KTH Electrical Engineering

Complementary test in EG2050 System Planning,
4 April 2011, 13:00-15:00, H21

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 of the following players have the responsibility to continuously maintain the physical balance between generation and consumption?

1. Each producer and consumer.
2. The balance responsible players.
3. The system operator.

b) (2 p) The consumers in a bilateral electricity market has the following choices: I) They can choose which system operator they want, II) They can choose which retailer they want, III) The can choose which player should manage their balance responsibility.

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

c) (1 p) Consider a producer which between 13 and 14 is producing according to plan, except that at 13:40 the producer carries out a 180 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 more than 60 MWh regulating power to the system operator.

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. Data for the electricity consumption in Land is provided in table 2. The consumers' willingness to pay is assumed to be linear within the intervals, i.e., the consumption is zero if the price is at the higher price level and the consumption is maximal at the lower price level.

Table 1 Data for the power plants in Land.

Power source	Production capability [TWh/year]	Variable costs [¤/MWh]
Hydro	20	4–6
Nuclear	10	10–15
Biofuel	10	20–40
Fossil fuels	10	20–40

Table 2 Data for the electricity consumption in Land.

Type of consumer	Maximal consumption [TWh/year]	Willingness to pay [¤/MWh]
Base load	40	100
Price sensitive load	5	20–40
Energy intensive industries	5	0–10

a) (2 p) Which total generation would there be in Land if the electricity price was 30 ¤/MWh?

b) (2 p) Which total consumption would there be in Land if the electricity price was 30 ¤/MWh?

c) (2 p) At which electricity price will there be balance between supply and demand in Land?

Problem 3 (6 p)

Consider a power system divided in two areas, Land and Ön. The two areas are interconnected by an AC line with a maximal capacity of 400 MW. The line is equipped with a protection system which after a short time delay disconnects the line if the maximal capacity is exceeded. The transmission on this line at 1 pm. is 390 MW from Land to Ön.

Data for the power plants in Ön are shown in table 3. The power plants that are located in Land and which are participating in the primary control has a total gain of 4 400 MW/Hz. This gain is available in the frequency range 50±0.4 Hz.

Table 3 The power plants in Ön.

Power plant	Generation at 1 pm. [MW]	Minimal generation when committed [MW]	Installed capacity [MW]	Gain [MW/Hz]
Flisinge	75	35	120	200
Forsen	60	10	80.4	200
Udden	127.3	0	180	–

At 1 pm. there is balance between generation and consumption in the system, and the frequency is equal to 49.98 Hz in the entire system. At this point of time, 600 MW generation is lost due to a short-circuit in a transformer in Land.

a) (2 p) How large is the generation in Forsen when the primary control has restored the balance between generation and consumption?

b) (2 p) How large is the generation in Flisinge when the primary control has restored the balance between generation and consumption?

c) (1 p) Which frequency will there be in Ön? The answer should be given with three decimals!

d) (1 p) Which frequency will there be in Land? The answer should be given with three decimals!

Problem 4 (12 p)

AB Energi owns a combined heat and power plant with three blocks, as well as the nuclear power plant Strålinge with two reactors. Moreover, the company owns a wind farm. Assume that the company has formulated their short-term planning problem as a MILP problem and that the following symbols have been introduced:

Indices for the power plants: Flisinge block I - 1, Flisinge block II - 2,Flisinge block III - 3, Strålinge I - 4, Strålinge II - 5.

β_{Gg} = variable operation cost in power plant g, $g = 1, \ldots, 5$
C_g^+ = start-up cost in power plant g, $g = 1, \ldots, 5$,
$G_{g,t}$ = generation in power plant g, hour t, $g = 1, \ldots, 5$, $t = 1, \ldots, 24$,
$\overline{G}_g$ = installed capacity in power plant g, $g = 1, \ldots, 5$,
$\underline{G}_g$ = minimal generation when power plant g is committed, $g = 1, \ldots, 5$,
$s_{g,t}^+$ = start-up variable for power plant g, hour t, $g = 1, \ldots, 5$, $t = 1, \ldots, 24$,
$u_{g,0}$ = unit commitment of power plant g at the beginning of the planning period, $g = 1, \ldots, 5$,
$u_{g,t}$ = unit commitment of power plant g, hour t, $g = 1, \ldots, 5$, $t = 1, \ldots, 24$,
W_t = expected wind power generation in hour t, $t = 1, \ldots, 24$,

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

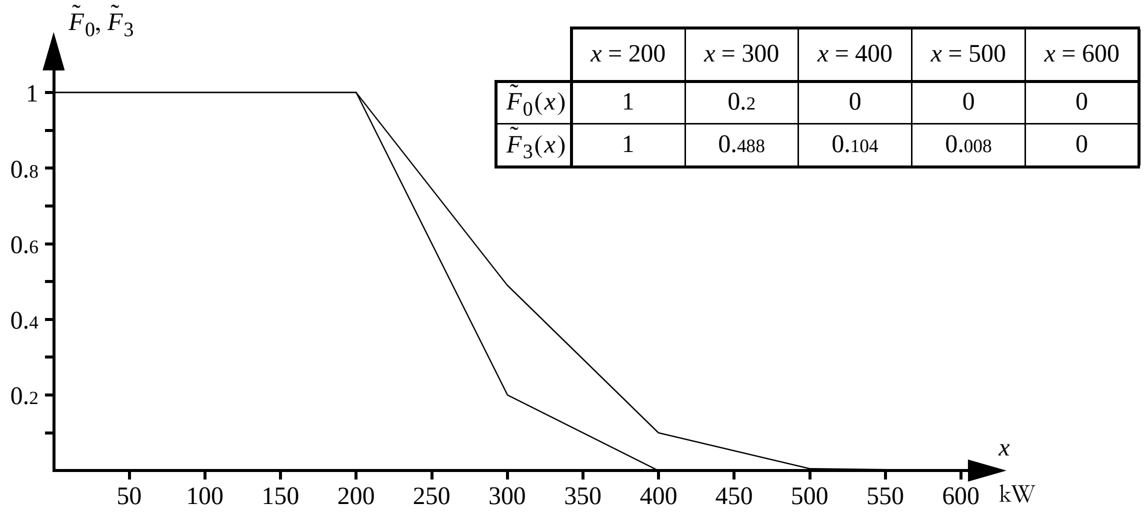
b) (4 p) AB Energi wants to minimise the operation cost for the coming 24 hours. Formulate the objective function of the short-term planning problem of the company. Use the symbols defined above.

c) (3 p) Formulate the limits for the optimisation variables defined above for the planning problem of AB Energi. To get full score for this problem, you will also have to state the possible index values for each limit!

d) (2 p) The maximal production equivalent in the hydro power plant Forsen is 0.6 MWh/HE. Assume that the power plant should generate 88.2 MWh between 13:00 and 14:00. How large is the discharge in Forsen during this hour if the relative efficiency is 98%? The answer should be given in HE.

Problem 5 (12 p)

Mji is a town in East Africa. The town is not connected to a national grid, but has a local system of its own. The local grid is supplied by a hydro power plant and two diesel generator sets. The hydro power plant does not have a reservoir, but the water flow is always sufficient to generate the installed capacity (300 kW) and the risk for outages in the power plant is negligible. The diesel generator sets have a capacity of 100 kW each. Both generators have the availability 80% and the operation cost is 2 ¤/kWh.



	$x = 200$	$x = 300$	$x = 400$	$x = 500$	$x = 600$
$\tilde{F}_0(x)$	1	0.2	0	0	0
$\tilde{F}_3(x)$	1	0.488	0.104	0.008	0

a) (2 p) Use probabilistic production cost simulation to compute the expected unserved energy per hour.

b) (2 p) Use probabilistic production cost simulation to compute the expected operation cost per hour.

c) (2 p) Use probabilistic production cost simulation to compute the risk of power deficit.

d) (2 p) Assume that a Monte Carlo simulation of the power system in Mji is to be performed, and that complementary random numbers should be used to randomise the total load of the system. What is the value of the complementary random number, D^*, if the total load of the system is randomised to $D = 350$ kW?

e) (4 p) Assume that a detailed model (taking into account the electric losses) is used in the Monte Carlo simulation. The results of 10 000 scenarios are shown in table 4. Both control variates and stratified sampling has been used in this simulation. The control variates are calculated using a simplified model corresponding to the model used in probabilistic production cost simulation. Which estimate of *ETOC* is obtained from this simulation?

Table 4 Results from a Monte Carlo simulation of the system in problem 5.

Stratum, h	Stratum weight, ω_h	Number of scenarios, n_h	Results from the detailed model, $\sum_{i=1}^{n_h} x_{i,h}$ (where $x_{i,h}$ is the observed value of *TOC* in scenario i, stratum h)	Results from the simplified model, $\sum_{i=1}^{n_h} z_{i,h}$ (where $z_{i,h}$ is the observed value of $\widetilde{TOC}$ in scenario i, stratum h)
1	0.75	100	0	0
2	0.05	4 900	58 800	0
3	0.2	5 000	602 000	490 000

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Answer sheet

Name: ....

Personal number: ....

Problem 1

a) Alternative .... is correct.

b) Alternative .... is correct.

c) Alternative .... is correct.

Problem 2

a) .... TWh/yr. **b)** .... TWh/yr.

c) .... ¤/MWh

Problem 3

a) .... MW **b)** .... MW

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

Problem 4

a) Parameters: ....

Optimisation variables: ....

b) ....

c) ....

....

....

d) .... HE

Problem 5

a) .... kWh/h **b)** .... ¤/h

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

e) .... ¤/h

Suggested solution for complementary test i EG2050 System Planning, 4 April 2011.

Problem 1

a) 3, **b)** 5, **c)** 2.

Problem 2

a) If the electricity price is 30 ¤/MWh then all hydro and nuclear will be used, as well as 50% each of the biofuel and fossil fuel generation, i.e., in total 20 + 10 + 5 + 5 = 40 TWh/year.

b) If the electricity price is 30 ¤/MWh then there will be demand for all base load and half the price sensitive load, i.e., the total consumption will be 40 + 2.5 = 42.5 TWh/year.

c) Assume a price, λ, between 20 and 40 ¤/MWh. The supply at these price levels can be written as $30 + (\lambda - 20)$ and the demand can be written $45 - (\lambda - 20)/4$. These two expressions should be equal, which results in the electricity price $\lambda = 32$ ¤/MWh.

Problem 3

a) As a consequence of the outage, each power plant will increase its generation according to its share of the total gain, which would mean an increase of $200/4800 \cdot 600 = 25$ MW in Forsen. However, it is only possible to increase the generation by 20.4 MW; hence, the power plant will generate as much as possible, i.e., 80.4 MW.

b) The total gain of the system is now 4 600 MW/Hz, since Forsen is no longer contributing to the gain. As Forsen has increased its generation by 20.4 MW the total increase in the remaining power plants must be 579.6 MW. The share of this generation increase that is allocated to Flisinge will be $200/4\,600 \cdot 579.6 = 25.2$ MW. Thus, the new generation is 100.2 MW.

c) The transmission from Land to Ön will decrease because the generation in Ön is increasing while the load remains the same. This means that there is no risk that the transmission line is disconnected. The new frequency in the system will be set by the power plants that are continuing to supply gain until the balance between generation and consumption has been restored, i.e, $\Delta f = 579.6/4\,600 = 0.126$ Hz. The new frequency in Ön is then $49.98 - 0.126 = 49.854$ Hz.

d) The frequency in Land is the same as in Ön, i.e., 49.854 Hz.

Problem 4

a) Parameters: β_{Gg}, C_g^+, $\overline{G}_g$, $\underline{G}_g$, $u_{g,0}$ and W_t. Optimisation variables: $G_{g,t}$, $s_{g,t}^+$, and $u_{g,t}$.

b) minimise $\sum_{t=1}^{24} \sum_{g=1}^{5} (C_g^+ s_{g,t}^+ + \beta_{Gg} G_{g,t})$.

c) The minimal and maximal generation for each hour is controlled by special constraints. The only limits that have to be stated are then for the binary variables:

$$s_{g,t}^+ \in \{0, 1\}, \qquad g = 1, 2, 3, t = 1, \ldots, 24,$$

$$u_{g,t} \in \{0, 1\}, \qquad g = 1, 2, 3, t = 1, \ldots, 24.$$

d) The generation as a function of discharge can be expressed as $H(Q) = \eta(Q)\gamma_{max}Q \Rightarrow$

$$Q = H(Q)/\eta(Q)\gamma_{max} = 88.2 \text{ MWh}/(0.98 \cdot 0.6 \text{ MWh/HE}) = 150 \text{ HE}.$$

Problem 5

a) The expected unserved energy is given by

$$EENS_3 = \int_{500}^{\infty} \tilde{F}_3(x)dx = 0.008 \cdot 100/2 = 0.4 \text{ kWh/h}.$$

b) First we notice that $\tilde{F}_1(x) = \tilde{F}_0(x)$, because there are no outages in the hydro power plant. The unserved energy when only considering the hydro power plant is then

$$EENS_1 = \int_{300}^{\infty} \tilde{F}_1(x)dx = 0.2 \cdot 100/2 = 10 \text{ kWh/h}.$$

The expected total generation in the two diesel generator sets is then $EG_{23} = EENS_1 - EENS_3 = 10 - 0.4 = 9.6$ kWh/h; thus, the expected operation cost is $ETOC = 2EG_{23} = 19.2$ ¤/h.

c) The risk of power deficit is given by

$$LOLP = \tilde{F}_3(500) = 0.8\%.$$

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 $D = \tilde{F}_0^{-1}(U)$. The original random number must then have been $U = \tilde{F}_0(350) = 0.1$. Hence, $U^* = 1 - U = 0.9$, which results in $D^* = \tilde{F}_0^{-1}(U^*) = 212.5$ kW.

e) We start by computing the expected difference between the detailed and the simplified model in each stratum:

$$m_{(X-Z),h} = \frac{1}{n_h} \sum_{i=1}^{n_h} (x_{i,h} - z_{i,h}) = \frac{1}{n_h}\left(\sum_{i=1}^{n_h} x_{i,h} - \sum_{i=1}^{n_h} z_{i,h}\right)$$

$$\Rightarrow \quad \begin{aligned} &m_{(X-Z),1} = 0, \\ &m_{(X-Z),2} = (58\,800 - 0)/4\,900 = 12, \\ &m_{(X-Z),3} = (602\,000 - 490\,000)/5\,000 = 22.4. \end{aligned}$$

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

$$m_{(X-Z)} = \sum_{h=1}^{3} \omega_h m_{(X-Z),h} = 0 + 0.05 \cdot 12 + 0.2 \cdot 22.4 = 5.08.$$

ETOC of the detailed model is given by the expected difference plus the result of the PPC model (which was computed in part b): $ETOC = m_{(X-Z)} + ETOC_{SPS} = 5.08 + 19.2 = 24.28$ ¤/h.