KTH Electrical Engineering

Supplementary test in 2C1118 System Planning, 27 March 2007, 17:00–19:00, Q36

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) The following properties characterise a modern, restructured ("deregulated") electricity market: I) There is a system operator who is responsible for safe operation of the power system, II) The producers do not compete with each other, III) A single company can run the entire chain from production, via transmission and distribution to the end consumer, i.e., the company is both a producer, a grid owner and a retailer.

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

b) (2 p) We use the notion "post trading" to describe all the trading which occurs after the hour of delivery (or any other trading period). The following types of contracts are traded in the post market: I) Balance power, i.e., when a balance responsible player is selling any surplus in their balance to the system operator, or when a balance responsible player is buying from the system operator to cover for any deficit in their balance, II) Firm power, i.e., the customer buys the same amount of energy in each trading period as long as the contract is valid, III) Regulation power, i.e., when a player at request from the system operator is supplying more power to the system (up-regulation) or when a player at request from the system operator is supplying less power to the system (down-regulation).

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 III are true but not II.

Problem 2 (6 p)

Consider a simplified model of the electricity market in Land. The maximal annual production and the variable costs are given in table 1 below. The electricity consumption in land is 145 TWh/year.

Table 1 Data for the electricity producers in Land.

Power source	Production capability [TWh/year]	Variable costs [¤/MWh]
Coal condensing	10	300
Nuclear	70	80
Hydro power	70	5
Wind power	1	5

a) (2 p) Which electricity price will there be in Land if it can be assumed that there is perfect competition, perfect information and neither capacity, transmission nor reservoir limitations in the market?

b) (3 p) The nuclear power plant Strålinge has a production capacity of 5 TWh/year. How large is the profit from this nuclear power plant if the fixed costs are 900 M¤/year?

c) (1 p) Consider an arbitrary electricity market and assume that the electricity price is equal to λ if there is perfect competition, perfect information and neither capacity, transmission nor reservoir limitations in the market. What will the electricity price become if the players of this electricity market do *not* have access to perfect information?

1. The electricity price must be lower than λ.
2. The electricity price must be higher than λ.
3. The electricity price can be lower than, equal to or higher than λ.

Problem 3 (6 p)

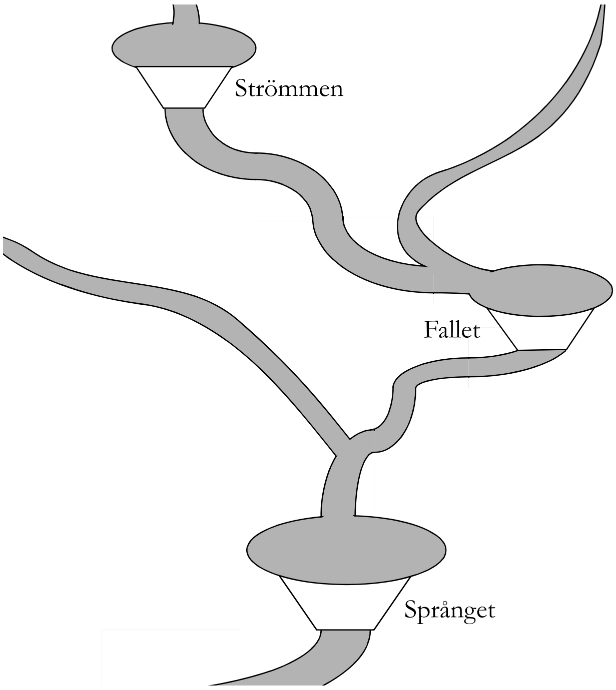
Consider a power system where the total gain is 2 000 MW/Hz in the interval 50 ± 0.1 Hz.

a) (2 p) At 10:00 there is balance between production and consumption in the system and the frequency is 50.01 Hz. At this time the thermal power plant Sotinge is increasing its generation by 100 MW. The power plant Sotinge is not participating in the primary control. What will the frequency be when the primary control has restored the balance between generation and consumption?

b) (2 p) At 10:03 there is balance between production and consumption in the system and the frequency is 50.04 Hz. At this time the load in the system is reduced by 60 MW. What will the frequency be when the primary control has restored the balance between generation and consumption?

c) (2 p) At 10:05 there is balance between production and consumption in the system and the frequency is 50.12 Hz. The hydro power plant Fors has a gain of 100 MW/Hz. The base generation (i.e., the generation when the frequency is exactly 50 Hz) is 80 MW and the installed capacity of the power plant is equal to 90 MW. How much will Fors generate at this time?

Problem 4 (12 p)



a) (3 p) The hydro power plant Språnget has a maximal discharge of 100 m^3/s. The best efficiency is obtained for the discharge 70 m^3/s. At maximal discharge the power plants generates its installed capacity, which is 20.8 MW. At best efficiency the power plant generates 15.4 MW.

Assume that we need a piecewise linear model of electricity generation as function of the discharge in Språnget. The model should have two segments and the breakpoint between them should be located at the best efficiency. Calculate the following parameters:

μ_j = marginal production equivalent in Språnget, segment j,
$\overline{Q}_j$ = maximal discharge in Språnget, segment j.

b) (4 p) The following symbols have been introduced in a short-term planning problem for the hydro power plants above:

Indices for the power plants: Strömmen 1, Fallet 2, Språnget 3.

$M_{i,0}$ = contents of reservoir i at the beginning of the planning period, i = 1, 2, 3,
$M_{i,t}$ = contents of the reservoir i at the end of hour t, i = 1, 2, 3, t = 1, …, 24,
$Q_{i,j,t}$ = discharge in power plant i, segment j, during hour t,
i = 1, 2, 3, j = 1, 2, t = 1, …, 24.
$S_{i,t}$ = spillage from reservoir i during hour t, i = 1, 2, 3, t = 1, …, 24,
$V_{i,t}$ = local inflow to reservoir i during hour t, i = 1, 2, 3, t = 1, …, 24.

Use these symbols to formulate the hydrological constraint for Språnget, hour t. The water delay time between the power plants can be neglected.

c) (3 p) The thermal power plant Flisinge is fuelled by biomass. The fuel costs 200 ¤/m^3 and has a density of 400 kg/m^3. The heat contents of the fuel is 5 MWh/ton and the efficiency of the power plant is 40%. How large is the variable generation cost in Flisinge?

d) (2 p) The following variables and parameters have been introduced in a short-term planning problem for Flisinge:

C^+ = start-up cost of the power plant,
C^- = stop cost of the power plant,
$G_{g,t}$ = generation in the power plant during hour *t*,
s_t^+ = start-up variable for hour *t* (1 if the power plants starts generating at the beginning of hour *t*, otherwise 0),
s_t^- = stop variable for hour *t* (1 if the power plant stops generating at the beginning of hour *t*, otherwise 0).
u_t = unit commitment during hour *t* (1 if the power plant is committed, otherwise 0),
β = variable generation cost.

The following objective function is used in the planning problem:

$$\text{minimise} \quad \sum_{t \in \mathcal{T}} (\beta G_t + C^+ s_t^+ + C^- s_t^-).$$

Which of the following constraints can be used to control the relation between start-up, stop and unit commitment?

I) $u_t - u_{t-1} - s_t^+ + s_t^- = 0.$

II) $u_t - u_{t-1} - s_t^+ \leq 0.$

III) $u_t - u_{t-1} + s_t^+ - s_t^- = 0.$

1. None of the alternatives is correct.
2. Only alternative I is correct.
3. Only alternative II is correct.
4. Only alternative III is correct.
5. It is possible to choose between using alternative I and alternative II.

Problem 5 (12 p)

The figure below shows the load duration curve of Nchi. Assume that the power plants in Nchi comprise hydro power plants, which are 100% available and have a total installed capacity of 700 MW, and a wind farm with an installed capacity of 200 MW, the available generation capacity of which is modelled according to table 2.

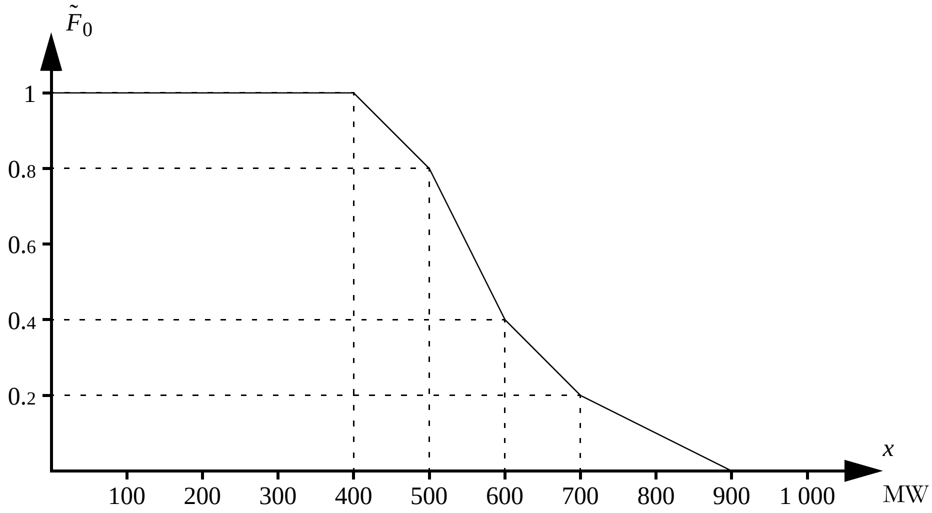


Table 2 Model of the wind farm in Nchi.

Available generation capacity [MW]	Probability [%]
0	20
50	20
100	10
150	10
200	40

a) (3 p) Assume that it is preferable to use hydro power plants and that the wind power plants are only used if the load exceeds the available hydro power capacity. How large is the expected generation per hour in the hydro power plants?

b) (3 p) What is the *LOLP* of the system?
Hint: The convolution formula for a multi-state model reads

$$\tilde{F}_g(x) = \sum_{i=1}^{N_g} p_{g,i}\tilde{F}_{g-1}(x - x_{g,i}).$$

c) (3 p) Assume that a scenario has been randomised where the total load is D_{tot} = 525 MW. What is the complementary random number of D_{tot}?

d) (3 p) A Monte Carlo simulation of Nchi used a more detailed model of the wind power farm than the one given in table 2. Moreover, the transmission losses in the power system have been considered. The results of 1 000 analysed scenarios is shown in table 3. Which estimate of *LOLP* is obtained from these results?

Table 3 Results from a Monte Carlo simulation of the electricity market in Nchi.

Stratum, h	Stratum weight, ω_h	Number of scenarios, n_h	Results, $\sum_{i=1}^{n_h} x_{i,h}$, (where $x_{i,h}$ is the observed value of *LOLO* in scenario i, stratum h)
1	0.85	50	0
2	0.06	900	150
3	0.09	50	50

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Answer sheet

Name: ....

Personal number: ....

Problem 1

a) Alternative .... is correct.

b) Alternative .... is correct.

Problem 2

a) .... ¤/MWh

b) .... M¤/year

c) Alternative .... is correct.

Problem 3

a) .... Hz

b) .... Hz

c) .... MW

Problem 4

a) μ_1 .... MWh/HE μ_2 .... MWh/HE

$\overline{Q}_1$ .... HE $\overline{Q}_2$ .... HE

b) ....

c) .... ¤/MWh

d) Alternative .... is correct.

Problem 5

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

c) .... MW **d)** .... %

Suggested solution for complementary test in 2C1118 System Planning.

Problem 1

a) 2, **b)** 2.

Problem 2

a) Hydro power, wind power and nuclear can produce in total 141 TWh/year, which is not sufficient. Hence, some of the coal condensing must be utilised and then the electricity price must be 300 ¤/MWh.

b) The income for Strålinge is 5 TWh/year · 300 ¤/MWh = 1 500 M¤/year. From this income we subtract the total variable costs (5 TWh/year · 80 ¤/MWh = 400 M¤/year) and the fixed costs, which yields a profit of 200 M¤/year.

c) 3.

Problem 3

a) The increase in electricity generation results in a frequency increase $\Delta f = \Delta G/R$ = 100/2 000 = 0.05 Hz, i.e., the new frequency is 50.01 + 0.05 = 50.06 Hz.

b) The decrease in the load results in a frequency increase $\Delta f = \Delta G/R$ = 60/2 000 = 0.03 Hz, i.e., the new frequency is 50.04 + 0.03 = 50.07 Hz.

c) According to the relation between frequency and generation, Fors should generate

$$G = G_0 - R(f - f_0) = 80 - 100(50.12 - 50) = 68 \text{ MW},$$

which does not exceed the installed capacity.

Problem 4

a) The following data are given in the problem text:

$\overline{Q}$ = maximal discharge in Språnget = 100,
$\hat{Q}$ = discharge in Språnget at best efficiency = 70,
H = generation in Språnget at best efficiency = 15.4,
$\overline{H}_i$ = maximal generation in Språnget = 20.8.

The marginal production equivalents can now be calculated according to

$$\mu_1 = \frac{\ddot{H}}{\hat{Q}}$$

and

$$\mu_2 = \frac{\overline{H} - \ddot{H}}{\overline{Q} - \hat{Q}},$$

which results in the following linear models of the power plant:

μ_j = marginal production equivalent in Språnget, segment j =

$$= \begin{cases} 0.22 & j = 1, \\ 0.18 & j = 2, \end{cases}$$

$$\overline{Q}_j = \text{maximal discharge in Språnget, segment } j = \begin{cases} 70 & j = 1, \\ 30 & j = 2. \end{cases}$$

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

c) One m^3 of the fuel corresponds to 0.4 ton. As the heat content is 5 MWh/ton and the efficiency is 40% we get 0,8 MWh electricity per m^3 fuel. If the fuel costs 200 ¤/m^3 then the variable generation cost is 200/0.8 = 250 ¤/MWh.

d) 2.

Problem 5

a) Since the hydro power is100% available, we know that $\tilde{F}_1(x) = \tilde{F}_0(x)$. The expected generation in the hydro power is then given by

$$EG_1 = EENS_0 - EENS_1 = \int_0^{\infty} \tilde{F}_0(x)dx - \int_{700}^{\infty} \tilde{F}_1(x)dx = \int_0^{700} \tilde{F}_0(x)dx = 580 \text{ MWh/h}.$$

b) $LOLP = \tilde{F}_2(900) = 0.4\tilde{F}_1(900) + 0.1\tilde{F}_1(850) + 0.1\tilde{F}_1(800) + 0.2\tilde{F}_1(750) + 0.2\tilde{F}_1(700) =$
$= 0.4 \cdot 0 + 0.1 \cdot 0.05 + 0.1 \cdot 0.1 + 0.2 \cdot 0.15 + 0.2 \cdot 0.2 = 8.5\%$.

c) The inverse transform method states that $D_{tot} = F_{D_{tot}}^{-1}(U)$, where U is a $U(0, 1)$-distributed random number. Since it is the duration curve that is given in the problem, we may as well use the transform $D_{tot} = \tilde{F}_{D_{tot}}^{-1}(U)$. The original random number must then have been $U = \tilde{F}_{D_{tot}}(D_{tot})$ = 0.7. Hence, $U^* = 1 - U = 0.3$, which results in $D_{tot}^* = \tilde{F}_{D_{tot}}^{-1}(U^*) = 650$ MW.

d) The estimate of the expectation value of a single stratum is given by

$$m_{Xh} = \frac{1}{n_h} \sum_{i=1}^{n_h} x_{i,h},$$

which yields $m_{X1} = 0$, $m_{X2} = 1/6$ and $m_{X1} = 1$. The results are weighted according to

$$m_X = \sum_{h=1}^{3} \omega_h m_{Xh},$$

which results in the *LOLP* estimate 0.85 · 0 + 0.06 · 1/6 + 0.09 · 1 = 10%.