Dynamic system modeling for control and diagnosis

Modeling project
Problem statement

2012

Two stage turbine model in a pressurized water nuclear power plant

System desription

Consider the two-stage turbine in the secondary circuit of a nuclear power plant (NPP) (see Fig. 1).

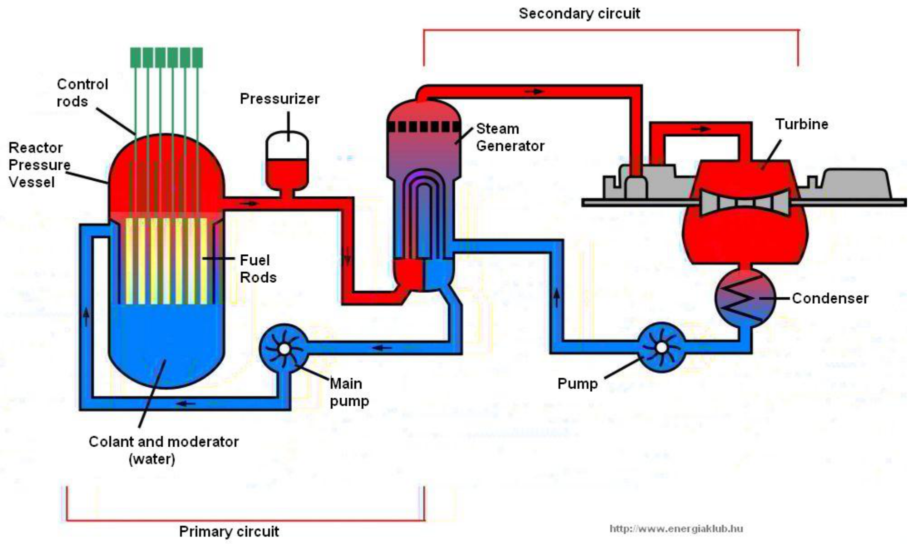


Figure 1: Flowsheet of the primary and secondary circuits in a pressurized water NPP

Let us consider the turbine subsystem, that consists of the following operating units:

- high pressure turbine stage
- super-heater (heat exchanger)
- low pressure turbine stage

- condenser

These operating units and their connections are shown in Fg. 2.

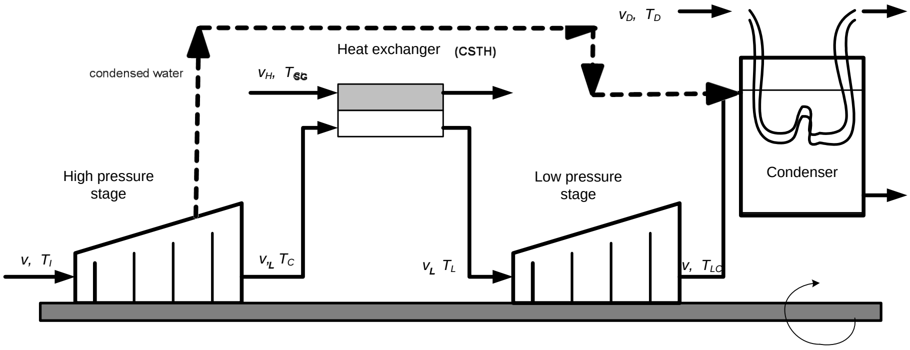


Figure 2: Operating units in the two stage turbine system

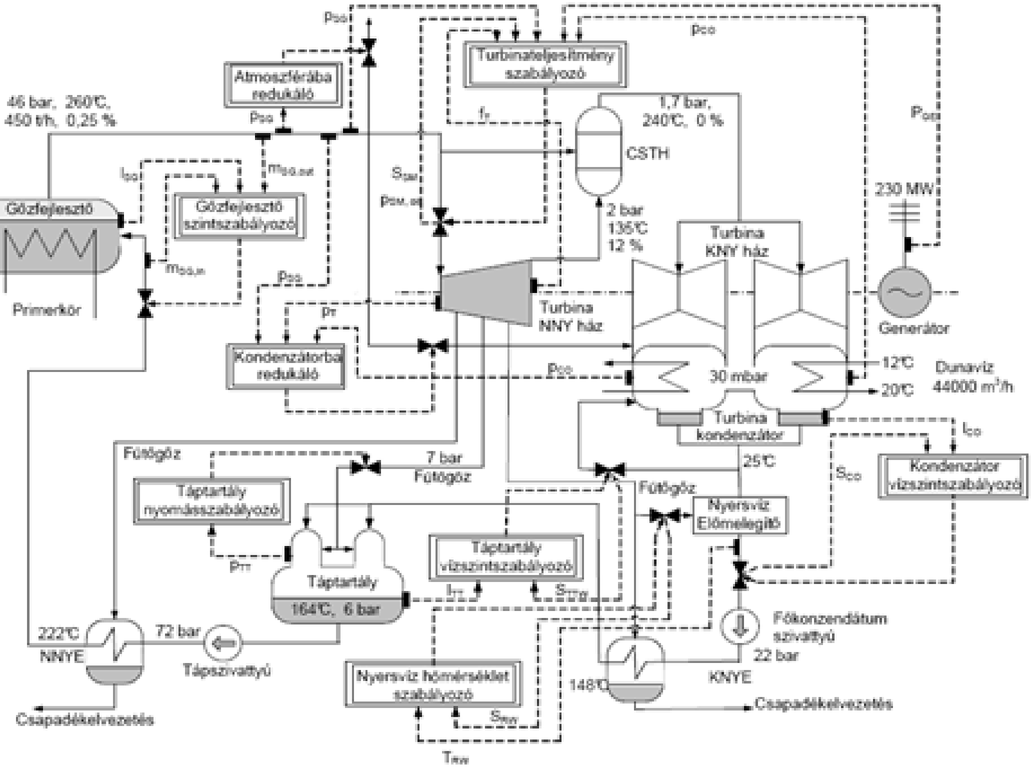
The operation principle of the turbine system can be followed in Fig. 2

1. The steam generated in the steam generator unit of the secondary circuit enters the high pressure turbine stage with a given (controlled) mass flow rate v, temperature T_I and pressure p_I in saturated state. Part of its internal energy converts to rotating energy of the turbine shaft (with efficiency factor η_H) while a part of the steam condensates with a given ratio κ_H, i.e. the water content of the steam increases. The steam and condensed water leave the high pressure stage, the condensed water is fed directly to the condenser.

2. Thereafter the steam enters into the heat exchanger (called CSTH) where the water content of the steam is reduced and the steam became overheated. A part of the steam (with mass flow of v_H and T_{sg} temperature) produced by the steam generators is by-passed in order to over-heat the steam which outflows from the high pressure turbine stage.

3. With the heated temperature the steam enters into the low pressure turbine stage with a given (controlled) mass flow rate v_L, Part of its internal energy converts to rotating energy of the turbine shaft (with efficiency factor η_L). The steam leaves the low pressure stage with the same mass flowrate but on the saturation temperature.

4. Finally, the water of the Danube with mass flowrate v_D and temperature T_D is used to condense and cool the steam that is collected in the condenser tank. From here, the steam generator level controller pumps the necessary water to the steam generator with a controlled mass flowrate v_{SG}.



2. ábra. *A szekunder kör felépítése.*

Figure 3: Schematic flow sheet of the secondary circuit with its controllers and nominal parameter values

Nominal states and water-steam properties

The nominal steady-state values can be found in fig. 3.

1. high pressure turbine inlet medium properties
   - mass flow: $v_n = 450\,t/h$
   - temperature: $T_n = 260\,C$
   - pressure: $p_n = 46\,bar$
   - water content: $0.25\,\%$
2. high pressure turbine outlet and super-heater (CsTH) inlet properties:
   - pressure: $2\,bar$
   - temperature: $135\,C$
   - water content: $12\,\%$

3. super-heater outlet and low pressure turbine inlet medium properties:
   - pressure: $1.7\,bar$
   - temperature: $240\,C$
   - water content: $0\,\%$
4. low pressure turbine outlet medium properties:
   - pressure: $0.03\,bar$
5. condenser properties:
   - pressure: $0.03\,bar$
   - outlet temperature: $25\,C$
   - temperature of the cooling water, inlet: $12\,C$, outlet: $20\,C$
   - cooling water volume flow: $v_D = 44000\,m^3/h$

Modeling problem

Firstly develop a static model using the nominal values of the steam and water properties to find the missing values of the efficiencies, then develop a simple dynamic model of the two stage turbine system that is driven by the time-dependent inputs v, p_I, v_H, T_{HL}, v_D, T_D and v_{SG}, and computes the torque of the rotating turbine shaft for the generator as its input (assuming constant angular velocity).

Modeling assumptions and suggestions

For the turbines In order to compute the turbine power one needs the pressure before and after the turbine. The pressure before the turbine is known (p_I), so only the second should be computed using the mass balance equation. Consider a control volume which consists of the turbine and the pipe which connects the turbine to the CSTH (assume its volume is known and constant). Rewrite the mass balance equation for the pressure assuming saturated steam condition. Tip: the partial derivative of the density with respect to the pressure can be numerically computed from the steam table, and can be assumed to be constant near the nominal operation point.

Write an energy balance for the turbine as follows. Assume constant mass flows m_T through the turbine, so the mass of water in the turbine is constant. How can this mass flow be calculated using the pressure and temperature of the steam? The energy balance equation will have three terms: inlet flow energy, outlet flow energy and mechanical work on the shaft. Use the specific enthalpy instead of temperature in the equation because phase-transition takes place. Consider the work efficiency constant.

Super-heater

- Consider two control volumes for the two sides of the heat-exchanger unit and consider only energy storage (only energy balance equation is needed).
- Use enthalpy instead of temperature because of the phase transition.
- Compute the temperature from the enthalpy and nominal pressure (which can be assumed constant).
- Assume constant heat transfer coefficient.
- The mass flows on each side can be assumed as model inputs.

Low pressure turbine stage The low pressure turbine stage can be described the same way as the high pressure turbine stage, but around a different operation point (the nominal properties of the steam and water are different).

Condenser Use the same assumptions as in the super heater.