KTH Electrical Engineering

Complementary test in EG2050 System Planning, 12 April 2012, 8:00-13:00, the small conference 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) (1 p) Which players are economically responsible that during a particular trading period (for example one hour) the system is supplied as much energy as the consumptionton?

1. The system operator.
2. The balance responsible players.
3. The consumers.

b) (2 p) The following applies to a centralised electricity market: I) Producers are free to sell to any other producer, retailer or consumer, II) All electricity trading has to be performed at a power pool, III) The consumers are free to buy from any producer or retailer.

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.

c) (1 p) Consider a producer which between 13 and 14 is producing according to plan, except that at 13:30 the producer carries out a 120 MW up regulation bid at the request of the system operator. Which real-time trading has this company been involved in during this hour?

1. The company has purchased 60 MWh regulating power from the system operator.
2. The company has sold 60 MWh regulating power to the system operator.
3. The company has sold 120 MWh regulating power to the system operator.

Problem 2 (6 p)

Assume that the electricity market in Land has perfect competition, all players have perfect information, and there are neither transmission nor capacity limitations. However the hydro reservoirs of Land has a maximal storage capacity of 50 TWh. The variable operation cost in the hydro power is negligible. On 1 January the reservoirs holds in total 40 TWh and according to the long-term forecast for the electricity market (which as already mentioned is assumed to be faultless), the reservoirs should hold 35 TWh on 31 December. The inflow and other data for the electricity market in Land are given in table 1 below. The variable costs 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 Dataor the electricity market in Land.

Power source	Production capability [TWh/year]		Variable cost [¤/MWh]
	1 January to 30 June	1 July to 31 December	
Nuclear	32	28	100–120
Coal condensing	20	20	300–500
Gas turbines	5	5	800–1 000
Inflow to the hydro reservoirs [TWh]	50	20	
Electricity consumption [TWh]	80	75	

a) (2 p) What would the price be in the electricity market of Land if there was *no* reservoir limitation, i.e., if the reservoirs had infinite storage capacity?

b) (2 p) How much would the reservoirs hold at midnight between 30 June and 1 July if there was *no* reservoir limitation, i.e., if the reservoirs had infinite storage capacity?

c) (1 p) Which electricity price will there be between 1 January and 30 June if the reservoir limitation is considered?

d) (1 p) Which electricity price will there be between 1 July and 31 December if the reservoir limitation is considered?

Problem 3 (6 p)

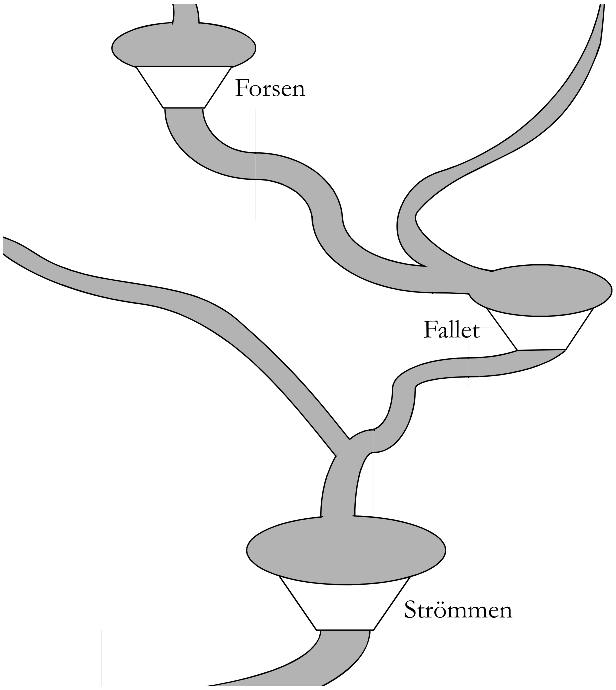
Consider a power system where the primary control is divided in a normal operation reserve and a disturbance reserve. The normal operation reserve has the gain 6 000 MW/Hz and is designed to manage normal variations in for example load and wind power generation. The disturbance reserve has the gain 2 000 MW/Hz and is designed to manage outages in larger power plants. The normal operation reserve is available in the frequency range 49.9–50.1 Hz and the disturbance reserve is available in the frequency range 49.5–49.9 Hz.

a) (2 p) At 11:02 there is balance between production and consumption in the system and the frequency is 50.01 Hz. At this time a lightning strike in a substation causes 300 MW of generation to be lost. The concerned power plants were not part of the primary control. What will the frequency be when the primary control has restored the balance between generation and consumption?

b) (2 p) At 11:06 there is balance between production and consumption in the system and the frequency is 49.95 Hz. At this time a lightning strike in a substation causes 1 020 MW of generation to be lost. The concerned power plants were not part of the primary control. What will the frequency be when the primary control has restored the balance between generation and consumption?

c) (2 p) At 11:08 there is balance between production and consumption in the system and the frequency is 49.86 Hz. At this time a lightning strikes in a substation disconnects the regional grid in Stad, which means that 980 MW load is lost. What will the frequency be when the primary control has restored the balance between generation and consumption?

Problem 4 (12 p)



AB Vattenkraft owns three hydro power plant located as in the figure above. The following symbols have been introduced in a short-term planning problem for these hydro power plants:

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

- γ_i = expected future production equivalent for water stored in reservoir i, $i = 1, 2, 3$,
- D_t = contracted load hour t, $t = 1, \ldots, 24$,
- λ_t = expected electricity price at ElKräng hour t, $t = 1, \ldots, 24$,
- λ_{25} = expected electricity price at ElKräng after the end of the planning period,
- $M_{i,0}$ = contents of reservoir i at the beginning of the planning period, $i = 1, 2, 3$,
- $M_{i,t}$ = contents of reservoir i at the end of hour t, $i = 1, 2, 3$, $t = 1, \ldots, 24$,
- $\overline{M}_i$ = maximal contents of reservoir i, $i = 1, 2, 3$,
- $\mu_{i,j}$ = marginal production equivalent in power plant i, segment j, $i = 1, 2, 3$, $j = 1, 2$,
- p_t = purchase from ElKräng hour t, $t = 1, \ldots, 24$,
- $Q_{i,j,t}$ = discharge in power plant i, segment j, during hour t, $i = 1, 2, 3$, $j = 1, 2$, $t = 1, \ldots, 24$,
- $\overline{Q}_{i,j}$ = maximal discharge in power plant i, segment j, $i = 1, 2, 3$, $j = 1, 2$,
- r_t = sales to ElKräng hour t, $t = 1, \ldots, 24$,
- $S_{i,t}$ = spillage from reservoir i during hour t, $i = 1, 2, 3$, $t = 1, \ldots, 24$,
- $\overline{S}_i$ = maximal spillage from reservoir i, $i = 1, 2, 3$,
- W_t = expected generation of the wind farm in hour t, $t = 1, \ldots, 24$.

a) (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.

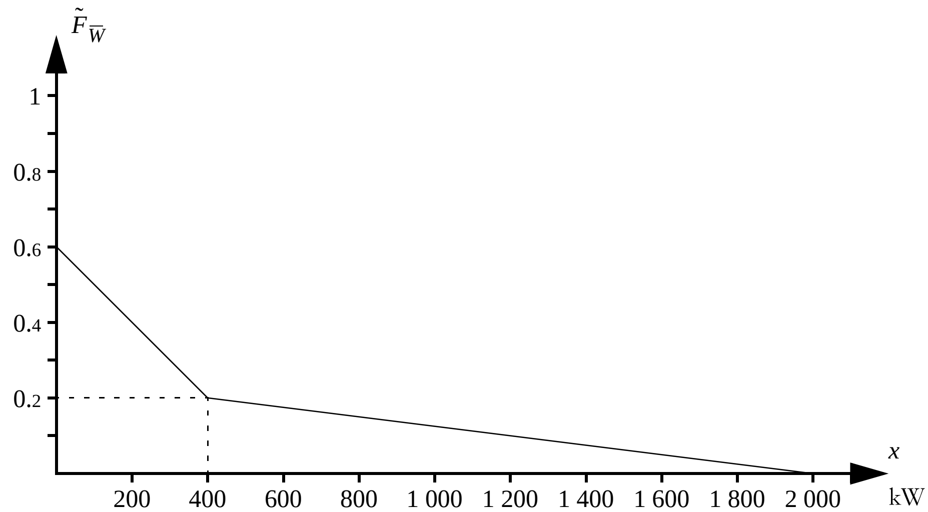
b) (4 p) Assume that AB Vattenkraft sells power to customers with firm power contracts, and is also trading at the local power exchange ElKräng, where the company has the possibility to both sell and purchase electricity. Formulate the load balance constraint of the company. Use the symbols defined above.

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 index values for each limit!

d) (1 p) The thermal power plant Flisinge is fuelled by biomass which costs 600 ¤/ton. The heat contents of the fuel is 5 MWh/ton and the power plant has an efficiency of 40%. How large is the variable operation cost in Flisinge?

Problem 5 (12 p)

Mji region is not connected to the national grid in Nchi, but has a regional 33-kV transmission system comprising the urban areas Mji and Kijiji, as well as a number of smaller villages. The regional grid is supplied by seven diesel generator sets in Mji, and a wind farm and two more diesel generator sets in Kijiji. Each diesel generator set in Mji has a capacity of 500 kW, 90% availability and the variable operation cost 10 ¤/kWh. Each diesel generator set in Kijiji has a capacity of 250 kW, 85% availability and the variable operation cost 10 ¤/kWh. The wind farm in Kijiji has a total installed capacity of 2 MW and the variable operation cost is negligible. The duration curve of the available generation capacity in the wind farm, $\tilde{F}_{\overline{W}}(x)$, is shown in the figure below. Some results from a probabilistic production cost simulation of the power system in Mji region is shown in table 2.



a) (2 p) How large is the expected available generation capacity (i.e., $E[\overline{W}]$) in the wind farm?

b) (2 p) Use probabilistic production cost simulation to calculate the *total* expected generation energy per hour in the nine diesel generator sets.

c) (1 p) Use probabilistic production cost simulation to calculate the expected operation cost per hour in Mji region.

d) (2 p) Use probabilistic production cost simulation to compute the risk of power deficit in Mji region.

e) (3 p) Assume that the power system in Mji region should be simulated using a detailed model,

Table 2 Results from a probabilistic production cost simulation of the power system in Mji region.

	$x = 0$	$x = 2\,000$	$x = 3\,000$	$x = 4\,000$	$x = 5\,000$	$x = 6\,000$	$x = 7\,000$	$x = 8\,000$	$x = 9\,000$
$\tilde{F}_0(x)$	1.000	1.000	0.200	0.100	0.000	0.000	0.000	0.000	0.000
$\int_x^\infty \tilde{F}_0(\xi)d\xi$	2 800.0	800.0	200.0	50.0	0.0	0.0	0.0	0.0	0.0
$\tilde{F}_1(x)$	1.000	1.000	0.950	0.788	0.168	0.074	0.000	0.000	0.000
$\int_x^\infty \tilde{F}_1(\xi)d\xi$	4 480.0	2 480.0	1 496.7	606.2	153.6	33.5	0.0	0.0	0.0
$\tilde{F}_8(x)$	1.000	1.000	0.971	0.854	0.366	0.113	0.024	0.001	0.000
$\int_x^\infty \tilde{F}_8(\xi)d\xi$	4 830.0	2 830.0	1 838.7	912.7	288.0	74.1	9.1	0.3	0.0
$\tilde{F}_{10}(x)$	1.000	1.000	0.976	0.868	0.405	0.125	0.030	0.002	0.000
$\int_x^\infty \tilde{F}_{10}(\xi)d\xi$	4 905.0	2 905.0	1 912.2	979.0	321.0	84.2	11.7	0.4	0.0

which for example accounts for the transmission losses and the technical details in scenarios where the system is operated with a large share of wind power; therefore, Monte Carlo simulation is used. The simulation is performed using control variates. The simplified model used to generate control variagtes is corresponding to the model used in probabilistic production cost simulation. 10 000 scenarios are generated in the Monte Carlo simulation. The result is power deficit for both the detailed and the simplified models in 1 216 of these scenarios. The result is power deficit only in the detailed model in 340 scenarios. Which estimate of *LOLP* is obtained from this simulation?

f) (2 p) A Monte Carlo simulation is considered efficient if there is a high probability that one obtains an estimate close to the true expectation value. One method to improve the efficiency of a Monte Carlo simulation is to use stratified sampling. The questions is under which circumstances stratified sampling is efficient: I) Stratified sampling is always more efficient than simple sampling, II) Stratified sampling can be more efficient than simple sampling, but it depends on how strata are defined, III) Stratified sampling can be more efficient than simple sampling, but it depends on how samples are distributed between the strata.

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

KTH Electrical Engineering

Answer sheet

Name: ....

Personal number: ....

Problem 1

a) Alternative .... is correct.

b) Alternative .... is correct.

c) Alternative .... is correct.

Problem 2

a) .... ¤/MWh **b)** .... TWh

c) .... ¤/MWh **d)** .... ¤/MWh

Problem 3

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

c) .... Hz

Problem 4

a) ....

b) ....

c) ....

....

....

d) .... ¤/MWh

Problem 5

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

c) .... ¤/h **d)** .... %

e) .... %

f) Alternative .... is correct.

Suggested solution for complementary test i EG2050 System Planning, 12 April 2012.

Problem 1

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

Problem 2

a) The total load in Land during the year is 155 TWh. The inflow and the start contents in the reservoirs together amount to 110 TWh, but as 35 TWh are to be saved for next year, the hydro power can only generate 75 TWh. Nuclear can provide 60 TWh, which is not sufficient. The last 20 TWh must originate from the coal condensing, which means that half the coal condensing capacity is utilised. The price must then be 400 ¤/MWh.

b) Nuclear is producing 32 TWh and coal condensing is generating 10 TWh during the first half of the year, which means that the hydro power generates 38 TWh, while the inflow is 50 TWh. Hence, the reservoirs are filled by 12 TWh during this period. As the reservoirs held 40 TWh at the beginning, they must then hold 52 TWh at the end of the period.

c) From part b we can conclude that the reservoirs must be filled on 30 June. To avoid spilling water, the hydro power must generate in total 40 TWh between 1 January and 30 June. Nuclear will contibute by 32 TWh, which means that the coal condensing has to generate 8 TWh during the same period. This means that 40% of the coal condensing capacity is utilised and therefore the price must be 380 ¤/MWh.

d) During the period 1 July to 31 December, the hydro power has access to 50 TWh (stored water from the first half of the year) + 20 TWh (inflow) – 35 TWh (water stored for next year) = 35 TWh. Nuclear will contribute by 28 TWh, which means that the coal condensing must generate 12 TWh during the same period. This means that 60% of the coal condensing capacity is utilised and therefore the price must be 420 ¤/MWh.

Problem 3

a) The decrease in electricity generation results in a frequency decrease $\Delta f = \Delta G/R$ = 300/6 000 = 0.05 Hz, i.e., the new frequency is 50.01 – 0.05 = 49.96 Hz.

b) The normal operation reserve can increase the generation by 0.05 · 6 000 = 300 MW if the frequency is 49.95 Hz. The frequency is then 49.9 Hz. The remaining 720 MW generation increase must be managed by the disturbance reserve, which results in a frequency decrease $\Delta f = \Delta G/R$ = 720/2 000 = 0.36 Hz, i.e., the new frequency is 49.9 – 0.36 = 49.54 Hz.

c) The disturbance reserve can decrease the generation by 0.04 · 2 000 = 80 MW if the frequency is 49.86 Hz. The frequency has then increased to 49.9 Hz. The remaining 800 MW generation decrease must be managed by the normal operation reserve, which results in a frequency increase $\Delta f = \Delta G/R$ = 900/6 000 = 0.15 Hz, i.e., the new frequency is 49.9 + 0.15 = 50.05 Hz.

Problem 4

a) maximise $\sum_{t=1}^{24} \lambda_t(r_t - p_t) + \lambda_{25}((\gamma_1 + \gamma_2 + \gamma_3)M_{1,24} + (\gamma_2 + \gamma_3)M_{2,24} + \gamma_3 M_{3,24})$.

b) $\sum_{i=1}^{3}\sum_{j=1}^{2} \mu_{i,j}Q_{i,j,t} + W_t + p_t = D_t + r_t$.

c) The optimisation variables involved in the problem are reservoir contents, discharge and spillage, which yields the following limits:

$0 \le M_{i,t} \le \overline{M}_i, \quad i = 1, 2, 3, t = 1, \ldots, 24,$

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

$0 \le S_{i,t} \le \bar{S}_i, \quad i = 1, 2, 3, t = 1, \ldots, 24.$

d) One tonne fuel yields 0.4 · 5 = 2 MWh and costs 600 ¤; hence, the variable operation cost is 600/2 = 300 ¤/MWh.

Problem 5

a) The expected available generation capacity in the wind farm is most easily computed directly from the duration curve $\tilde{F}_{\overline{W}}(x)$:

$$E[\overline{W}] = \int_0^{\infty} \tilde{F}_{\overline{W}}(x)dx = 400 \cdot (0.6 + 0.2)/2 + 1\,600 \cdot 0.2/2 = 320 \text{ kW}.$$

An alternative solution is to observe that the installed capacity does not exceed the minimum load (which can be concluded from $\tilde{F}_0(2\,000) = 1$); hence, all the available wind power generation will be utilised. Therefore, expected available generation capacity is equal to expected generation for the wind farm, where the latter can be computed using probabilistic production cost simulation:

$$EG_1 = EENS_0 - EENS_1 = \int_0^{\infty} \tilde{F}_0(x)dx - \int_{2\,000}^{\infty} \tilde{F}_1(x)dx = 2\,800.0 - 2\,480.0 = 320.0 \text{ kWh/h}.$$

b) The total generation is given by

$$EG_{\text{diesel}} = EENS_1 - EENS_{10} = \int_{2\,000}^{\infty} \tilde{F}_1(x)dx - \int_{6\,000}^{\infty} \tilde{F}_{10}(x)dx = 2\,480.0 - 84.2 = 2\,395.8 \text{ kWh/h}.$$

c) The expected total operation cost is given by

$$ETOC = 10EG_{\text{diesel}} = 10 \cdot 2\,395.8 = 23\,958 \text{ ¤/h}.$$

d) The risk of power deficit is given by

$$LOLP = \tilde{F}_{10}(6\,000) = 12.5\%.$$

e) $m_{LOLO} = \eta_{(LOLO - \tilde{LOLO})} + \mu_{\tilde{LOLO}} = \frac{1}{n}\sum_{i=1}^{n}(lolo_i - \tilde{lolo}_i) + 0.125 = \frac{1}{10\,000}340 + 0.125 = 15.9\%.$

f) 5.