KTH VETENSKAP OCH KONST

KTH Electrical Engineering

Complementary test in EG2050 System Planning, 12 April 2013, 13:00-15:00, 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) Consider a balance responsible company which during one hour has generated 890 MWh, sold 400 MWh to the power exchange, sold 460 MWh to consumers with take-and-pay contracts and sold 20 MWh regulation power to the system operator. How large is the imbalance of this company for this hour? (Disregards whether the imbalance is positive or negative.)

1. 0 MWh.
2. 10 MWh.
3. 20 MWh.
4. 30 MWh.
5. None of the alternatives above is correct.

b) (2 p) The following applies to a vertically integrated electricity market I) The power companies are free to sell to any other power company, II) All electricity trading must be performed via a power exchange, III) The consumers are free to buy from which producer or retailer they want.

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)

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 limited storage capacity. The variable operation cost in the hydro power is negligible. On 1 January the reservoirs holds in total 20 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 25 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; the production is zero if the price is on the lower price level and the production is maximal at the higher price level.

Assume that the electricity price is 360 ¤/MWh between 1 January and 30 June, and that it is 380 ¤/MWh between 1 July and 31 December.

Table 1 Data for 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	40	35	100–120
Coal condensing	15	15	300–450
Gas turbines	5	5	800–1 000
Inflow to the hydro reservoirs [TWh]	50	20	
Electricity consumption [TWh]	74	69	

a) (1 p) How large is the total nuclear generation in Land between 1 January and 30 June?

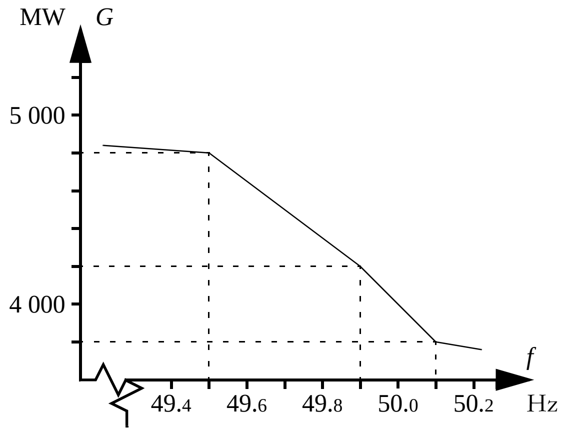
b) (1 p) How large is the total gas turbine generation in Land between 1 July and 31 December?

c) (2 p) How large is the total coal condensing generation in Land between 1 January and 30 June?

d) (2 p) How large is the total storage capacity of the hydro reservoirs in Land?

Problem 3 (6 p)

The primary control in Land is divided in a normal operation reserve and a disturbance reserve, where the former has the gain 2 000 MW/Hz and is intended to manage normal variations in for example load and wind power generation, whereas the latter is intended 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. The figure below shows the total generation in the power plants participating in the primary control as a function of the frequency in a certain power system.

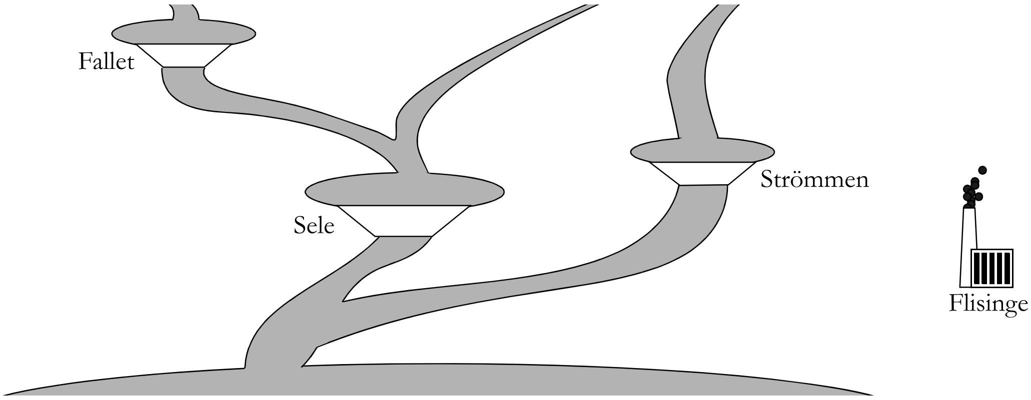


a) (2 p) How much remains of the normal operation reserve when the frequency is 49.93 Hz (i.e, how much can the generation increase in these power plants)?

b) (1 p) How large is the gain of the disturbance reserve?

c) (3 p) At a certain occasion the frequency of the system is stable at 49.93 Hz, when the hydro power plant Språnget is disconnected from the grid due to an outage in a transformer. Språnget was not part of the primary control and produced 480 MW before the outage. What will the frequency be once it has been stabilised after the outage?

Problem 4 (12 p)



AB Elkraft owns three hydro power plant located as in the figure above. Besides, the company also owns the biomass-fuelled power plant Flisinge. The following symbols have been introduced in a short-term planning problem for the power plants of the company:

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

β = variable operation cost in Flisinge,
C^+ = start-up cost in Flisinge,
γ_i = expected future production equivalent for water stored in reservoir i, i = 1, 2, 3,
G_t = generation in Flisinge, hour t, t = 1, …, 24,
$\overline{G}$ = installed capacity in Flisinge,
$\underline{G}$ = minimal generation when Flisinge is committed,
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,
$M_{i,\,0}$ = 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, …, 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, 3,
$Q_{i,\,j,\,t}$ = discharge in power plant i, segment j, during hour t, i = 1, 2, 3, j = 1, 2, 3, t = 1, …, 24,
$\overline{Q}_{i,\,j}$ = maximal discharge in power plant i, segment j, i = 1, 2, 3, j = 1, 2, 3,
$S_{i,\,t}$ = spillage from reservoir i during hour t, i = 1, 2, 3, t = 1, …, 24,
$\overline{S}_i$ = maximal spillage from reservoir i, i = 1, 2, 3,
s_t^+ = start-up variable for Flisinge hour t, t = 1, …, 24,
u_0 = unit commitment of Flisinge at the beginning of the planning period,
u_t = unit commitment of Flisinge hour t, t = 1, …, 24.
$V_{i,\,t}$ = local inflow to reservoir i, hour t, i= 1, 2, 3, t = 1, …, 24.

a) (2 p) The following symbols in the planning problem of AB Elkraft denote optimisation variables: I) γ_i, II) u_0, III) u_t.

1. None of the statements are 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.

b) (6 p) Formulate the objective function if the aim of the planning is to maximise the income of sold electricity plus the value of stored water minus the costs of Flisinge. Use the symbols defined above.

c) (4 p) Formulate the constraint that sets the relation between minimal generation and unit commitment in Flisinge during hour *t*. Use the symbols defined above.

Problem 5 (12 p)

The national grid in Nchi is suplied by a wind farm, three hydro power plants and two thermal power plants (see table 2). The figure below shows the duration curve of the total load in Nchi, $\tilde{F}_0(x)$, as well as the equivalent load duration curve when including outages in the hydro power plants and the wind farm, $\tilde{F}_2(x)$.

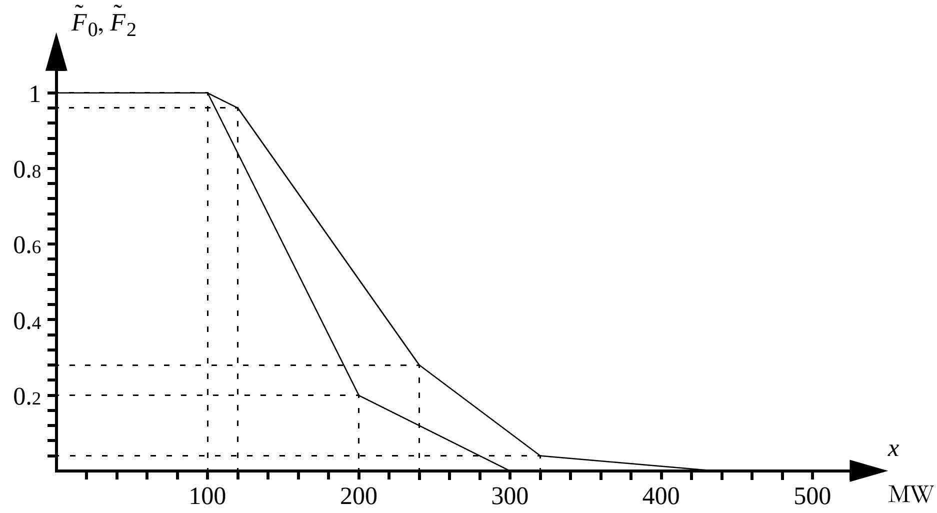


Table 2 Data for the power plants in Nchi.

Power plants	Total installed capacity [MW]	Variable costs [¤/MWh]	Availability [%]
Mlima wind farm	20	0	97*
Hydro power in River Mto	220	0	99*
Diesel generator set in Mji	20	600	80
Oil condensing power plant in Jiji	60	500	90

* Refers to the technical availability; the available generation capacity is also depending on the present weather conditions.

a) (1 p) How large is the probability that the load can be supplied using only wind power and hydro power?

b) (1 p) How large is the probability that neither of the two thermal power plants is available?

c) (1 p) How large is the probability that the marginal cost of the system (i.e., the variable cost of the most expensive unit which is committed) is equal to zero?

d) (3 p) Use probabilistic production cost simulation to compute the risk of power deficit in the system.

e) (2 p) Generate a value of the load using the inverse transform method and the random number 0.04 from a $U(0, 1)$-distribution.

f) (4 p) Assume that a power system is simulated using stratified sampling and complementary random numbers. A pilot study is performed in order to decide how to distribute the samples between the strata. 10 scenarios and 10 complementary scenarios are generated for each stratum. The results of the pilot study are shown in table 3. Which estimate of *ETOC* is obtained after the pilot study?

Table 3 Results from a Monte Carlo simulation of the power system in problem 5.

Stratum, h	Stratum weight, ω_h	Total operation cost in the original scenarios, $\sum_{i=1}^{10} g(y_i)$ [¤/h]	Total operation cost in the complementary scenarios, $\sum_{i=1}^{10} g(y_i{}^*)$ [¤/h]
1	0.40	0	0
2	0.35	28 000	26 000
3	0.25	300 000	320 000

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Answer sheet

Name: ....

Personal number: ....

Problem 1

a) Alternative .... is correct.

b) Alternative .... is correct.

Problem 2

a) .... TWh **b)** .... TWh

c) .... TWh **d)** .... TWh

Problem 3

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

c) .... Hz

Problem 4

a) Alternative .... is correct.

b) ....

....

....

c) ....

Problem 5

a) .... % **b)** .... %

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

e) .... MW **f)** .... ¤/h

Problem 1

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

Problem 2

a) As the electricity price is higher than the variable operation cost in the most expensive nuclear power plant, all nuclear power in Land will be utilised, i.e., 40 TWh.

b) As the electricity price is lower than the variable operation cost in the least expensive gas turbine, no gas turbines will be used.

c) The part of the coal condensing which has a lower variable operation cost than the electricity price 360 ¤/MWh will be used, i.e., (360 – 300)/(450 – 300) · 15 = 6 TWh.

d) As the price is lower during the first half of the year, the reservoir will be filled between 30 June and 1 July (if there had not been a reservoir limitation then the electricity price would have been the same for the entire year). The hydro power can generate in total 20 TWh (start contents) + 50 TWh (inflow) = 70 TWh during the first half of the year. The electricity consumption during this period is 74 TWh, out of which 46 TWh will be covered by nuclear power and coal condensing; hence, the hydro generation must be 28 TWh. Consequently, the reservoirs must store 42 TWh.

Problem 3

a) The frequency can decrease by 0.03 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 · 0.03 Hz = 60 MW.

b) The gain can be determinied from the figure: 600 MW/0.4 Hz = 1 500 MW/Hz.

c) Apparently a failure of this size will result in a frequency less than 49.9 Hz. Consequently, the power plants in the normal operation reserve will increase their electricity generation as much as they can, i.e., by 60 MW. At this point, the frequency has decreased to 49.9 Hz, but there is still a need for another 420 MW, which must be supplied by the disturbance reserve. The frequency must thus decrease by another 420/1 500 = 0.28 Hz. Hence, the new frequency is 49.9 – 0.28 = 49.62 Hz.

Problem 4

a) 4.

b) maximise

$$\sum_{t=1}^{24} \lambda_t\left(G_t + \sum_{i=1}^{3}\sum_{j=1}^{3} \mu_{i,j} Q_{i,j,t}\right) + \lambda_f(\gamma_1 + \gamma_2)M_{1,24} + \lambda_f\gamma_2 M_{2,24} + \lambda_f\gamma_3 M_{3,24}$$

$$- \sum_{t=1}^{24} (C^+ s_t^+ + \beta G_t).$$

c) $G_t \geq u_t \underline{G}$.

Problem 5

a) The probability that there wind power and hydro power *is not* sufficient is equal to the probability that the equivalent load exceeds the installed capacity of wind power and hydro power, i.e., $\tilde{F}_2(240) = 28\%$. Hence, the probability that wind power and hydro power is sufficient must be 72%.

b) The probability that none of the thermal power plants is available is $q_3 \cdot q_4 = 0.1 \cdot 0.2 = 2\%$.

c) The marginal cost of the system is equal to 0 ¤/MWh when wind power and hydro power has enough available capacity to supply the entire load, or when wind and hydro are insufficient, but none of the thermal power plants is available. From problem a we know that the probability of the former case is 72%. The probability of the second case is 0.28 (probability that there is a need for the thermal power plants) · 0.02 (probability that none of the thermal power plants is available) = 0.56%. In total, we then have the probability 72.56% that the marginal cost of the system is equal to 0 ¤/MWh.

d) The risk of power deficit is given by

$$\tilde{F}_4(320) = 0.8\tilde{F}_3(320) + 0.2\tilde{F}_3(300) =$$
$$= 0.8(0.9\tilde{F}_2(320) + 0.1\tilde{F}_2(260)) + 0.2(0.9\tilde{F}_2(300) + 0.1\tilde{F}_2(240)) =$$
$$= 0.8 \cdot (0.9 \cdot 0.04 + 0.1 \cdot 0.22) + 0.2 \cdot (0.9 \cdot 0.1 + 0.1 \cdot 0.28) = 0.07.$$

Hence, the risk of power deficit is 7%.

e) If the given random number is denoted U then the load is calculated by $D = \tilde{F}_0^{-1}(U)$ = {use the figure} = 280 MW.

f) We start by computing the expectation value for each stratum. In practice there is no need to differentiate between observations based on the original scenarios and the complementary scenarios; hence, we get the following estimates:

$$m_{Xh} = \frac{1}{20}\left(\sum_{i=1}^{10} g(y_i) + \sum_{i=1}^{10} g(y_i^*)\right) = \begin{cases} 0 & h = 1, \\ 2\,700 & h = 2, \\ 31\,000 & h = 3. \end{cases}$$

We can now combine the results of each stratum weighted by their stratum weights:

$$ETOC = m_X = \sum_{h=1}^{3} \omega_h m_{Xh} = 0.4 \cdot 0 + 0.35 \cdot 2\,700 + 0.25 \cdot 31\,000 = 8\,695 \text{ ¤/h}.$$