

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

Exam 29 May 2019

You may write your answers in English, Finnish, German, or Swedish. You are allowed to use a calculator in the exam (Peter Lund 0405150144). Answer 4 questions.

### 1. Energy system flexibility strategies (each 3 p)

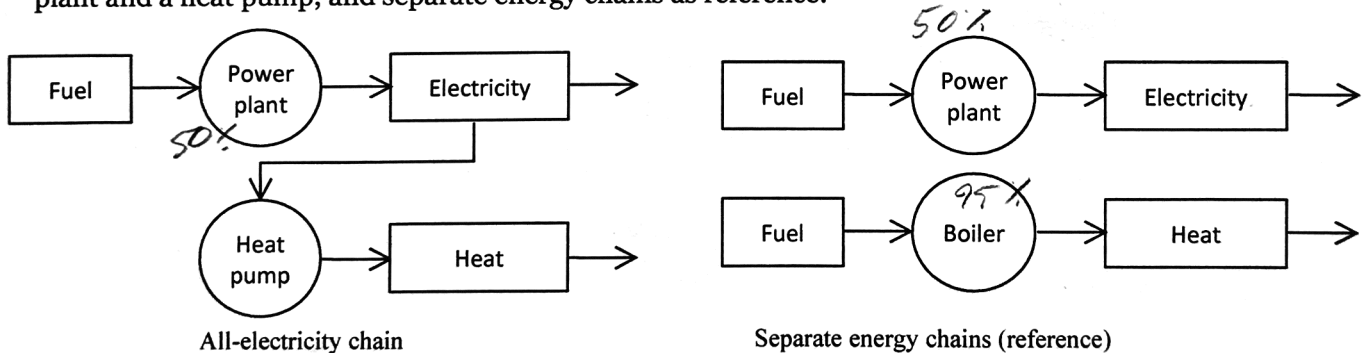
- Justify the use of curtailment of solar power as part of an energy system flexibility strategy
- Explain the different options and principles for Power-to-X (P2X) conversion strategies

### 2. Inertia of energy systems (each 2p)

- Let's assume a power system with an inertia constant of  $T=25$  seconds. Describe quantitatively how will the frequency of the power system behave during 30 s after a sudden -10% drop in the nominal power. The nominal frequency is 50 Hz.
- 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 10000 rounds per minute.
- 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<sup>3</sup>, thermal conductivity of insulation is 0.03 W/mK. The temperature difference between forward and return water is 40 K.

### 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:



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  $\eta_{elec} = 50\%$  for the power plant (traditional condensing power) and  $\eta_{heat} = 95\%$  for the boiler. The heat pump has an unknown COP.

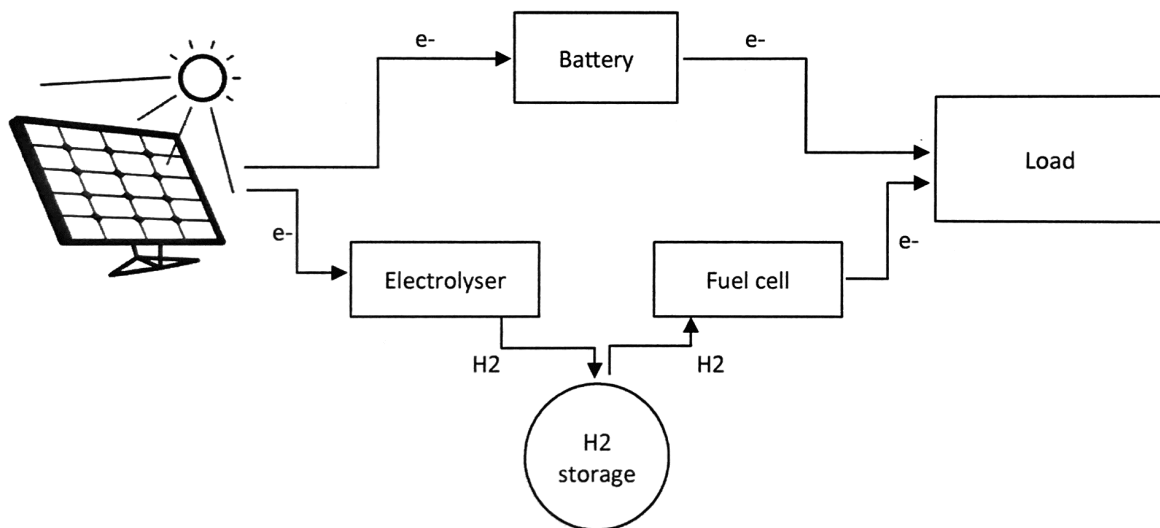
- Calculate the energy effectiveness ratio  $r$  of the all-electricity chain compared to the reference, based on the energy chain analysis principle. Denote the ratio of the electricity and heat demand by  $\theta = \frac{E_{elec}}{E_{heat}}$ .
- What should the COP of the heat pump be so that the all-electricity chain would be more efficient than separate heat and power production?

#### 4. Energy system analysis (6p)

Consider a system with solar PV and storage. PV produces electricity mostly in the summer, but electricity can also be stored for the winter. The nominal power of the panels is 5 kW, and the panels have 850 full load hours in a year resulting in 4250 kWh of electricity. The maximum power of the load is 20 kW, but the total load can be adjusted so.

Your task is to design a storage system, which is able to store the solar electricity output of one year. There are two options for the storage system: (1) Li-ion battery; (2) Hydrogen-based storage system which includes an electrolyser, a hydrogen storage and a fuel cell. The specifications of the system components can be found in the table.

- Calculate the total volume of both storage options (in litres or m<sup>3</sup>) and the available electricity after storage assuming that the storage is full loaded. Discuss your results. **(4p)**
- What is the difference between the two systems in terms of energy and power capacity? **(2p)**



	Energy density (kWh/l)	Power density (kW/l)	Efficiency (%)
Li-ion battery	0.40	2.5	90 %
Electrolyser	-	2.0	70 %
Fuel cell	-	2.5	60 %
Hydrogen storage	1.4	-	100 %