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

Exam 5 April 2016

You may write your answers in English, Finnish, German, or Swedish. You are allowed to use a calculator in the exam (Peter Lund 0405150144). Observe that there are questions on both sides of the paper. Answer 5 questions.

1. **Energy system flexibility strategies** (each 3 p)
a) Justify the use of curtailment of photovoltaics and wind power as part of an energy system flexibility strategy
b) Explain the different options and principles for Power-to-X (P2X) conversion strategies

2. **Inertia of energy systems** (each 2p)
a) Let's assume a power system with an inertia constant of T=20 seconds. Describe quantitatively how will the frequency of the power system behave during 1 minute after a sudden -30% drop in the nominal power. The nominal frequency is 50 Hz.
b) The inertia of a power system can be increased e.g. by using a flywheel. To add 1 MWh of electrical storage, estimate how large mass is required if the flywheel is designed for a spinning rate of 1000 rounds per second.
c) Estimate the thermal inertia (thermal storage capacity, GWh) of the district heating pipe network of Helsinki city. The length is 1300 km, pipe diameter 1 m, thickness of insulation around the pipe 30 cm, heat capacity of water is 4.2 kJ/kgK, density of water is 1000 kg/m^3, thermal conductivity of insulation is 0.03 W/mK. The temperature difference between forward and return water is 50 K.

3. **Energy chain analysis** (6p)
The energy effectiveness of a "new energy system" compared to an old system is described by the energy effectiveness ratio (r). The old system comprises a power plant and a heat boiler. The new energy system is based on electricity only and the heat is produced through an electric heat pump. Using the energy chain principle, show that the energy effectiveness ratio in this case is

$$r_{HP} = \frac{\theta + \dfrac{\eta_{elec}}{\eta_{heat}}}{1/COP + \theta}$$

The ratio of the electricity and heat demand is defined as

$$\theta = \frac{E_{el}}{E_{he}} = \frac{\eta_{elec} e_{el} m_{el}}{\eta_{heat} e_{he} m_{he}} = \frac{\eta_{elec} P_{el}}{\eta_{heat} P_{he}} \qquad (5)$$

η_{elec} and η_{heat} are the conversion efficiencies of separate electricity and heat plants. COP is the coefficient of performance of the heat pump

4. **Energy system analysis** (6p)
Tesla recently launched the Tesla Powerwall Li-ion battery for homes and small applications. The 7 kWh battery costs €3000 and should stand 3500 full-cycles with a 10 year guarantee. Consumer electricity in Finland costs 150€/MWh. Assume that you have a household with a solar PV system (size 3 kW$_p$, unit cost €1.7/W$_p$, yearly PV output 3 MWh) which provides 100% of the yearly electricity, but which can directly use only 33% of the PV electricity produced, because of the mismatch between the demand and the PV production. The Powerwall could increase the self-use of PV up to 70%. The utility pays €20/MWh for the PV electricity fed into the grid. With these assumptions and your own estimates on other economic parameters, if necessary, provide an assessment if it were profitable to add such a battery to the PV system, or not?

5. **Quiz**

Shortly explain 3 out 6 questions (each 2p):

a) Explain the key points of the German energy transition (Energiewende)
b) Power factor
c) Type of reserves in the power system
d) Multi-carrier energy network
e) Type of grid architectures and typologies
f) Ramping rates of power plants (also numeric estimates)