KTH Electrical Engineering

Complementary test in EG2050 / 2C1118 System Planning, 24 June 2010, 16:00-18:00, 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 the common electricity market of the two countries Rike and Maa. Assume that there is perfect competition, that all players have perfect information, and that there are neither reservoir nor capacity limitations in the power plants. Data for the common electricity market are shown in table 1. The variable production costs are assumed to be linear in 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 market in Rike and Maa.

Power source	Production capability [TWh/year]		Variable cost [¤/MWh]
	Rike	Maa	
Hydro power	60	10	30–60
Nuclear power	60	20	100–120
Coal condensing	10	20	350–500
Gas turbines	5	5	800–1 000
Electricity consumption [TWh/year]	110	55	

a) (2 p) What would the price be in the common electricity market if there is no transmission limitation between the two countries?

b) (2 p) How much should be traded between the two countries if there is no transmission limitation, i.e., which country would export and how much?

c) (2 p) The power systems of Rike and Maa are interconnected by an HVDC line, which can transfer a certain amount of TWh per year. How large is the transmission capacity of this HVDC line if the electricity price in Rike is 395 ¤/MWh, whereas the electricity price in Maa is 440 ¤/MWh?

Problem 3 (6 p)

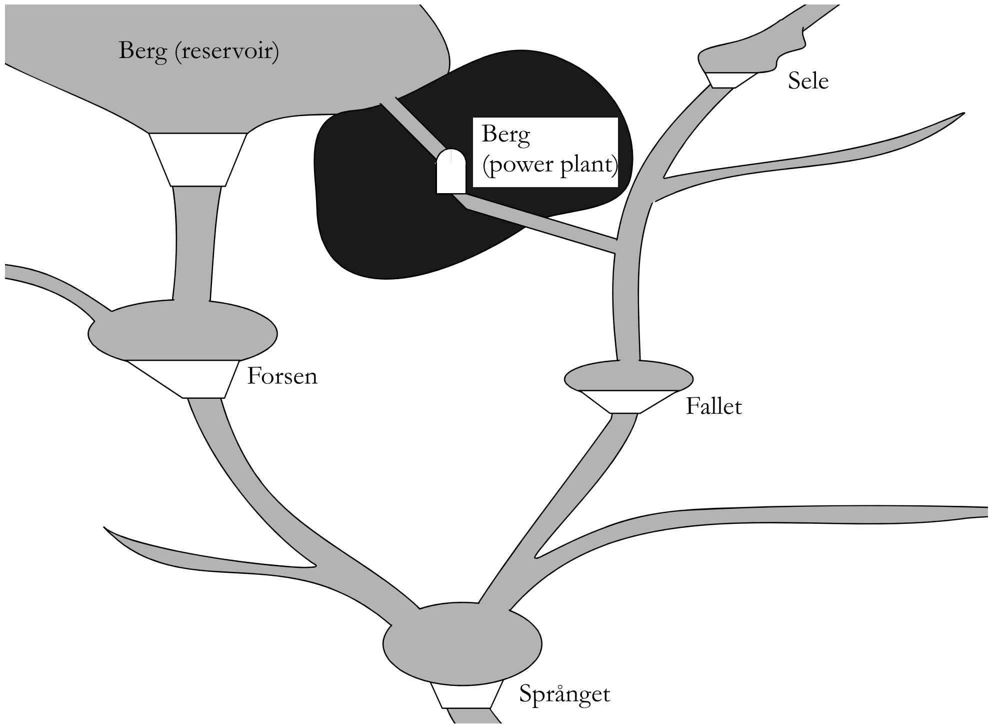
Consider a power system where the primary control is divided in a normal operation reserve and a disturbance reserve. The normal operation reserve has the gain 5 000 MW/Hz and is designed to manage normal variations in for example load and wind power generation. The disturbance reserve has the gain 2 000 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 50.02 Hz. At this time a lightning strike in a substation causes 200 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 11:05 there is balance between production and consumption in the system and the frequency is 49.80 Hz. At this time the nuclear power plant Strålinge is restarted after an earlier emergency stop, which means that the generation in the system is increased by 1 000 MW. The nuclear power plant Strålinge is not participating in 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 49.91 Hz. At this time the load of the system is decreased by 100 MW. What will the frequency be when the primary control has restored the balance between generation and consumption?

Problem 4 (12 p)



AB Vattenkraft owns five hydro power plant located as in the figure above. Notice that Berg is an underground power plant and that water that is discharged through the turbine is flowing to Fallet, whereas spillage ends up in Forsen. The following symbols have been introduced in a short-term planning problem for these hydro power plants:

Indices for the power plants: Berg - 1, Sele - 2, Forsen - 3, Fallet - 4, Språnget - 5.

λ_t = expected electricity price hour t, t = 1, …, 24,
$M_{i,0}$ = contents of reservoir i at the beginning of the planning period, i = 1, …, 5,
$M_{i,t}$ = contents of reservoir i at the end of hour t, i = 1, …, 5, t = 1, …, 24,
$\overline{M}_i$ = maximal contents of reservoir i, i = 1, …, 5,
$\mu_{i,j}$ = marginal production equivalent in power plant i, segment j, i = 1, …, 5, j = 1, 2.
$Q_{i,j,t}$ = discharge in power plant i, segment j, during hour t, i = 1, …, 5, j = 1, 2, t = 1, …, 24,
$\overline{Q}_{i,j}$ = maximal discharge in power plant i, segment j, i = 1, …, 5, j = 1, 2,
$S_{i,t}$ = spillage from reservoir i during hour t, i = 1, …, 5, t = 1, …, 24,
$V_{i,t}$ = local inflow to reservoir i during hour t, i = 1, …, 5, t = 1, …, 24.

a) (3 p) The hydro power plant Språnget has a maximal discharge of 200 m^3/s. The best efficiency is obtained for the discharge 150 m^3/s. At maximal discharge the power plants generates its installed capacity, which is 60.5 MW. At best efficiency the power plant generates 48.0 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:

$\mu_{5,j}$ = marginal production equivalent in Språnget, segment j,
$\overline{Q}_{5,j}$ = maximal discharge in Språnget, segment j.

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

c) (4 p) Formulate the hydrological constraint of Fallet, hour *t*. The water delay time between the power plants can be neglected. Use the symbols above.

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

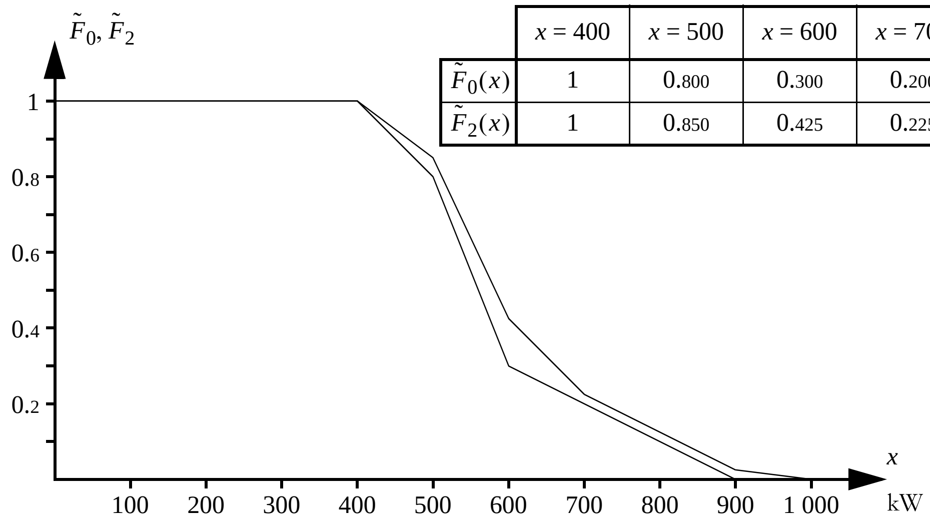
$\overline{G}$ = maximal generation when the power plant is committed,
G_t = generation in the power plant during hour *t*,
u_t = unit commitment in the power plant during hour *t* (1 if the power plant is committed during hour *t*, otherwise 0).

How should a linear constraint be formulated in order to describe the relation between $\overline{G}$, G_t and u_t for hour *t*?

1. $G_t + \overline{G} + u_t \leq 0$.
2. $G_t + \overline{G} \cdot u_t \leq 0$.
3. $G_t + \overline{G} \cdot u_t = 0$.
4. $G_t + \overline{G} \cdot u_t \geq 0$.
5. $G_t - \overline{G} \cdot u_t \leq 0$.

Problem 5 (12 p)

Ekibuga is a town in East Africa. The town is not connected to a national grid, but has a local system of its own, which is supplied by a hydro power plant in nearby Ekiyira. The local grid also supplies a few smaller villages along the road between Ekiyira and Ekibuga. The hydro power plant does not have a reservoir, but the water flow is always sufficient to generate the installed capacity (800 kW) and the risk for outages in the power plant is negligible.Moreover, there is a diesel generator set which has a capacity of 100 kW. The figure below shows the load duration curve of Ekibuga and the small villages, $\tilde{F}_0(x)$, as well as the equivalent load duration curve including outages in the diesel generator set, $\tilde{F}_2(x)$.



	$x = 400$	$x = 500$	$x = 600$	$x = 700$	$x = 900$	$x = 1\,000$
$\tilde{F}_0(x)$	1	0.800	0.300	0.200	0	0
$\tilde{F}_2(x)$	1	0.850	0.425	0.225	0.025	0

a) (3 p) Use probabilistic production cost simulation to compute the expected generation per hour in the diesel generator set.

b) (3 p) What is the availability of the first power plant?
Hint: Examine how $\tilde{F}_2(900)!$ is calculated!

c) (2 p) Generate a value of the load using the inverse transform method and the random number 0.5 from a *U*(0, 1)-distribution.

d) (3 p) Assume that the power system in Ekibuga is simulated using control variates. The simplified model corresponds to the model used in probabilistic production cost simulation, while the detailed model is a multi-area model which takes into account the losses on the lines between Ekiyira and Ekibuga. 5 000 scenarios are generated in the Monte Carlo simulation. The result is power deficit for both the multi-area model and the simplified model in 132 of these scenarios. The result is power deficit only in the multi-area model in 110 scenarios. Assume that the *LOLP* of the simplified model is 2.5%. Which estimate of *LOLP* is obtained from this simulation?

e) (1 p) Assume that stratified sampling is used instead of control variates for the simulation of Ekibuga. Results for each stratum are given in table 2. Which estimate of *LOLP* is obtained for this simulation?

Table 2 Strata in the simulation of Ekibuga.

Stratum, h	1	2	3	4	5
Stratum weight, ω_h	0.8	0.025	0.025	0.075	0.075
Estimated risk of power deficit, m_{LOLOh}	0	0.26	1	0	0.18

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Answer sheet

Name: ....

Personal number: ....

Problem 1

a) Alternative .... is correct.

b) Alternative .... is correct.

Problem 2

a) .... ¤/MWh

b) .... would export .... TWh/year

c) .... TWh/year

Problem 3

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

c) .... Hz

Problem 4

a) $\mu_{5,1}$ .... MWh/HE $\mu_{5,2}$ .... MWh/HE

$\overline{Q}_{5,1}$ .... HE $\overline{Q}_{5,2}$ .... HE

b) Parameters: ....

Optimisation variables: ....

c) ....

d) Alternative .... is correct.

Problem 5

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

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

e) .... %

Problem 1

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

Problem 2

a) The total consumption of the two nations amounts to 165 TWh. Hydro power and nuclear can in total produce 150 TWh, which means that 15 TWh coal condensing must be used. Hence, 15/30 of the price interval of the coal condensing is used, i.e., the electricity price must be 350 + 15/30 · 150 = 425 ¤/MWh.

b) The electricity production is 125 TWh in Rike (50 TWh hydro, 50 TWh nuclear and 15/30 · 30 = 5 TWh coal condensing). As the consumption in Rike is only 110 TWh, the export to Maa would be 15 TWh.

c) Since the electricity price is lower in Rike than in Maa; hence, the interconnection between Rike and Maa will be fully utilised (if there was no transmission limitation, the price would be the same in both countries). The total generation in Rike is 123 TWh/year (all hydro power and nuclear plus 45/150 = 30% of the coal condensing capacity), whereas the consumption is 110 TWh/year. The surplus is exported to Maa. Thus, we can conclude that the maximal transmission capacity is 13 TWh/year.

Problem 3

a) The decrease in electricity generation results in a frequency decrease $\Delta f = \Delta G/R$ = 200/5 000 = 0.04 Hz, i.e., the new frequency is 50.02 – 0.04 = 49.98 Hz.

b) The disturbance reserve can decrease the generation by 0.1 · 2 000 = 200 MW when the frequency is 49.9 Hz. The remaining 800 MW will be managed by the normal operation reserve, which results in a frequency increase $\Delta f = \Delta G/R$ = 800/5 000 = 0.16 Hz, i.e., the new frequency is 49.9 + 0.16 = 50.06 Hz.

c) The decrease in electricity consumption results in a frequency increase $\Delta f = \Delta G/R$ = 100/5 000 = 0.02 Hz, i.e., the new frequency is 49.91 + 0.02 = 49.93 Hz.

Problem 4

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

$\overline{Q}$ = maximal discharge in Språnget = 200,
$\hat{Q}$ = discharge in Språnget at best efficiency = 150,
$\hat{H}$ = generation in Språnget at best efficiency = 48,
$\overline{H}_i$ = maximal generation in Språnget = 60.5.

The marginal production equivalents can now be calculated according to

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

and

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

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

μ_j = marginal production equivalent in Språnget, segment j =

$$= \begin{cases} 0.32 & j = 1, \\ 0.25 & j = 2, \end{cases}$$

$$\overline{Q}_j = \text{maximal discharge in Språnget, segment } j = \begin{cases} 150 & j = 1, \\ 50 & j = 2. \end{cases}$$

b) Parameters: λ_t, $M_{i,0}$, $\overline{M}_i$, $\overline{Q}_{i,j}$, $\mu_{i,j}$ and $V_{i,t}$. Optimisation variables: $M_{i,t}$, $Q_{i,j,t}$ and $S_{i,t}$.

c) $M_{4,t} = M_{4,t-1} + V_{4,t} + Q_{1,1,t} + Q_{1,2,t} + Q_{2,1,t} + Q_{2,2,t} + S_{2,t} - Q_{4,1,t} - Q_{4,2,t} - S_{4,t}$.

d) 5.

Problem 5

a) First we can observe that $\tilde{F}_1(x) = \tilde{F}_0(x)$, because we do not have any outages in the hydro power plant. The expected generation in the diesel generator is then computed by

$$EG_2 = EENS_1 - EENS_2 = \int_{800}^{\infty} \tilde{F}_1(x)dx - \int_{900}^{\infty} \tilde{F}_2(x)dx = 0.1 \cdot 100/2 - 0.025 \cdot 100/2 =$$
$$= 3.75 \text{ kW/h/h.}$$

b) $\tilde{F}_2(900) = p_1\tilde{F}_1(900) + (1 - p_1)\tilde{F}_1(900 - 100) \Rightarrow$

$$p_1 = \frac{\tilde{F}_2(900) - \tilde{F}_1(800)}{\tilde{F}_1(900) - \tilde{F}_1(800)} = \frac{0.025 - 0.1}{0 - 0.1} = 75\%.$$

c) If the given random number is denoted U then the load is calculated by $D = \tilde{F}_0^{-1}(U)$ = {interpolate using either the figure or the table} = 560 MW.

d) $m_{LOLO} = \eta_{(LOLO - \tilde{LOLO})} + \mu_{\tilde{LOLO}} = \frac{1}{n}\sum_{i=1}^{n}(lolo_i - \tilde{lolo}_i) + 0.025 = \frac{1}{5\,000}110 + 0.025 = 4.7\%$.

e) $m_{LOLO} = \sum_{h=1}^{5} \omega_h m_{LOLOh} = 0 + 0.025 \cdot 0.26 + 0.025 \cdot 1 + 0 + 0.075 \cdot 0.18 = 4.5\%$.