PHYS-E0483 Advances in New Energy Technologies (5 cr)

Virtual Exam 13 April 2021

You may write your answers in English, Finnish, German, or Swedish.
Handwrite on paper, scan or photo your answers and upload in MyCourses by 8.15 PM.
Include your name and study number.
Peter Lund: tel. 0405150144, peter.lund@aalto.fi. Answer all 5 questions.

1. Future flexible energy system (6p)

- Family name first letter A-L: Your task is to plan a zero-emission total energy system with wind power as the main energy source (at least 50% of all energy).
- Family name first letter M-Z..Ö: Your task is to plan a zero-emission total energy system with solar power as the main energy source (at least 50% of all energy).

Your essay should discuss the key integration/flexibility strategies striving for a functioning energy system, also keeping in mind the whole energy system and costs. You may freely choose the parameters needed.

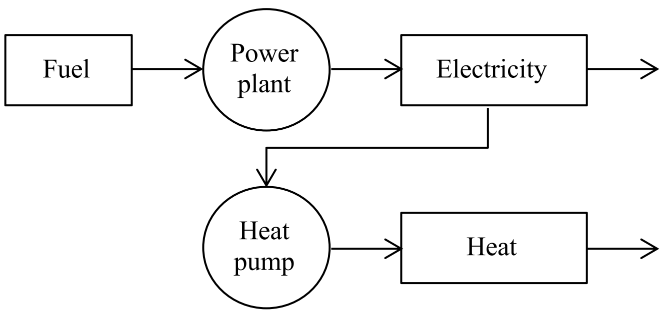
2. Inertia of energy systems (6p, each 3p)

a) Let's assume a power system with an inertia constant of T=30 seconds. Describe quantitatively how will the frequency of the power system behave during X minute after a sudden -Y% drop in the nominal power. The nominal frequency is 50 Hz.
Family name first letter A-L: X=1, Y=10
Family name first letter M-Z..Ö: X=1/2, Y=20

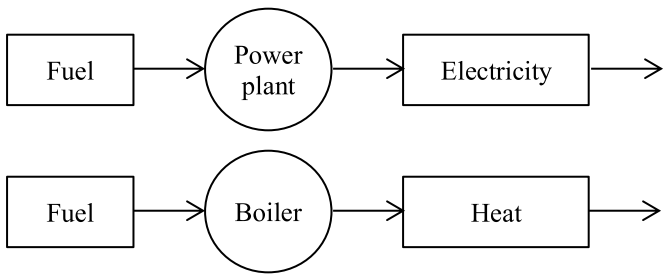
b) The inertia of a power system can be increased e.g., by using a flywheel. To add X kWh of electrical storage, estimate how large mass is required if the flywheel is designed for a spinning rate of Y rounds per second.
Family name first letter A-L: X=100, Y=1000
Family name first letter M-Z..Ö: X=1000, Y=100

3. Energy chain analysis (6p)

Consider an all-electricity energy chain topology, which consists of an electricity-producing power plant and a heat pump, and separate energy chains as reference:



All-electricity chain



Separate energy chains (reference)

In the all-electricity chain, part of the electricity is converted into heat via the heat pump, whereas the rest of the electricity is used to cover the electricity demand.

The conversion efficiencies are η_{elec} = 45 % for the power plant (traditional condensing power) and η_{heat} = 97 % for the boiler. The heat pump has an unknown COP.

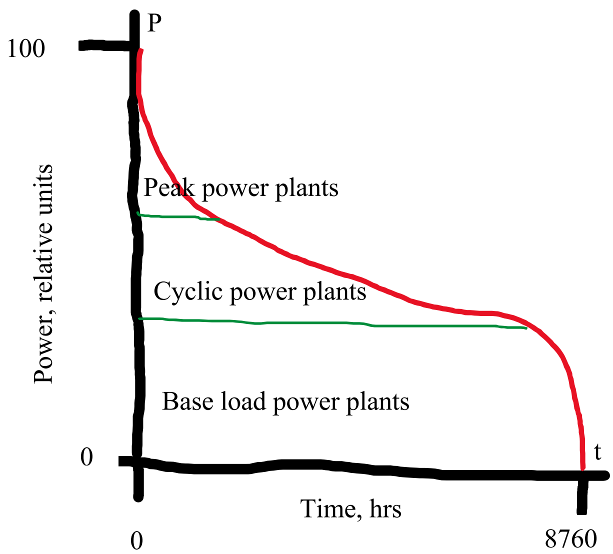
- **a)** Derive the energy effectiveness ratio r of the all-electricity chain compared to the reference, based on the energy chain analysis principle. Denote the ratio of the electricity and heat demand by $\theta = \frac{E_{elec}}{E_{heat}}$. (2p)
- **b)** What should the COP of the heat pump be so that the all-electricity chain would be more efficient than the separate heat and power production? (2p)
- **c)** How much would a 25% energy efficiency improvement in the heat demand correspond to in the COP of the heat pump? (2p)

4. **Energy system analysis** (6p, each 2p)

Typically, the portfolio of power plants required to meet the power demand (P) consists of traditional base, cyclic, and peak power plants. Adding wind or solar power (RE) to the energy system will affect the power demand profile, which the traditional power plants also need to meet, i.e. the residual power demand is P-RE. For analyzing how RE affects the residual demand and plant portfolio, one may use the power duration curve. Your task is to draw the resulting power duration curve for the residual power P-RE, when RE is added and explain how the mix of base, cyclic, and peak power would be influenced. The cases are the following:

(a) RE (=wind) is sized so that the yearly wind power production equals the yearly power demand
(b) Same case as (a) but adding a short-term diurnal electric storage to wind power
(c) Same as (a) but adding a long-term seasonal electric storage that can store all wind power
(d) Same as (a) but adding a power-to-heat scheme with a heat pump using all the surplus wind power
(e) Same as (a) but curtailing of 50% of the wind power

Family name first letter A-L: tasks a,b,d
Family name first letter M-Z..Ö: tasks a,c,e



On the left, we have the power duration curve of the power demand P (the hourly power demand over a year sorted in descending order). At point t=0, we have the peak demand equal to 100. Also, the shares of different types of power plants are shown.

Draw the residual power P-RE-curves. Need not exactly to be in scale.

5. **Power system analysis** (6p; each 1p)
Assume that a power demand of L is evenly distributed over a distribution line and produces a line voltage V(x) shown below. Your task is to draw the resulting new line voltage V'(x) for the following cases, assuming that the voltage at x=0 always remains at 100.

(a) Add a wind power plant of a size equal to the whole power demand L to point #A
(b) Add a wind power plant of a size equal to the whole power demand L to point #B
(c) Add a wind power plant of a size equal to the whole power demand L to point #C
(d) Add a wind power plant of a size twice the whole power demand L to point #A
(e) Add a wind power plant of a size twice the whole power demand L to point #B
(f) Add a wind power plant of a size twice the whole power demand L to point #C
(g) Add a wind power plant of a size twice the whole power demand L to point #O
(h) Add a wind power plant of a size equal the whole power demand L to point #O
(i) How would the line voltage change (red curve) if the cable resistance would be halved?
(j) How would the line voltage change (red curve) if the power demand is doubled?
(k) In case of a weak line, which point would be the optimal for placing the wind power?
(l) In case of a strong line, which point would be the optimal for placing the wind power?

Family name first letter A-L: tasks a,c,e,g,i, k
Family name first letter M-Z..Ö: tasks b,d,f,h,j,l