Power systems

First semester 2021-2022 **Name (Print):**
Topic 2
26/01/22
Time Limit: 105 Minutes Total: 100 points

Figure 1 shows a schematic of a hybrid power plant that combines a concentrated solar power (CSP) plant and a nuclear reactor. The solar plant consists of a central tower and a field of mirrors that collect sun radiation. The nuclear reactor is a small Pressurized Water Reactor (PWR). Both systems are connected by means of a thermal energy storage (TES) system. The fluid circulating through the solar field is a molten salt. The thermal energy is then transferred to the superheat and reheat the steam generated in the secondary side of the nuclear reactor. Finally, a system of turbines generate electricity. The following are some additional parameters of the plant:

- Nominal electric output power: $90MW$
- Nominal thermal nuclear power: $160MW$
- Electrical generator efficiency: $\eta_g = 0.93\%$
- Turbines mechanical efficiency: $\eta_m = 0.92\%$
- Molten salt heat capacity: $1510J/kgK$
- Molten salt hot and cold temperatures: $565°C$ and $296°C$
- Effective area of sun collection in the solar field $632000m^2$

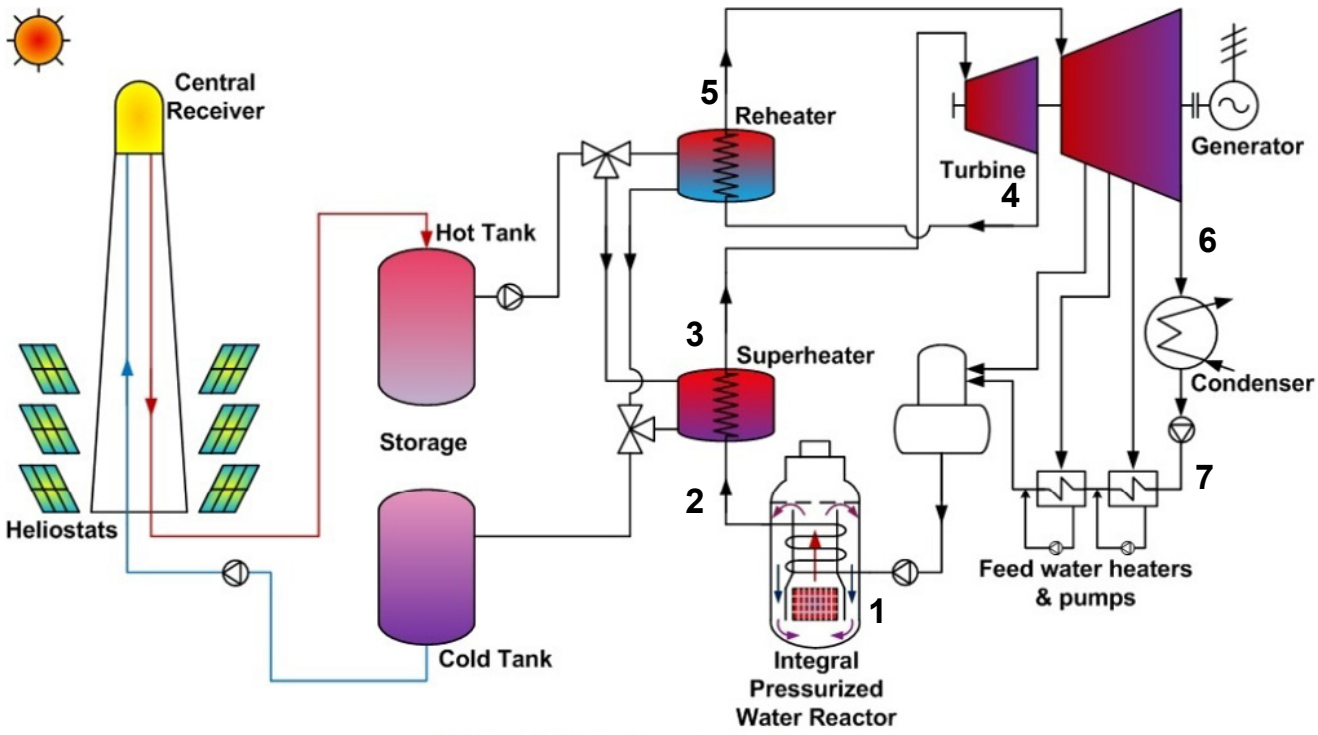

Figure 1: Scheme of the CSP nuclear power plant.

1. Consider first the thermal part of the power plant:
   (a) (15 points) Draw roughly the T-S diagram for the water-steam circuit (points 1 to 7) (Table 1 displays the points in the Rankine cycle).

Table 1: Pressure and enthalpy of different points of the Rankine cycle

Point	Pressure (bar)	Enthalpy (kJ/kgK)
1	34	630
2	34	2865
3	34	3579
4	6	3115
5	6	3602
6	0.09	2608
7	0.09	180

   (b) (10 points) What is the efficiency of the Rankine cycle?
   (c) (15 points) What is the mass flow that goes from the hot tank to the cold tank (the total, the reheater plus the superheater)?
   (d) (15 points) After four weeks of continuous operation, the hot and cold tank have the same volume as it was at the start of the time period. If the mean irradiation during this period was $250 W/m^2$, what is the average solar collector efficiency (optical + thermal)?
   (e) (15 points) Separately, the standalone nuclear power plant and the standalone solar tower would have a Rankine cycle efficiency of 33% and 44% respectively (without the mechanical and generator efficiencies). What is the increase (in percentage) of energy production with the hybrid system in comparison to the two power plants working separately (you will need results from previous answers (b and d), if you do not have them use guessed values or postulate the solution)

2. The nuclear reactor has a thermal power of $160 MW$ and the core is composed of $2.5t$ of UO_2 at an enrichment of 4.5%.
   (a) (10 points) Considering the typical Rankine cycle of a PWR reactor, what is the benefit of the present hybrid plant?
   (b) (10 points) At the start of the 4 week period, the average fuel burn-up was $15000 MWd/tU$, what is the expected average fuel burn-up after the 4 week period?
   (c) (10 points) For the next 4 weeks, we expect to have less solar radiation. In order to avoid the full depletion of the hot tank, the engineers calculated that the reactor should operate at 80% power. Explain the procedure to bring the reactor from 100 to 80 % indicating the evolution of the power, positioning of the control rods and the reactivity in the reactor.