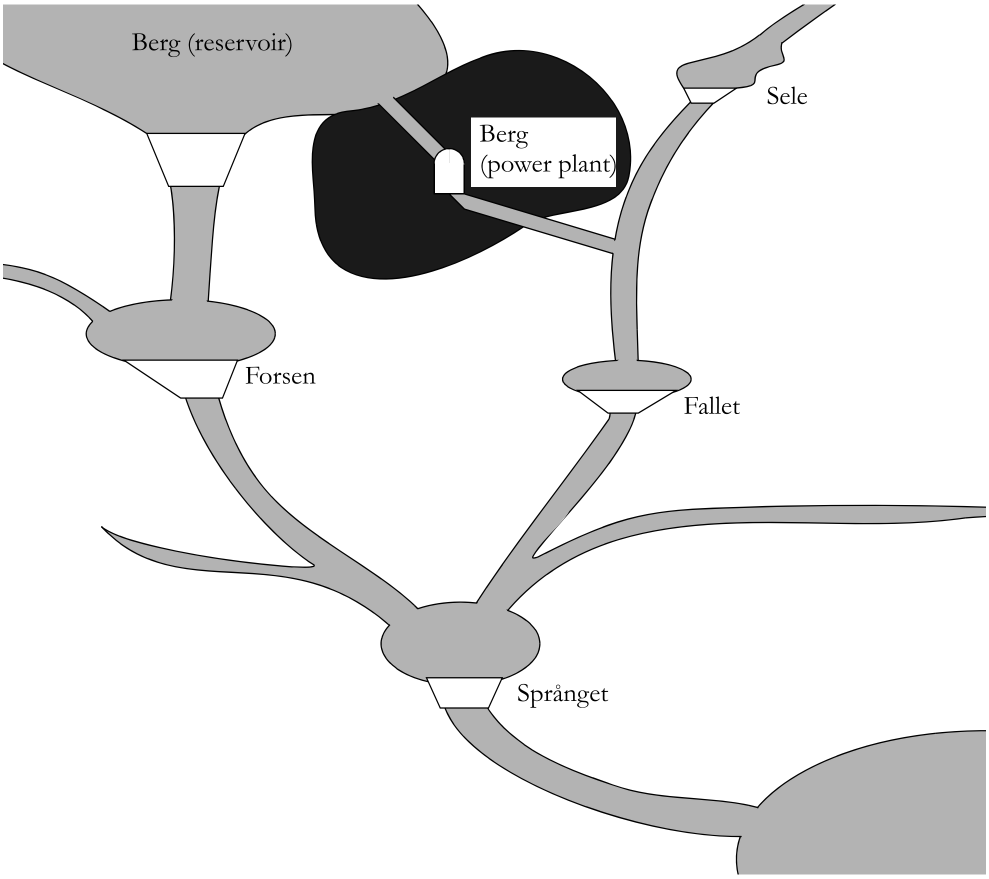
1. $G_{g,t} + \underline{G}_g \cdot u_{g,t} \leq 0$.
2. $G_{g,t} - \underline{G}_g \cdot u_{g,t} \leq 0$.
3. $G_{g,t} + \underline{G}_g \cdot u_{g,t} = 0$.
4. $G_{g,t} - \underline{G}_g \cdot u_{g,t} \geq 0$.
5. $G_{g,t} + \underline{G}_g \cdot u_{g,t} \geq 0$.

c) (1 p) The best production equivalent in the power plant Forsen is 0.8 MWh/HE and is attained at the discharge 125 HE. The relative efficiency at the discharge 187.5 HE is 96%. How much is generated in Forsen at the discharge 187.5 HE?

d) (1 p) The reservoir of Forsen holds 1 000 HE at 10:00. The local inflow as well as discharge and spillage from the power plant upstream amounts to 100 m^3/s between 10:00 and 11:00. During the same time, 140 HE are discharged from Forsen. How much will the reservoir of Forsen hold at 11:00? Notice that the answer should be given in m^3!

e) (2 p) In the following cases it is necessary to use integer variables to model the electricity generation in a hydro power plant: I) When a piecewise linear model is used and the marginal production equivalent is increasing with increasing discharge, II) When there is a forbidden interval for the discharge, III) When the power plant directly upstream is a run-of-the-river unit (i.e., a hydro power plant without reservoir).

1. None of the statements is true.
2. I and II are true but not III.
3. I and III are true but not II.
4. II and III are true but not I.
5. All the statements are true.



f) (2 p) Consider the hydro power plants in the figure above. Notice that Berg is an underground power plant and water that is discharged through the turbine is flowing to Fallet, whereas spillage goes to Forsen. The water delay time between the power plants can be neglected.

The following symbols have been introduced in a short-term planning problem of these power pants:

$M_{i,t}$ = contents of reservoir i at the end of hour t,
$Q_{i,t}$ = discharge in power plant i, hour t,
$S_{i,t}$ = spillage from reservoir i during hour t,
$V_{i,t}$ = local inflow to reservoir i, hour t.

The power plants have been assigned indices $i = 1, \ldots, 5$ and the hydrological constraint of power plant 3, hour t is formulated as:

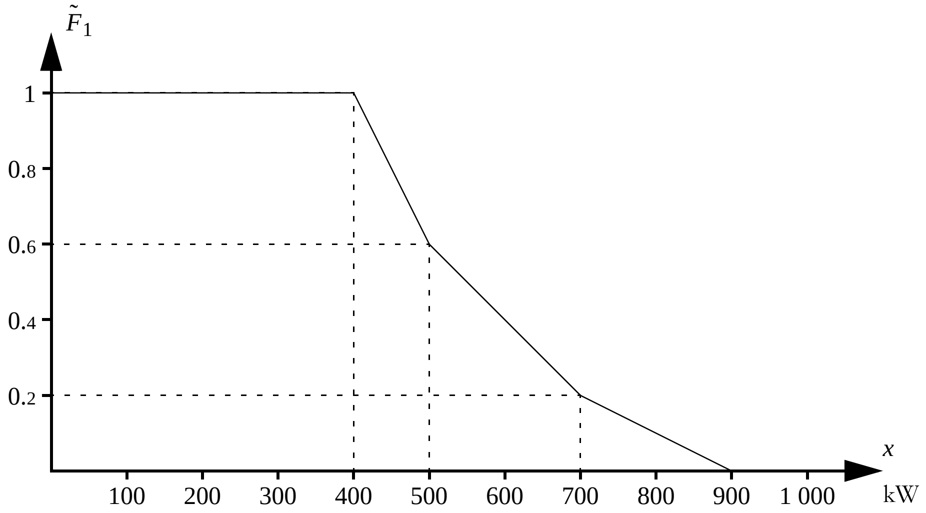
$$M_{3,t} - M_{3,t-1} + Q_{3,t} + S_{3,t} - Q_{2,t} - S_{2,t} - Q_{5,t} - S_{5,t} = V_{3,t}.$$

Which power plant has been assigned the index $i = 3$?

1. Berg
2. Fallet
3. Forsen
4. Sele
5. Språnget

Problem 5 (12 p)

Shahir is a small town in Eastern Africa. The town is not connected to a national grid, but has a local system of its own. The local grid is supplied by a hydro power plant. The power plant does not have a reservoir, but the water flow is always sufficient to allow generation of the installed capacity (800 kW) and the risk of failures in the power plant is negligible.



a) (3 p) The figure above shows the duration curve of the equivalent load including outages in the hydro power plant. How large is the expected electricity generation per hour in the hydro power plant?

b) (3 p) Which *LOLP* will they have in Shahir if they add a diesel generator set to the system? The diesel generator set has a capacity of 150 kW and the availability is 75%?

c) (3 p) The grid in Shahir is poorly maintained and it is common with failures in transformers and distribution lines. A Monte Carlo simulation of the system has been performed in order to consider the failures in the grid. Control variates have been used in order to achieve the best possible results. The detailed model includes failures in the grids. The grid is neglected in the simplified model, which means that the simplified model corresponds to the model used in a probabilistic production cost simulation. The results are shown in table 3. Which estimate of *LOLP* is obtained from the detailed model if the *LOLP* of the simplified model is 10%?

d) (3 p) Which estimate of *EENS* is obtained from the detailed model if the *EENS* of the simplified model is 5 kWh/h?

Table 3 Results from a Monte Carlo simulation of the power system in Shahir.

Number of scenarios, n	Results from the detailed model		Results from the simplified model	
	$\sum_{i=1}^{n} lolo_i$	$\sum_{i=1}^{n} ens_i$	$\sum_{i=1}^{n} \tilde{lolo}_i$	$\sum_{i=1}^{n} \tilde{ens}_i$
1 000	199	11 400	108	5 300

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Answer sheet

Name: ....

Personal number: ....

Problem 1

a) Alternative .... is correct.

b) Alternative .... is correct.

c) Alternative .... is correct.

Problem 2

a) .... ¤/MWh

b) .... M¤/year

c) .... ¤/MWh

Problem 3

a) .... MW

b) .... MW/Hz

c) .... Hz

Problem 4

a) ....

b) Alternative .... is correct.

c) .... MW **d)** .... m^3

e) Alternative .... is correct.

f) Alternative .... is correct.

Problem 5

a) .... kWh/h **b)** .... %

c) .... % **d)** .... kWh/h

Suggested solution for complementary test in 2C1118 System Planning.

Problem 1

a) 2, **b)** 2, **c)** 3.

Problem 2

a) Hydro power and nuclear power can generate in total 150 TWh, which means that half of the coal condensing potential must be used too. The electricity price must therefore be in the middle of the interval for coal condensing, i.e., 400 ¤/MWh.

b) As the electricity price is higher than the variable operation cost, the nuclear power plant will generate as much as possible. This generates an annual profit equal to 10 TWh · 380 ¤/MWh (income of sold electricity) – 10 TWh · 100 ¤/MWh (variable costs) – 2 000 M¤ (fixed costs) = 800 M¤.

c) From the results of part a, we can conclude that the electricity consumption will be less than 175 TWh. If we assume that the electricity price, λ, is larger than 300 ¤/MWh, the total generation (hydro + nuclear + coal condensing) will be

$$75 + 75 + \frac{\lambda - 300}{500 - 300}50,$$

while the demand is equal to

$$175 - 0.25(\lambda - 300).$$

If these two expressions are set to be equal, we get $\lambda = 350$ ¤/MWh.

Problem 3

a) The power plants in categories I and II have the total gain $R_{I+II} = 2\,500$ MW/Hz, which means that if the frequency drops by 0.02 Hz then the generation increases by 2 500 · 0.02 = 50 MW.

b) At this frequency, only the power plants in category III contribute to the total gain, which means that the total gain will be 2 500 MW/Hz.

c) Apparently a failure of this size will result in a frequency less than 49.9 Hz. Consequently, the power plants in categories I and II will increase their electricity generation as much as they can, i.e., by 50 MW. The remaining 1 000 MW must be supplied by the power plants in category III, which means that the frequency must drop by $\Delta f = \Delta G/R_{49.5} = 1\,000/2\,500 = 0.4$ Hz. Thus, the new frequency is 49.92 – 0.4 = 49.52 Hz.

Problem 4

a) minimise $\sum_{t=1}^{24} \sum_{g=1}^{3} (C_g^+ s_{g,t}^+ + \beta_{Gg} G_{g,t})$.

b) 4.

c) The generation is given by $H(Q) = \gamma_{max} \cdot \eta(Q) \cdot Q = 0.8 \cdot 0.96 \cdot 187.5 = 144$ MW.

d) As the flow into the reservoir is 100 HE and the flow out from the reservoir is 140 HE, it must hold 960 HE = 3 456 000 m^3 water at the end of the hour.

e) 2.

f) 5.

Problem 5

a) We start by noting that $\tilde{F}_0(x) = \tilde{F}_1(x)$, because the hydro power plant is 100% available. Hence, we get

$$EG_1 = EENS_0 - EENS_1 = \int_0^{\infty} \tilde{F}_0(x)dx - \int_{800}^{\infty} \tilde{F}_1(x)dx = \int_0^{800} \tilde{F}_1(x)dx =$$

$$= 400 \cdot 1 + 100 \cdot (1 + 0.6)/2 + 200 \cdot (0.6 + 0.2)/2 + 100 \cdot (0.2 + 0.1)/2 = 575 \text{ kWh/h}.$$

b) $LOLP = \tilde{F}_2(950) = 0.75\tilde{F}_1(950) + 0.25\tilde{F}_1(950 - 150) = 0.75 \cdot 0 + 0.25 \cdot 0.1 = 2.5\%$.

c) $m_{LOLO} = m_{(LOLO - \tilde{LOLO})} + \mu_{\tilde{LOLO}} = \frac{1}{n}\left(\sum_{i=1}^{n} lolo_i - \sum_{i=1}^{n} \tilde{lolo}_i\right) + 0.1 =$

$= \frac{1}{1\,000}(199 - 108) + 0.1 = 19.1\%$.

d) $m_{ENS} = m_{(ENS - \tilde{ENS})} + \mu_{\tilde{ENS}} = \frac{1}{n}\left(\sum_{i=1}^{n} ens_i - \sum_{i=1}^{n} \tilde{ens}_i\right) + 5 =$

$= \frac{1}{1\,000}(11\,400 - 5\,300) + 5 = 11.1$ kWh/h.