POLITECNICO DI MILANO

MASTERS OF SCIENCE IN ENERGY ENGINEERING

LOW-CARBON TECHNOLOGIES – A.A. 2018-19

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Nuclear Power Plants

Considering the process flow diagram reported in Figure 11 associated to a nuclear reactor for the steam generation, it is required to:

- Determine the thermodynamic condition of the points reported in the scheme.
- Draw the T-s diagram of the steam cycle.
- Determine the net electrical power produced by the plant.
- Determine the net electric efficiency.
- Determine the second law efficiency considering both cases with the thermal power at the condenser recovered and wasted.

Assumptions:

- Steam generator outlet condition: $p_0 = 70$ bar, $x_0 = 0.997$.
- Relative pressure drop between the steam generator and the intercept stop valve V_i: $\Delta p/p_I = 0.015$.
- Relative pressure drop of the intercept stop valve V_i: $\Delta p/p_{Vi} = 0.02$.
- Relative pressure drop of the inlet control valves V_l: $\Delta p/p_{Vl} = 0.035$.
- Condensing steam pressure of preheater IV: $p_4 = p_{sat}(215°C)$.
- Adiabatic efficiency of the high-pressure turbine H.P.: $\eta_{IS,HP} = 0.83$.
- Low-pressure turbine inlet pressure: $p_{10} = 14.33$ bar.
- Relative pressure drop at the cold side of the re-heater RH: $\Delta p/p_{RH,cold} = 0.02$.
- Relative pressure drop at the hot side of the re-heater RH: $\Delta p/p_{RH,hot} = 0.005$.
- Temperature difference at the hot end of the re-heater RH: $\Delta T_{RH,hot\ end} = 15°C$.
- Outlet condition of the condensing vapor in the re-heater RH: saturated liquid.
- Condensing steam pressure of preheater II: $p_{12} = p_{sat}(150°C)$.
- Adiabatic efficiency of the low-pressure turbine L.P.: $\eta_{IS,LP} = 0.85$.
- Condensing steam pressure of preheater I: $p_{13} = p_{sat}(100°C)$.
- Condensing temperature: $T_{COND} = 45°C$.
- Feed pump P_a inlet pressure: $p_{18} = 6$ bar.
- Pressure drop at the cold side of each preheaters I and II: $\Delta p_{I\&II,cold} = 2$ bar.
- Hydraulic efficiency of the pumps P_e and P_a: $\eta_{Pump} = 0.7$.
- Temperature difference between the condensing temperature and the feed water exiting the preheaters I, II, III and IV: $\Delta T_{Preh} = 5°C$.
- Pressure drop at the cold side of each preheaters III and IV: $\Delta p_{III\&IV,cold} = 5$ bar.
- Pressure drop in the steam generator: $\Delta p_{SG} = 15$ bar.
- Thermal power of the nuclear reactor: $W_{th,core} = 2650$ MW
- Mechanical efficiency of the turbomachinery: $\eta_{mec} = 0.98$.
- Electrical efficiency of the generator: $\eta_{gen} = 0.99$.
- Electrical power consumption of the auxiliaries as a fraction of the condenser heat rejection: $W_{aux\%} = 0.01$.

- Temperature of the primary water entering the steam generator: $T_{prim,in}$ = 326.6°C.
- Temperature of the primary water exiting the steam generator: $T_{prim,out}$ = 291.7°C.
- Temperature of the cooling water entering the condenser: $T_{COND,in}$ = 20°C.
- Temperature of the cooling water exiting the condenser: $T_{COND,out}$ = 35°C.
- Negligible thermal losses.
- Negligible pressure drop in the condenser (cycle side).
- Negligible pressure drop in the phase separator at the high-pressure turbine outlet.
- Negligible pressure drop at the hot side of the preheaters I, II, III and IV.

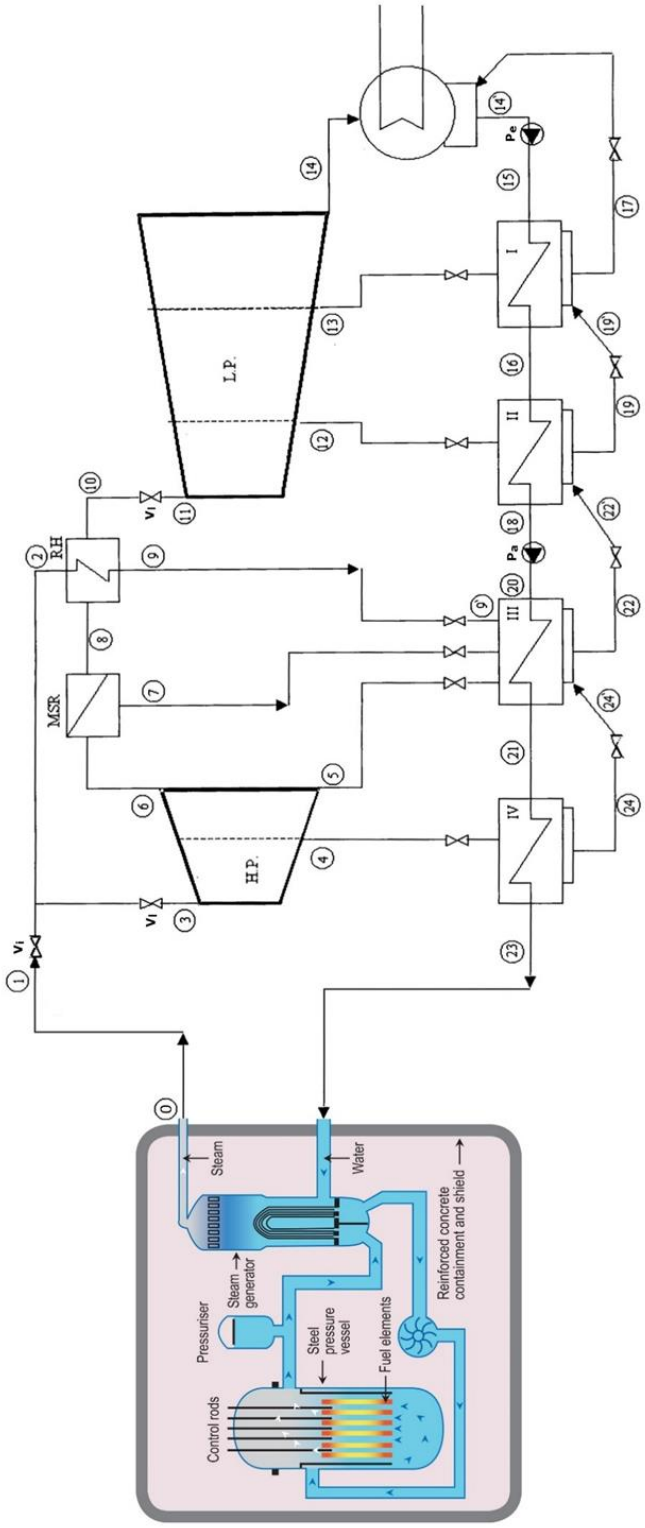

Figure 1: Simplified process flow diagram of the steam cycle of a Nuclear Power Plant