KTH Electrical Engineering

Complementary test in EG2050 System Planning, 28 June 2012, 14:00-16:00, the seminar room

Instructions

Only the problems indicated on the attached answer sheet have to be answered (the score of the remaining problems is kept from the exam). Motivations and calculations do not have to be presented.

The maximal score of the complementary test is 40 points including the points that are kept from the exam. You are guaranteed to pass if you get at least 33 points.

Allowed aids

In this complementary 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) A balance responsible player has the following responsibilities: I) Economical responsibility that the system during each trading period (for example one hour) is supplied as much energy as consumed by the customers of the player, II) Physical responsibility that the system during each trading period (for example one hour) is supplied as much energy as consumed by the customers of the player, III) Physical responsibility that the system continuously is supplied as much power as consumed by the customers of the player.

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) (2 p) The following applies to a down-regulation bid in a regulation market: I) If the bid is activated it means that the player who submitted the bid is buying energy from the system operator, II) A down-regulation bid can be performed by decreasing the generation in for example a hydro power plant, III) A down-regulation bid can be performed by decreasing the consumption in for example a large factory.

1. Only I 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.

Problem 2 (6 p)

Consider a simplified model of the electricity market in Land. Data for the power plants in Land are shown in table 1. The variable operation costs are assumed to be linear within the intervals, 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 power	55	5
Nuclear power	50	100–120
Biofuel	16	100–260
Fossil fuels	20	240–440

a) (2 p) Assume that the electricity market in Land has perfect competition, perfect information and that there are neither capacity, transmission nor reservoir limitations. How large is the electricity consumption in Land if the electricity price during a certain year is 250 ¤/MWh?

b) (2 p) Strålinge AB owns a nuclear power plant with a production capability of 8 TWh per year. The variable costs of the power plant are 110 ¤/MWh and the company has fixed costs of 2 400 M¤/year. How high must the electricity price at least become if the company is not going to make a loss?

c) (2 p) Assume that the electricity price during one hour is 200 ¤/MWh and in the next hour it is 220 ¤/MWh. Possible explanations are that I) The hydro reservoirs are full at the end of the first hour, II) The hydro reservoirs are empty at the end of the first hour, III) The hydro power generates installed capacity during the second hour.

1. Only I is true.
2. Only II is true.
3. Only III is true.
4. I and III are true but not II.
5. II and III are true but not I.

Problem 3 (6 p)

Consider a power system divided in five areas. At a certain occasion there is balance between production and consumption in the system and the frequency is exactly equal to 50 Hz. Data for the primary control in the system are given in table 2. Data for the transmission lines between the countries are shown in table 3. Each transmission line is equipped with a protection system which after a short time delay disconnects the line if the power flow exceeds the maximal capacity of the line. The power flow on the HVDC line are not affected by the frequency of the system, but can only be controlled manually..

Table 2 Data for the primary control.

Area	Gain (available between 49.9 and 50.1 Hz) [MW/Hz]
A	2 000
B	2 000
C	1 000
D	500
E	500

Table 3 Data for the interconnections.

Connection	Type	Current transmission [MW]	Maximal capacity [MW]
A ↔ B	Alternating current	1 000 MW from A to B	2 000
A ↔ C	Direct current (HVDC)	600 MW from A to C	600
A ↔ D	Direct current (HVDC)	400 MW from A to D	400
A ↔ E	Alternating current	1 000 MW from A to E	1 500
B ↔ D	Alternating current	500 MW from B to D	1 200

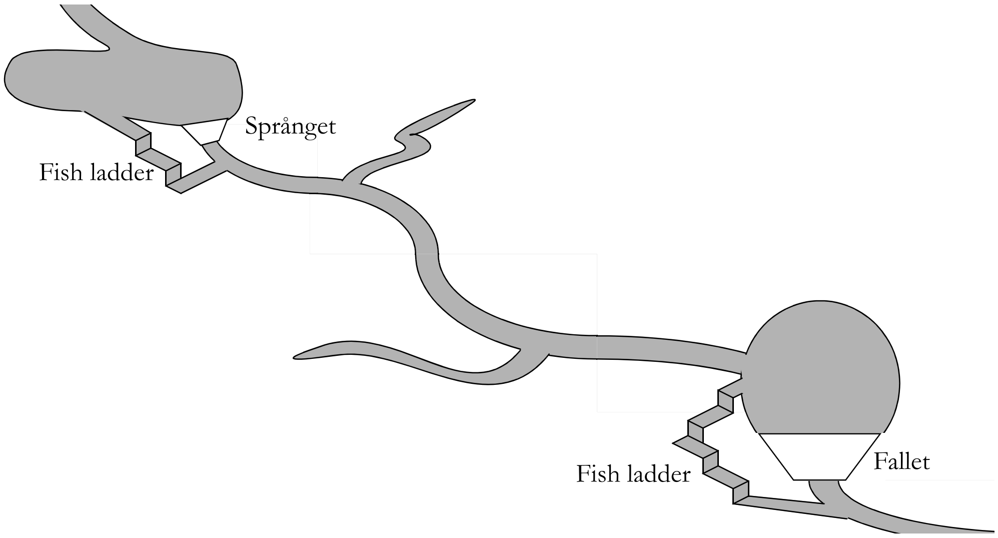
a) (3 p) At this occasion, a lightning strike in a substation causes 450 MW of generation to be lost in area A. The concerned power plants were not part of the primary control. What will the frequency be in area A when the primary control has restored the balance between generation and consumption?

b) (1 p) What will the frequency be in area B after the event in area A?

c) (1 p) What will the frequency be in area C after the event in area A?

d) (1 p) What will the frequency be in area D after the event in area A?

Problem 4 (12 p)



AB Vattenkraft owns two hydro power plant located as in the figure above. In order to enable salmon to pass the power plants, the environment court has decided that AB Vattenkraft always must release a flow of 2 m^3/s in the fish ladders at Språnget and Fallet.

The following symbols have been introduced in a short-term planning problem for these hydro power plants:

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

γ_i = expected future production equivalent for water stored in reservoir i, i = 1, 2,
λ_t = expected electricity price at ElKräng hour t, t = 1, …, 24,
λ_{25} = expected electricity price at ElKräng after the end of the planning period,
$M_{i,t}$ = contents of reservoir i at the end of hour t, i = 1, 2, t = 1, …, 24,
$\overline{M}_i$ = maximal contents of reservoir i, i = 1, 2,
p_t = purchase from ElKräng hour t, t = 1, …, 24,
$Q_{i,j,t}$ = discharge in power plant i, segment j, during hour t, i = 1, 2, j = 1, 2, 3, t = 1, …, 24,
$\overline{Q}_{i,j}$ = maximal discharge in power plant i, segment j, i = 1, 2, j = 1, 2, 3,
r_t = sales to ElKräng hour t, t = 1, …, 24,
$S_{i,t}$ = spillage from reservoir i (including the flow through the fish ladders) during hour t, i = 1, 2, t = 1, …, 24,
$\underline{S}_i$ = minimal allowed flow through the fish ladders at reservoir i, i = 1, 2.

a) (3 p) Which of the symbols above represent optimisation variables and parameters respectively?

b) (4 p) AB Vattenkraft sells power to customers with firm power contracts, but the company also has the possibility to trade at the local power exchange ElKräng. Formulate the objective function if the aim of the planning problem is to maximise the income of sold electricity at ElKräng plus the value of stored water minus the costs of purchasing electricity from ElKräng. Use the symbols defined above.

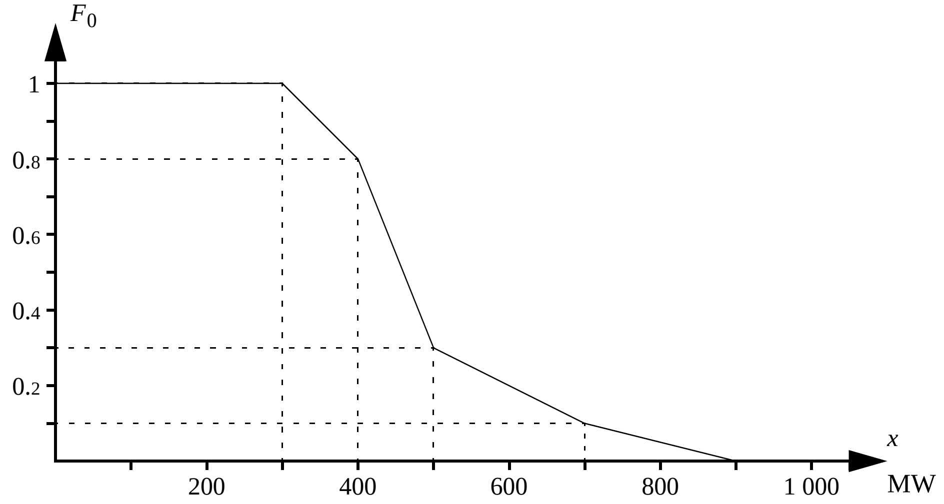
c) (3 p) Formulate the limits for the optimisation variables in the short-term planning problem of AB Vattenkraft as defined above. To receive full score for this problem, you also have to state the possible values for each index value and limit!

d) (2 p) In the following cases it is necessary to use integer variables for a linear model of the electricity generation in a thermal power plant: I) When the power plant has a start-up cost stated in SEK/start, II) When the power plant has a stop cost which is stated in SEK/stop, III) When the power plant has a minimum generation level, $\underline{G}$, when committed.

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.

Problem 5 (12 p)

The national grid in Nchi is supplied by three larger hydro power plants with a combined installed capacity of 750 MW and a 50 MW thermal power plant. The figure below shows the duration curve of the total load in Nchi.



a) (3 p) Assume that all power plants have 100% availability and that the variable operation cost is 10 ¤/MWh in the thermal power plant, whereas the variable operation cost in the hydro power plants is negligible. Use probabilistic production cost simulation to calculate the expected total operation cost per hour.

b) (3 p) Assume that the hydro power plants have 100% availability and that the thermal power plant has 90% availability. What is the risk of power deficit in Nchi?

c) (4 p) The Ministry of Energy in Nchi is investigating the possibility to introduce wind power. In connection to this investigation, the ministry has developed a model that includes the losses in the national grid. Ten scenarios have been generated for a Monte Carlo-simulation using this model (see table 4). Control variates are used to increase the accuracy of the simulation. Assume that *ETOC* according to the simplified model has been calculated to 20 ¤/h and that *LOLP* for the simplified model has been calculated to 3.0%. Which estimates of *ETOC* and *LOLP* are obtained for the detailed model?

Table 4 Results from a Monte Carlo simulation of the electricity market in problem 5c.

Scenario	1	2	3	4	5	6	7	8	9	10
TOC [¤/h]										
Simplified model	0	0	0	0	0	0	0	0	100	0
Detailed model	0	20	0	180	0	0	0	0	500	0
LOLO										
Simplified model	0	0	0	0	0	0	0	0	0	0
Detailed model	0	0	0	0	0	0	0	0	1	0

d) (2 p) Assume that complementary random numbers are used to improve the simulation of Nchi. What is the value of the complementary random number, *D**, if the total load of the system is randomised to *D* = 400 MW?

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Answer sheet

Name: ....

Personal number: ....

Problem 1

a) Alternative .... is correct.

b) Alternative .... is correct.

Problem 2

a) .... TWh/year

b) The price must be higher than .... ¤/MWh

c) Alternative .... is correct.

Problem 3

a) .... Hz **b)** .... Hz

c) .... Hz **d)** .... Hz

Problem 4

a) Parameters: ....

Optimisation variables: ....

b) ....

c) ....

....

....

d) Alternative .... is correct.

Problem 5

a) .... ¤/h **b)** .... %

c) *ETOC* .... ¤/h *LOLP* .... %

d) .... MW

Suggested solution for complementary test i EG2050 System Planning, 28 June 2012.

Problem 1

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

Problem 2

a) Both hydro and nuclear are generating as much as possible, i.e., 53 + 49 = 102 TWh, when the electricity price is 220 ¤/MWh. The contribution from biofuel is equal to (250 – 100)/(260 – 100) · 16 = 15 TWh and fossil fuels generate (250 – 240)/(440 – 240) · 20 = 1 TWh. All in all, 121 TWh is generated in a year and the electricity consumption is of course equally large.

b) For each ¤/MWh the electricity price exceeds the variable costs, the company earns 1 ¤/MWh · 8 TWh/year = 8 M¤/year. This surplus must be sufficient to cover the fixed costs, which means that the electricity price must be 110 + 2 400/8 = 410 ¤/MWh.

c) 4.

Problem 3

a) Area A is part of the same synchronous grid as areas B, D and E, which means that the total gain of the system is 5 000 MW/Hz. The decrease in electricity generation results in a frequency decrease $\Delta f = \Delta G/R$ = 450/5 000 = 0.09 Hz, i.e., the new frequency is 50 – 0.09 = 49.91 Hz.

b) Since area B is part of the same synchronous grid as area A, the frequency must be the same, i.e., 49.91 Hz.

c) Since area C does not belong to the same synchronous grid as area A, the frequency remains the same, i.e., it is still exactly 50 Hz.

d) Since area D is part of the same synchronous grid as area A, the frequency must be the same, i.e., 49.91 Hz.

Problem 4

a) Parameters: γ_i, λ_t, λ_{25}, $\overline{M}_i$, $\overline{Q}_{i,j}$ and $\underline{S}_i$. Optimisation variables: $M_{i,t}$, p_t, $Q_{i,j,t}$, r_t and $S_{i,t}$.

b) maximise $\sum_{t=1}^{24} \lambda_t(r_t - p_t) + \lambda_{25}((\gamma_1 + \gamma_2)M_{1,24} + \gamma_2 M_{2,24})$.

c)

$0 \le M_{i,t} \le \overline{M}_i,\qquad i = 1, 2, t = 1, \ldots, 24,$

$0 \le p_t,\qquad t = 1, \ldots, 24,$

$0 \le Q_{i,j,t} \le \overline{Q}_{i,j}\qquad i = 1, 2, j = 1, 2, 3, t = 1, \ldots, 24,$

$0 \le r_t,\qquad t = 1, \ldots, 24,$

$\underline{S}_i \le S_{i,t},\qquad i = 1, 2, t = 1, \ldots, 24.$

d) 5.

Problem 5

a) Since all power plants have 100% availability, we get $\tilde{F}_2(x) = \tilde{F}_1(x) = \tilde{F}_0(x)$, which means that

$$EG_2 = EENS_1 - EENS_2 = \int_{750}^{\infty} \tilde{F}_1(x)dx - \int_{800}^{\infty} \tilde{F}_2(x)dx = \int_{750}^{800} \tilde{F}_0(x)dx =$$

$$= (0.075 + 0.05) \cdot 50/2 = 3.125 \text{ MWh/h}.$$

We can assume that the operation cost of hydro power is negligible; hence, the expected operation cost per hour is $ETOC = 10EG_2$ = 31.25 ¤/h.

b) $LOLP = \tilde{F}_2(800) = 0.9\tilde{F}_1(800) + 0.1\tilde{F}_1(800 - 50)$ = 0.9 · 0.05 + 0.1 · 0.075 = 5.25%.

c) $m_{TOC} = m_{(TOC - \tilde{TOC})} + \mu_{\tilde{TOC}} = \frac{1}{10}\sum_{i=1}^{10}(TOC_i - \tilde{TOC}_i) + 35$ = (20 + 180 + 400)/10 + 20 = =80 ¤/h.

$$m_{LOLO} = m_{(LOLO - \tilde{LOLO})} + \mu_{\tilde{LOLO}} = \frac{1}{10}\sum_{i=1}^{10}(LOLO_i - \tilde{LOLO}_i) + 0.05 = 1/10 + 0.03 = 13\%.$$

d) The inverse transform method states that $D = F_D^{-1}(U)$, 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 $D = \tilde{F}_D^{-1}(U)$. The original random number must then have been $U = \tilde{F}_D(400) = 0.8$. Hence, $U^* = 1 - U = 0.2$, which results in $D^* = \tilde{F}_D^{-1}(U^*) = 600$ MW.