NTech Lehrstuhl für Nukleartechnik

GRS Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH

Development and implementation of a Nuclear Power Plant steam turbine model in the system code ATHLET.

INTRODUCTION

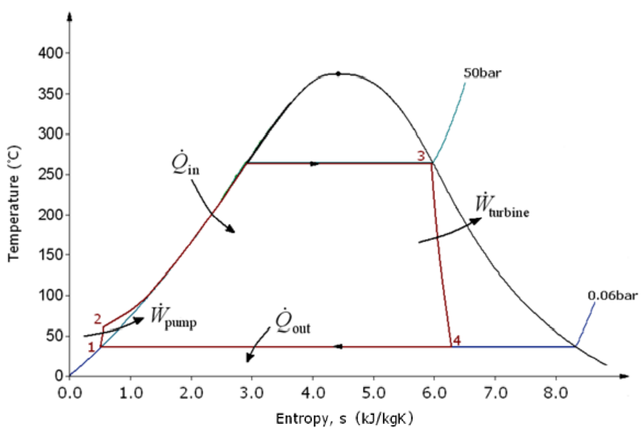
A steam turbine model is necessary in order to improve the simulation of the secondary loop of a NPP

OBJECTIVE

To develop a thermo-hydraulic steam turbine model and to implement it in ATHLET

THE RANKINE CYCLE

Temperature – Entropy diagram



Process 1-2: Working fluid compression

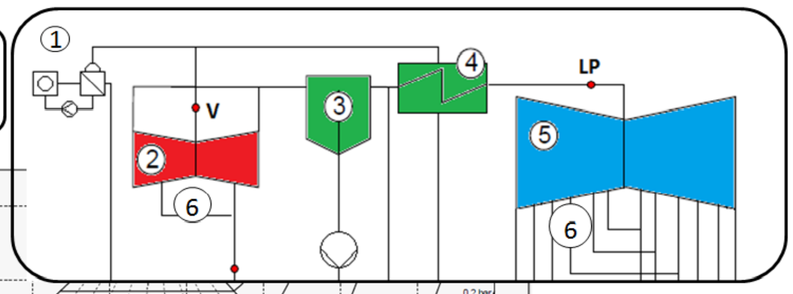
Process 2-3: Isobaric evaporation of the working fluid

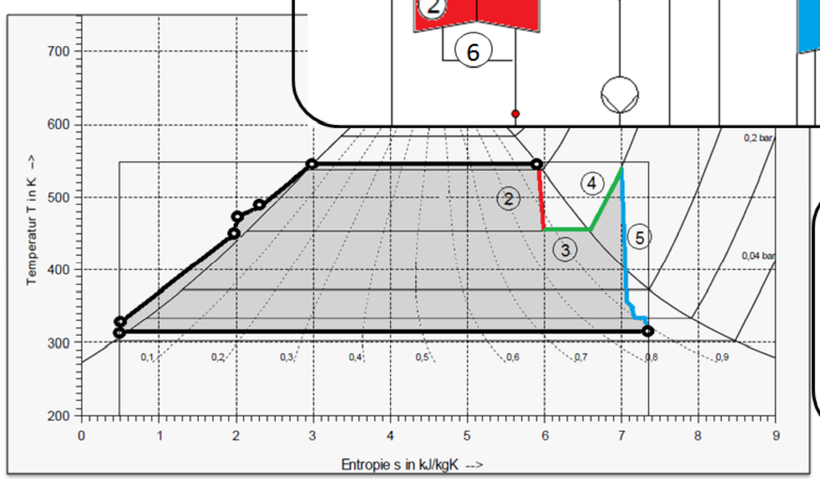
Process 3-4: Expansion of the working fluid

Process 4-1: Condensation of the working fluid

PARTICULARITIES OF A NPP TURBINE

- Saturated steam
- Condensate extractions

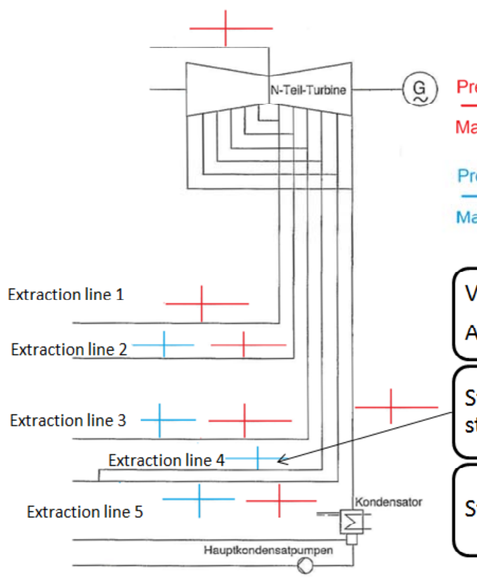




1. Primary Loop
2. HP-Turbine
3. Water Separator
4. Re-heater
5. LP-Turbine
6. Steam and Water extractions

REFERENCE PARAMETERS

Heat and mass balances of NPP Philippsburg 2 (100%, 80%, 60%, 40% nominal power)



Pressure | Enthalpy
Mass flow | Temperature/ Steam quality

❒ Steam extraction

Pressure | Enthalpy
Mass flow | Temperature

❒ Water extraction

Values at extractions known:
Assumption: Correspond to the values in the turbine

Steam quality at extraction 4 unknown, interpolation of steam quality

Steam quality improvement due to water extractions

ATHLET

- Analysis of Thermal-hydraulics of Leaks and Transients
- 1D- system code developed by GRS
- Based on Conservation Equations for mass, momentum and energy
- Modular code structure
  - Thermo-fluid dynamics
  - Heat Transfer and Heat Conduction
  - Neutron Kinetics
  - GCSM (General Control and Simulation Module)

IMPLEMENTATION STRATEGY

In a thermo-hydraulic system a turbine causes a pressure drop and a power extraction.
Additional source terms in the ATHLET equations for mass flow and steam temperature have to be developed:

$$\frac{d\dot{m}}{dt} = \frac{1}{\int \frac{1}{A} ds} \left[\Delta p_s + \Delta p_{TURBINE}\right] \qquad \frac{dT_V}{dt} = f(,,,) + Q_{TURBINE}$$

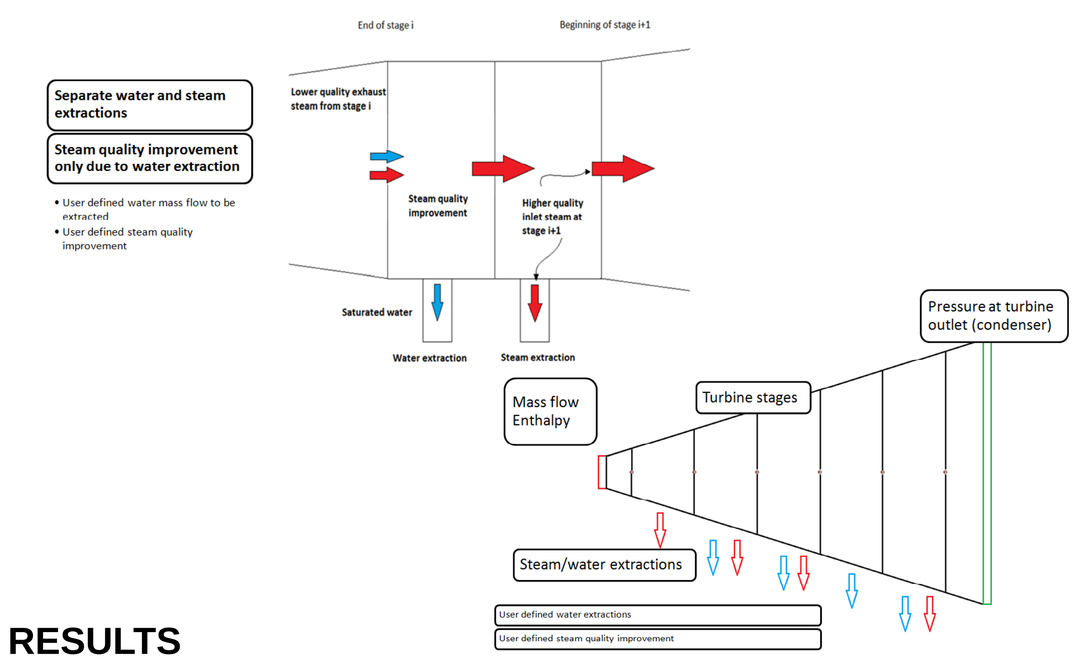
Development of models for $\Delta p_{TURBINE}$ and $Q_{TURBINE}$

- A stage is defined by a turbine section between two consecutive extractions

$$\Delta p_{STAGE} = p_a - p_a \sqrt{1 - \left(\frac{\dot{m}\, p_{a0}\sqrt{T_a}}{\dot{m}_0\, p_a \sqrt{T_{a0}}}\right)^2 \left(1 - \left(\frac{p_{b0}}{p_{a0}}\right)^2\right)}$$

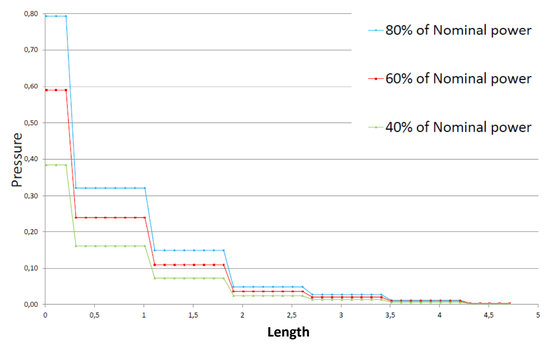
$$Q_{STAGE} = \eta_i\, \dot{m}\, \frac{1}{\rho}\, \Delta p_{STAGE}$$

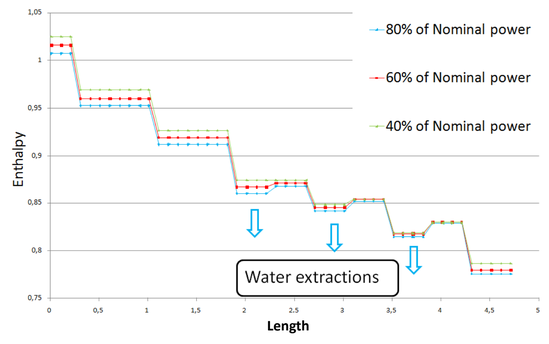
STEAM AND WATER EXTRACTIONS



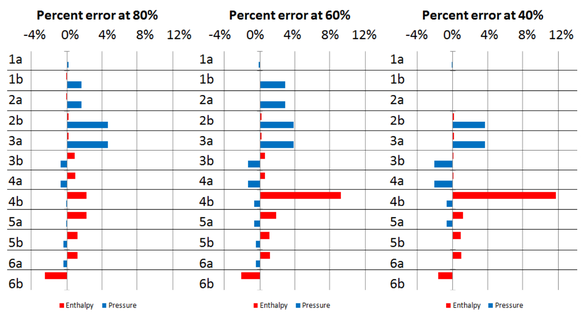
RESULTS

Pressure and enthalpy evolution along the low pressure turbine

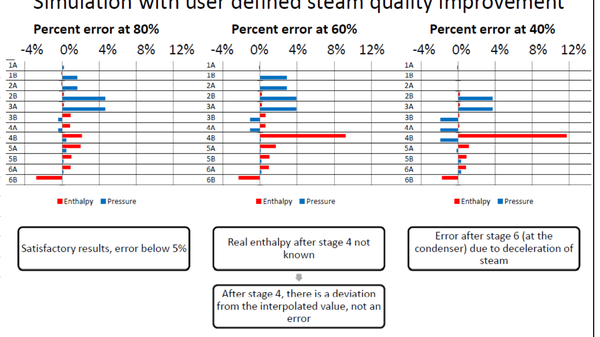




Simulation with user defined water extractions



Simulation with user defined steam quality improvement



Satisfactory results, error below 5%

Real enthalpy after stage 4 not known

After stage 4, there is a deviation from the interpolated value, not an error

Error after stage 6 (at the condenser) due to deceleration of steam

CONCLUSION

- Turbine model successfully developed and implemented in ATHLET
- Thermodynamic approach
- No need of detailed construction data
- Satisfactory description of steady state situations the errors can be attributed to incomplete reference data
- Geometrical data required for transient simulations
- The main aspects of a turbine model have been adressed

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