KTH Electrical Engineering

Complementary test in EG2050 System Planning, 23 June 2011, 9:00-11:00, 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)

Assume that the electricity market in Land has perfect competition, perfect information and that there are neither capacity, transmission nor reservoir limitations. 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	60	5
Nuclear power	60	90–100
Biofuel	30	200–350
Coal condensing	10	305–505

a) (1 p) How much is generated in the bio-fuelled power plants during a year if the electricity price is 320 ¤/MWh?

b) (3 p) What will the electricity price be in Land if the electricity consumption is not price sensitive and amounts to 151 TWh/year?

c) (2 p) Assume that carbon dioxide fees are introduced in Land. Biofuel is not considered to cause any net emission of carbon dioxide, but the coal condensing producers have to pay a fee of 80 ¤/MWh. What will the electricity price be in Land?

Problem 3 (6 p)

The primary control in Rike is divided in a normal operation reserve and a disturbance reserve. The power plants that are part of each reserve only provide gain in a specific frequency range, as shown in table 2. If the frequency is beyond this range, the power plants will not contribute with any gain.

Table 2 Primary control in Rike.

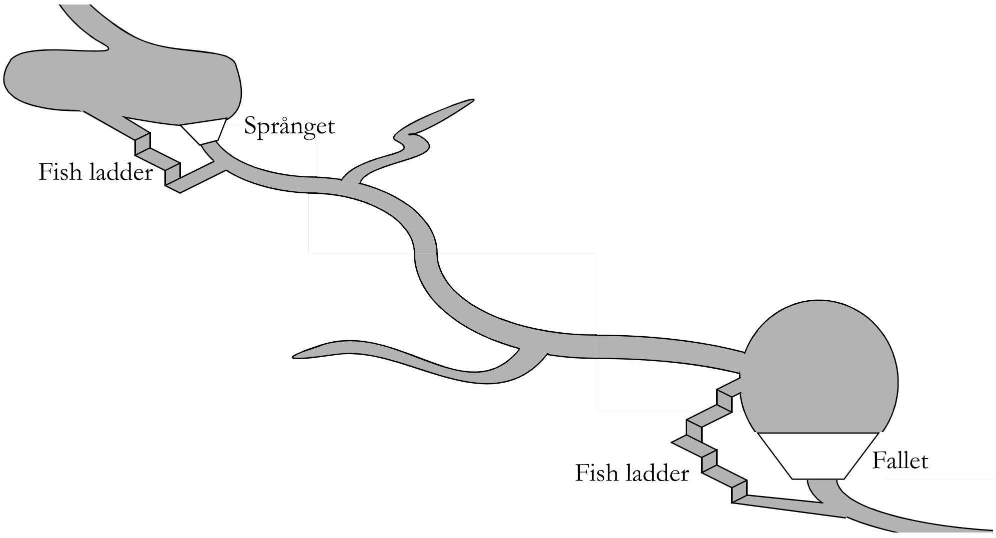
Category	Gain [MW/Hz]	Frequency range [Hz]
Normal operation reserve	2 000	49.9–50.1
Disturbance reserve	3 000	49.5–49.9

a) (2 p) How much remains of the normal operation reserve when the frequency is 49.94 Hz (i.e, how much can the generation increase in these power plants)?

b) (1 p) How large is the total gain of the system when the frequency is 49.8 Hz?

c) (3 p) At a certain occasion the frequency of the system is stable at 49.94 Hz, when a nuclear power plant must be stopped immediately. The nuclear power plant was not part of the primary control and produced 1 010 MW before the stop. What will the frequency be once it has been stabilised after the stop?

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)

Consider an electricity market where the load can be assumed to be normally distributed with the expectation value 500 kW and the standard deviation 50 kW. Selected data of the duration curve $\tilde{F}_0(x)$ are given in table 3.

Table 3 The load duration curve in problem 5.

	x = 450	x = 500	x = 550	x = 600	x = 650	x = 700
$\tilde{F}_0(x)$	0.841	0.500	0.159	0.023	0.001	0.000
$\int_x^\infty \tilde{F}_0(\xi)d\xi$	54.17	19.95	4.17	0.42	0.02	0.00

a) (1 p) Calculate $EENS_0$, i.e., the expected unserved energy if there is no power plant in the system.

b) (2 p) Assume that this electricity market is supplied by a 600 kW hydro power plant, and that the installed capacity of this power plant always is available. How large is the expected generation in the hydro power plant?

c) (3 p) Assume that this electricity market is supplied by the hydro power plant from the previous question as well as a wind power plant. A model of the available generation capacity is given in table 4. What is the*LOLP* of this system?

Hint: The convolution formula for a multi-state model reads

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

Table 4 Model of the wind power plant in problem 5c–e.

Available generation capacity [MW]	Probability [%]
0	30
50	50
100	20

d) (2 p) A Monte Carlo simulation of the system in Akabuga requires that random values of the available wind power generation capacity, $\overline{W}$, is generated. Assume that the random number U = 0.76 is obtained from a $U(0, 1)$-distribution. U is transformed into $\overline{W}$ = 0 using the inverse transform method. What is the complementary random number of this value of $\overline{W}$?

e) (4 p) Assume that the power system from part c is simulated using a combination of complementary random numbers and control variates. The simulation comprises 1 000 original scenarios, y_i, $i = 1, \ldots, 1\,000$. The corresponding complementary scenarios, y_i^*, $i = 1, \ldots, 1\,000$, have also been generated. The simplified model $\tilde{g}(Y)$, corresponds to the model used in probabilistic production cost simulation, whereas the detailed model, $g(Y)$, considers factors such as the losses being dependent on which power plants that are operated and that the load is varying in different parts of the system. The results are shown in table 5. Which estimate of *LOLP* is obtained?

Table 5 Results from a Monte Carlo simulation of the power system in Akabuga.

Detailed model		Simplified model	
Number of loss of load occasions in the original scenarios, $\sum_{i=1}^{1000} g(y_i)$	Number of loss of load occasions in the complementary scenarios, $\sum_{i=1}^{1000} g(y_i^*)$	Number of loss of load occasions in the original scenarios, $\sum_{i=1}^{1000} \tilde{g}(y_i)$	Number of loss of load occasions in the complementary scenarios, $\sum_{i=1}^{1000} \tilde{g}(y_i^*)$
12	9	9	7

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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)** .... ¤/MWh

c) .... ¤/MWh

Problem 3

a) .... MW **b)** .... MW/Hz

c) .... Hz

Problem 4

a) Parameters: ....

Optimisation variables: ....

b) ....

c) ....

....

....

d) Alternative .... is correct.

Problem 5

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

c) .... % **d)** .... kW

e) .... %

Problem 1

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

Problem 2

a) 120/150 = 80% of the biofuel capacity will be used at the electricity price 320 ¤/MWh; hence, the annual generation is 24 TWh/year.

b) Assume that the electricity price, λ, is in the range 305 to 350 ¤/MWh. Hydro power and nuclear power will generate 120 TWh; thus, the other two power sources must generate 31 TWh together. The contribution from biofuel and coal condensing can be expressed as

$$\frac{\lambda - 200}{350 - 200}30 + \frac{\lambda - 305}{505 - 305}10.$$

Setting this expression equal to 31 and solving for λ yields the electricity price λ = 345 ¤/MWh.

c) The variable costs of coal condensing including the carbon dioxide fee will be in the interval 385–585 ¤/MWh, which means that the least expensive coal condensing is now more expensive than the highest variable cost of the biofuel generation. Hydro, nuclear and biofuel can however not cover the consumption; there is still a need for 1 TWh coal condensing. This corresponds to 10% of the coal condensing capability; consequently, 10% of the price interval is used. The electricity price is therefore 405 ¤/MWh.

Problem 3

a) The frequency can decrease by 0.04 Hz before the power plants in the normal operation reserve stops participating in the primary control; this means that the remaining reserve is 2 000 MW/Hz · 0.04 Hz = 80 MW.

b) The gain at this frequency is equal to the gain of the disturbance reserve, i.e., 3 000 MW/Hz.

c) Apparently a failure of this size will result in a frequency less than 49.9 Hz. Consequently, the power plants in the normal operation reserve will increase their electricity generation as much as they can, i.e., by 80 MW. At this point, the frequency has decreased to 49.9 Hz, but there is still a need for another 930 MW, which must be supplied by the disturbance reserve. The frequency must thus decrease by another 930/3 000 = 0.31 Hz. Hence, the new frequency is 49.9 – 0.31 = 49.59 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)

$$0 \le M_{i,t} \le \overline{M}_i, \quad i = 1, 2, t = 1, \ldots, 24,$$
$$0 \le p_t, \quad t = 1, \ldots, 24,$$
$$0 \le Q_{i,j,t} \le \overline{Q}_{i,j} \quad i = 1, 2, j = 1, 2, 3, t = 1, \ldots, 24,$$
$$0 \le r_t, \quad t = 1, \ldots, 24,$$
$$\underline{S}_i \le S_{i,t}, \quad i = 1, 2, t = 1, \ldots, 24.$$

d) 5.

Problem 5

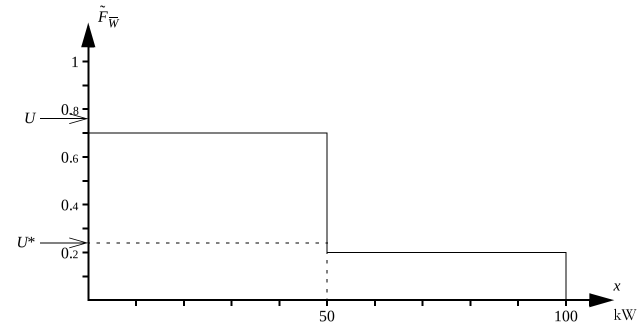
a) $EENS_0 = E[D]$ = 500 kWh/h.

b) Since the hydro power plant is 100% we get $\tilde{F}_1(x) = \tilde{F}_0(x)$. The expected generation is then

$$EG_1 = EENS_0 - EENS_1 = 500 - \int_{600}^{\infty} \tilde{F}_1(x)dx = 500 - 0.42 = 499.58 \text{ kWh/h}.$$

c) $LOLP = \tilde{F}_2(700) = 0.2\tilde{F}_1(700) + 0.5\tilde{F}_1(650) + 0.3\tilde{F}_1(600) =$
$= 0.2 \cdot 0 + 0.5 \cdot 0.001 + 0.3 \cdot 0.023 = 0.74\%$.

d) The transform must be based on the duration curve, because U_0 is transformed into $\overline{W} = 0$ (cf. the figure below). The complementary random number is given by $U^* = 1 - U$, which is transformed into 50, i.e., $\overline{W}^* = 50$ kW.



e) In practice there is no need to differentiate between observations based on the original scenarios and the complementary scenarios; the expected difference between the detailed and simplified models is given by

$$m_{(LOLO - \tilde{LOLO})} = \frac{1}{2000}\left(\sum_{i=1}^{1000} (g(y_i) - \tilde{g}(y_i)) + \sum_{i=1}^{1000} (g(y_i^*) - \tilde{g}(y_i^*))\right) = 0.25\ \%.$$

The expectation value of the simplified model (which corresponds to a PPC model) was calculated to 0.74% /h in part c. The estimate of *LOLP* for the detailed model is thus

$$m_{LOLO} = m_{(LOLO - \tilde{LOLO})} + \mu_{\tilde{LOLO}} = 0.25 + 0.74 = 0.99\%.$$