Use of ClaRa in the DYNSTART Project

A brief Overview

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Institute of Energy Systems

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Content

Background

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- **DYNCAP: Dynamic Investigation of thermal Power Plants**
  - Predecessor to DYNSTART, duration 01/2011 to 09/2014
  - Load range of 100 – 40 % (above Benson point)
  - In cooperation with among others XRG and TLK (establish ClaRa library)

- **DYNSTART: Start-Up and dynamic Behavior of thermal Power Plants**
  - Successor of DYNCAP, duration 08/2015 to 06/2019
  - Extending load range from 40 % down to idle, including shut-down and start-up
  - Additional focus on control system and step chains (ClaRa_Control)
  - Evaluation of power plant operation in entire load range

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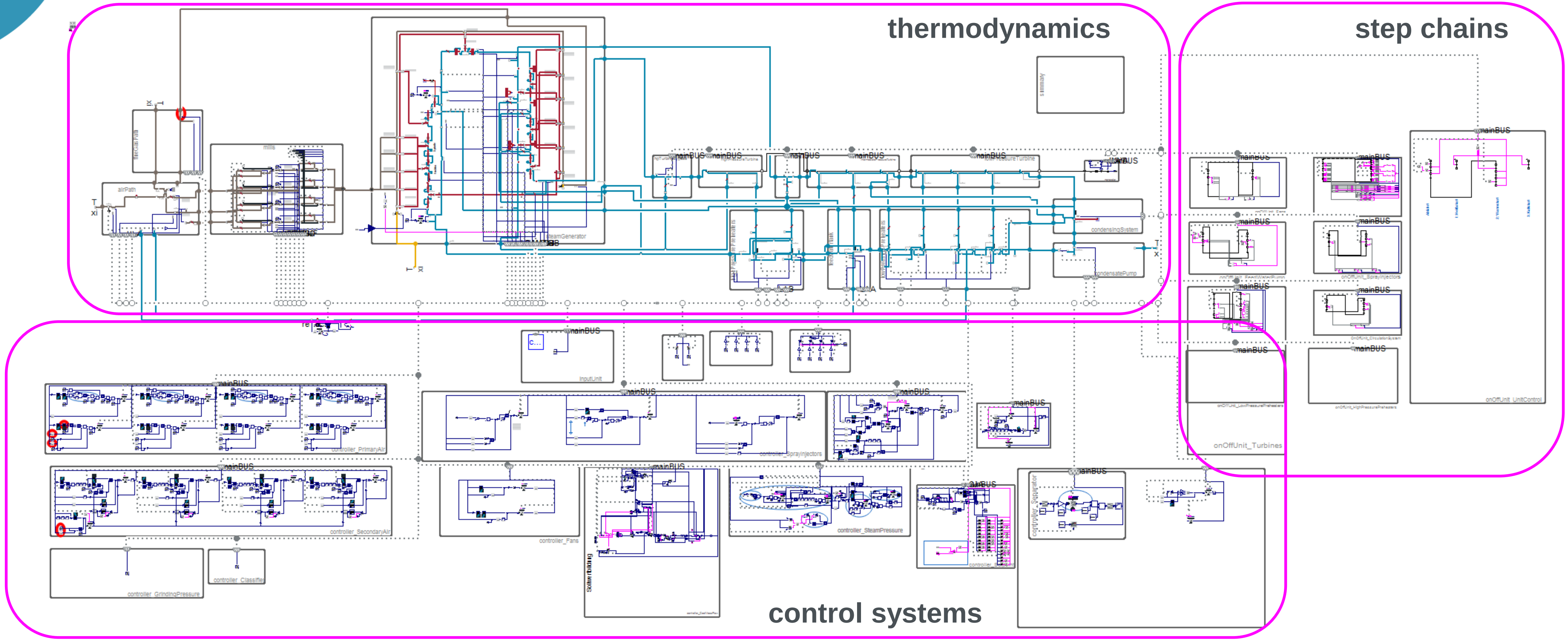
Project Scope

- **Scenarios**
  - Shut-down and different start-up procedures (cold, warm)
  - Component surface heating, modified control of the high pressure bypass valve, etc.
- **Modelling in Modelica/ClaRa**
  - Hard coal fired power plant according to a reference plant
  - Including complete water-steam-cycle, air path, coal and oil supply, control systems and step chains
  - Output 900 $MW_{el,gross}$, live steam 545 °C / 210 bar
- **Evaluation criteria**
  - Thermal and mechanical wall stresses in crucial, thick walled components

Model Structure



- In total 120.000 equations, thereof 30.000 for control systems, 2.600 states

Modelling Approach

- **Modularized structure using replaceable models**
  - Working in parallel in the same structure but with different focus
  - Allows different levels of detail for each module
  - Challenge of re-declaration, number of interface variables may differ

- **Expandable Connectors using BUS-System**
  - Keeps model executable even if inputs are “missing”
  - Beneficial especially for re-declaring controller modules
  - Reduces number of (visible) connection drastically

Expandable Connectors

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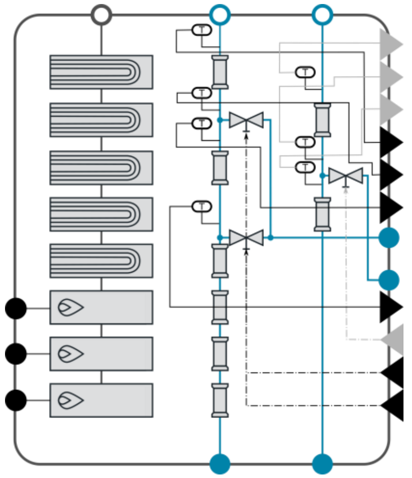
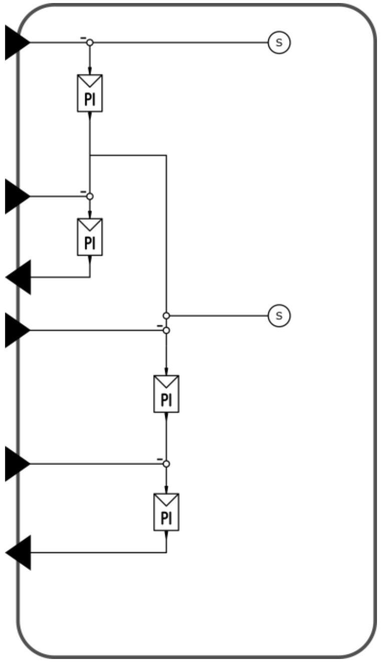
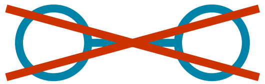
Complex Model



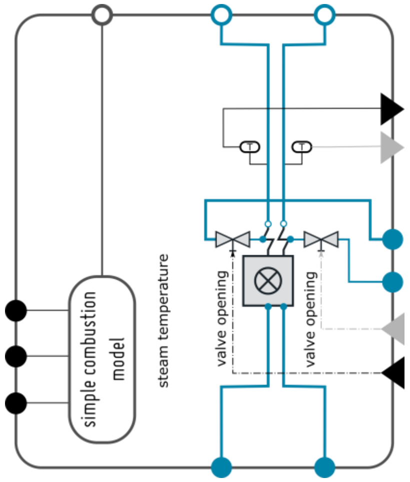
steam generator and
spray injectors



controller spray injectors



Simple Model



steam generator and
spray injectors

Expandable Connectors

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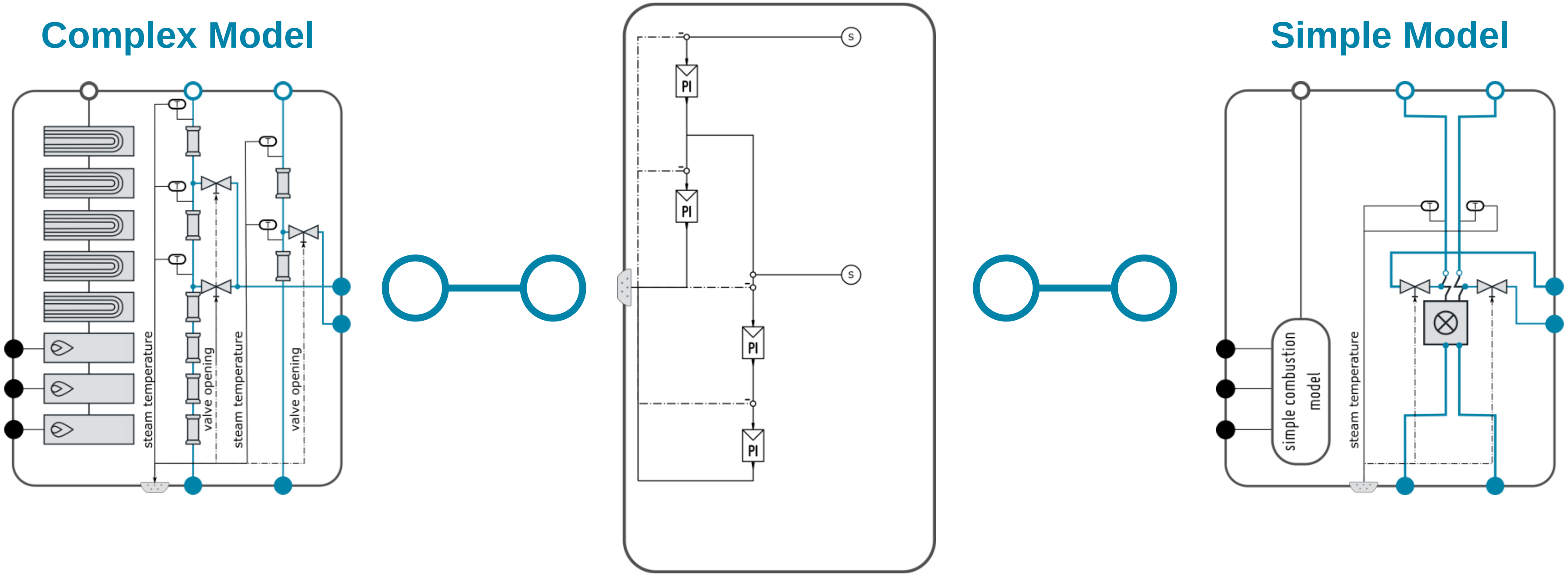
Diagram View

Complex Model

Simple Model



Modelica Code View

```
model complexSteamgenerator
  extends partialSteamGenerator;

  TemperatureSensor measurement_1;
  TemperatureSensor measurement_2;
  .
  Valve valve_1;
  .
  .
  .
  Bus bus;
equation
  .
  .
  .
  connect(measurement_1.T, bus.T_1);
  connect(measurement_2.T, bus.T_2);
  connect(measurement_3.T, bus.T_3);
  connect(measurement_4.T, bus.T_4);
  connect(bus.y_1, valve_1.opening);
  connect(bus.y_2, valve_2.opening);

end complexSteamgenerator;
```

```
expandable connector Bus
  Real T_1;
  Real T_2;
  Real T_3;
  Real T_4;
  Real y_1;
  Real y_2;
```

```
model controller_Injectors
  extends partialController_Injectors;

  controller PID_1;
  controller PID_2;
  .
  .
  Bus bus;
equation
  .
  .
  .
  .
  connect(bus.T_1, sum_1.u1);
  connect(bus.T_2, sum_2.u1);
  connect(bus.T_3, sum_3.u1);
  connect(bus.T_4, sum_4.u1);
  connect(PID_1, valve_1.opening);
  connect(PID_2.y, valve_2.opening);

end controller_Injectors;
```

```
expandable connector Bus
  Real T_1;
  Real T_2;
  Real T_3;
  Real T_4;
  Real y_1;
  Real y_2;
```

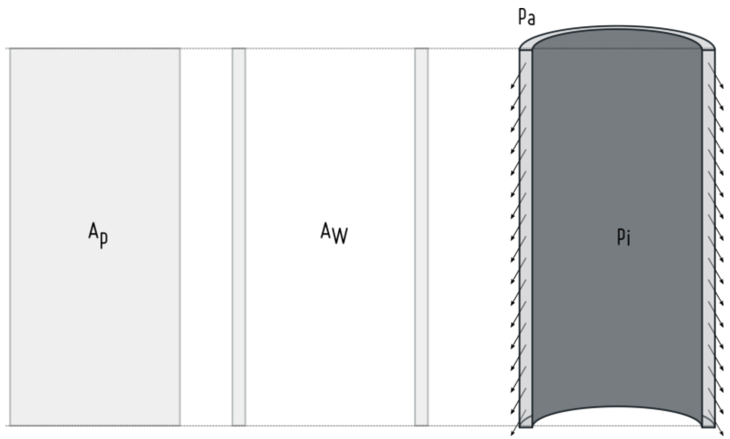
```
model simpleSteamgenerator
  extends partialSteamGenerator;

  TemperatureSensor measurement_1;
  TemperatureSensor measurement_2;
  .
  Valve valve_1;
  .
  .
  .
  Bus bus;
equation
  .
  .
  .
  .
  .
  connect(measurement_4.T, bus.T_4);

  connect(bus.y_2, valve_2.opening);

end simpleSteamgenerator;
```

Stress Computation

- **Component wall stresses**
  - For evaluation and comparison of different scenarios
  - Pressure inside the components
  - Temperature profile within the component walls
  - Component geometry

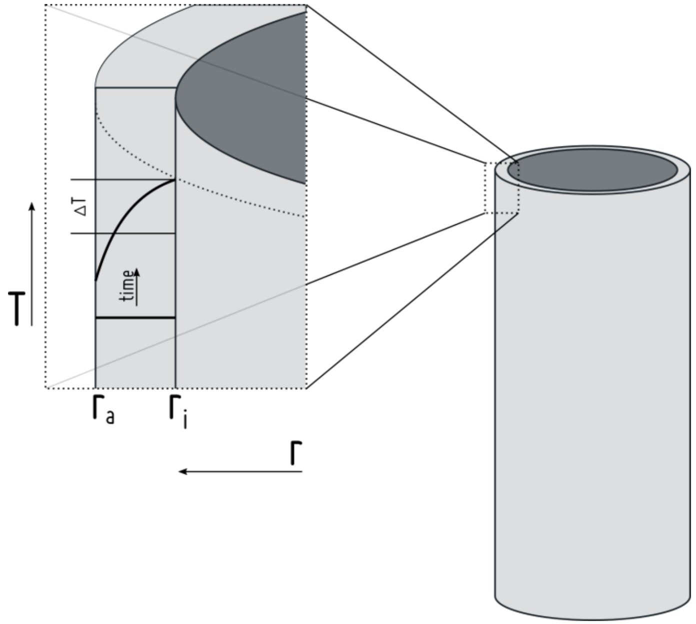
Mechanical Stress

$$\sigma_m = \alpha_m \frac{d_{ms}}{2e_{ms}} \cdot p$$



Thermal Stress

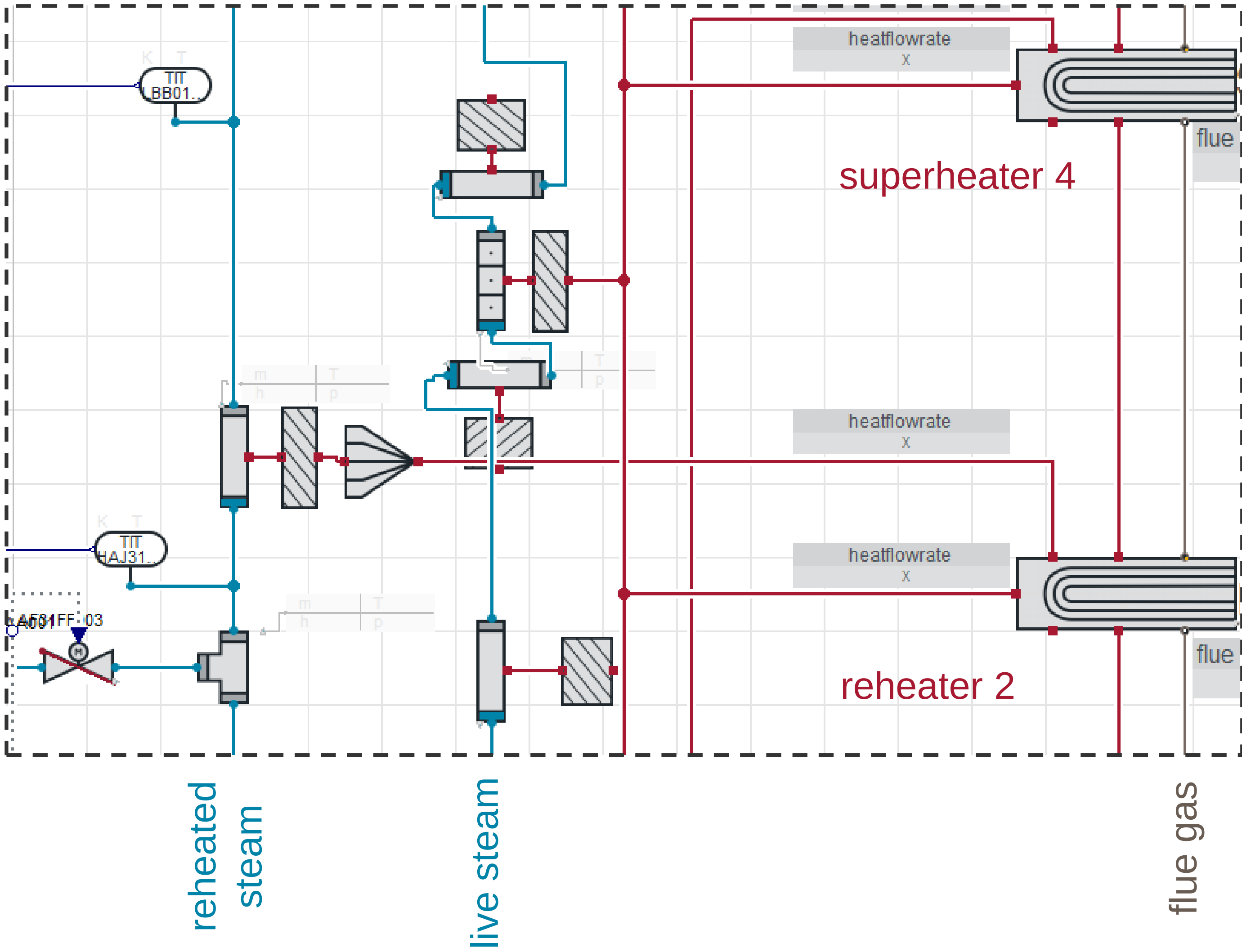
$$\sigma_t = \alpha_t \frac{\beta_t \cdot E_t}{1-\nu} \Delta T_w$$



Model Application

- **Component wall stresses**
  - Fluid temperatures and pressures taken from ClaRa volume elements
  - Application of heat transfer models in ClaRa wall elements
  - Basis for stress calculation in component walls

detail steam generator

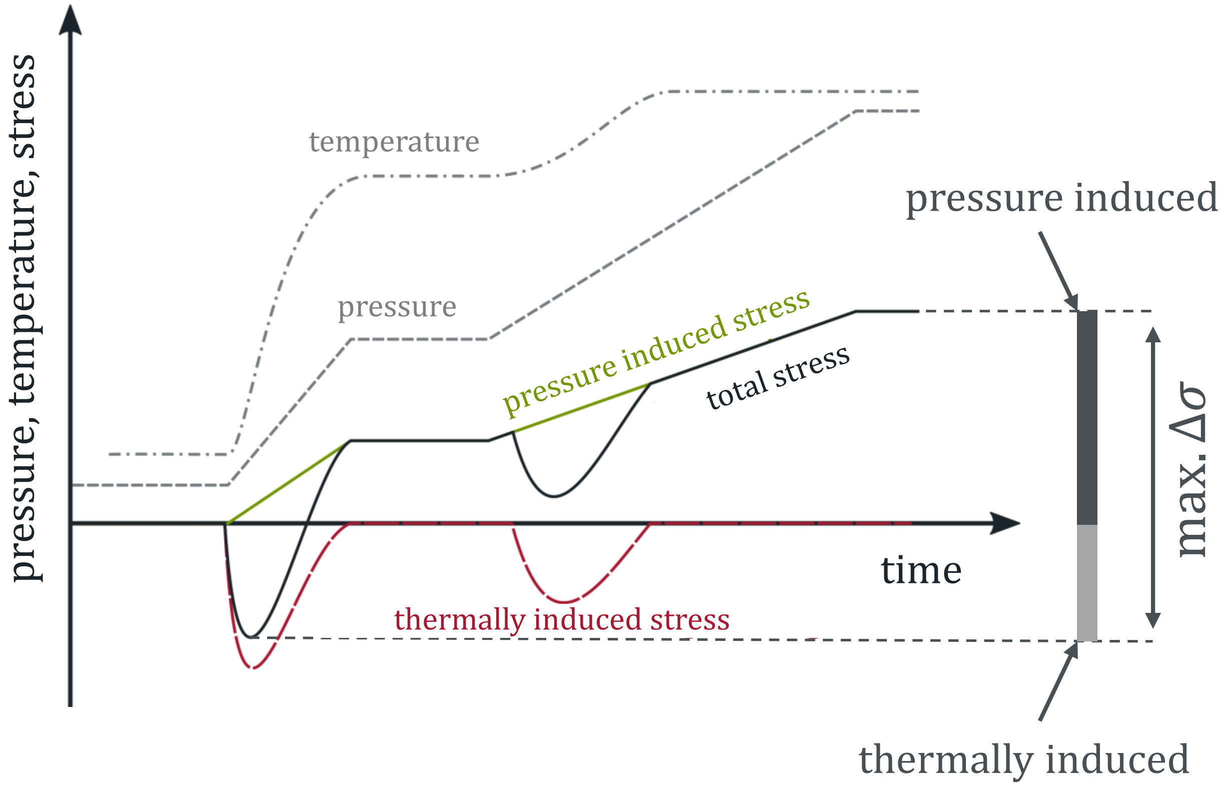


Start-Up Scenario

• Component wall stresses

- Fluid temperatures and pressures taken from ClaRa volume elements
- Application of heat transfer models in ClaRa wall elements
- Basis for stress calculation in component walls
- MATLAB post-processing according to DIN 12952

Superheater 4 Header



Exemplary Simulations Results

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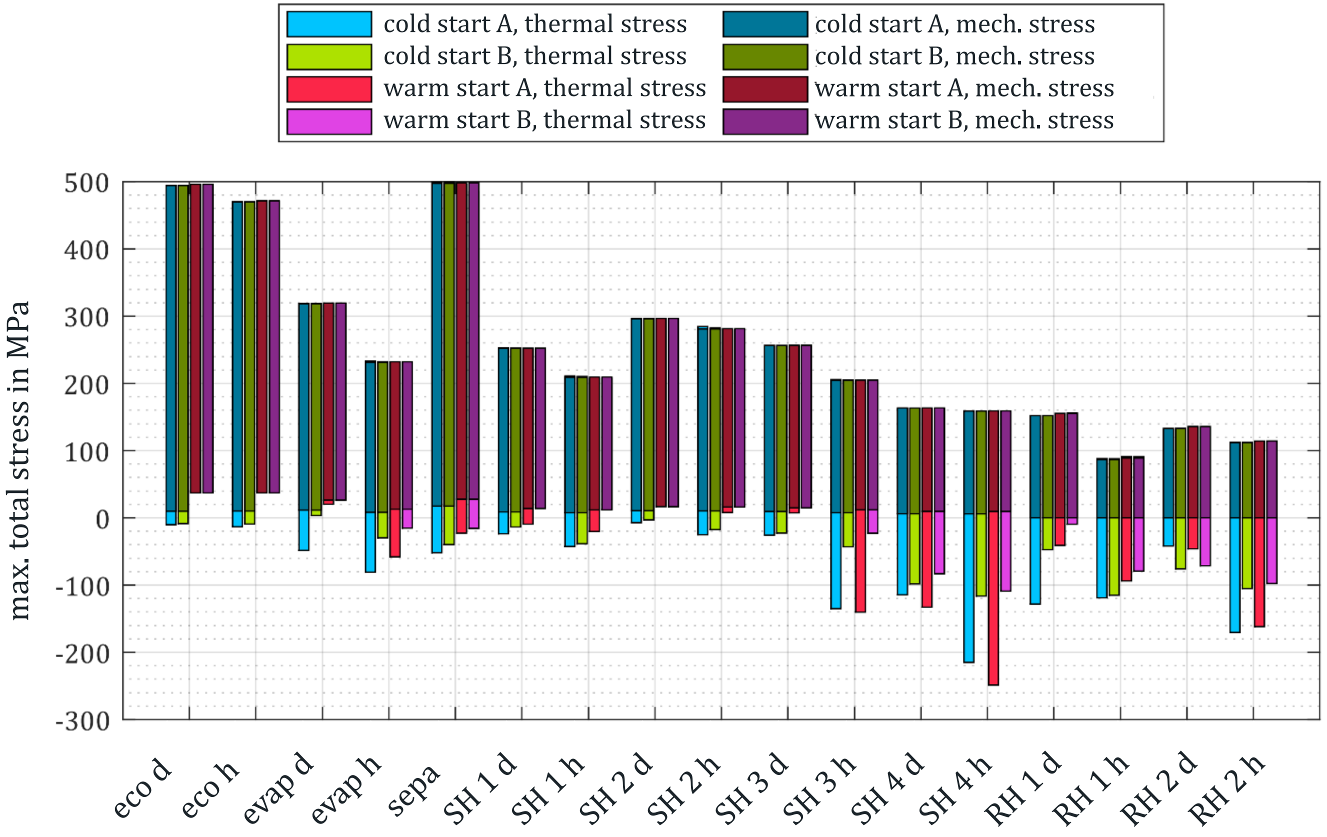
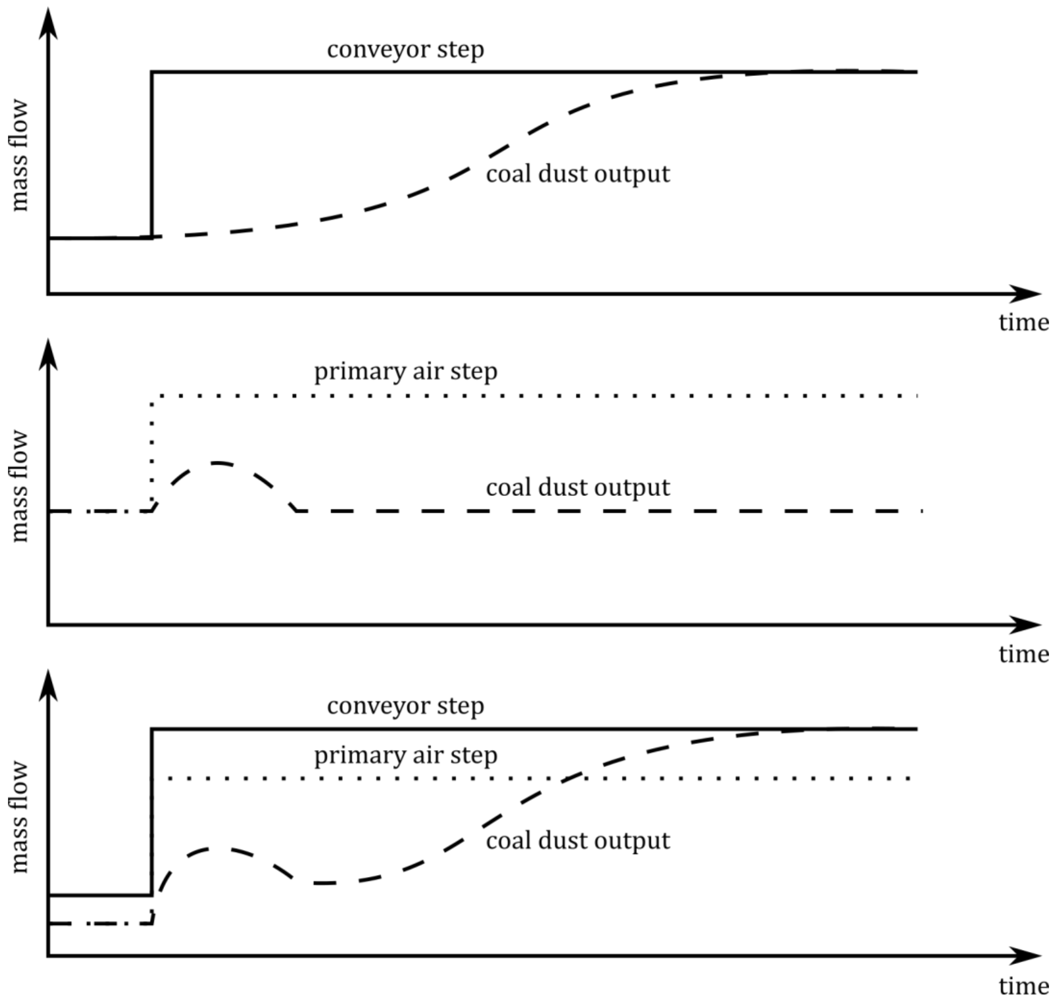
• Oscillation Width of Wall Stresses

- Main evaluation criterion for simulation results
- Considering thick-walled component such as separator and high pressure outlet header
- Bar plot allows comparison of different scenarios
- E. g. start-up of cold/warm system, above mentioned component surface heating and modified high pressure bypass valve control



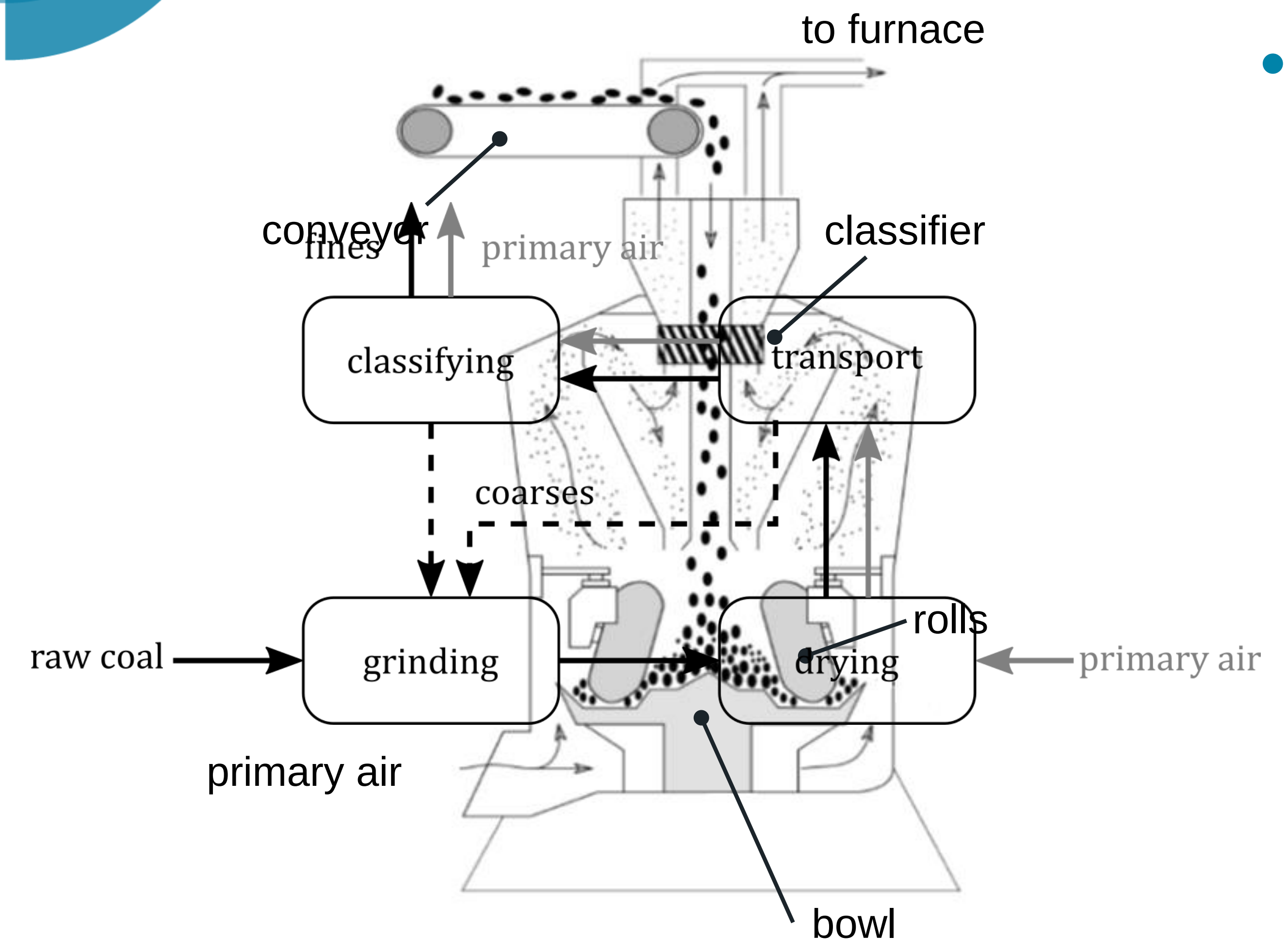
Physically-motivated Mill Model

- **Building-up a mill model**
  - … based on physical equations
  - … for a wide range of application
  - … with interpretable parameters
  - … without a parametrization algorithm
  - … with reasonable computation time
  - … to model dynamic operation behavior



source: Steinmetz (1991)

Fundamental Processes within a Hard Coal Mill



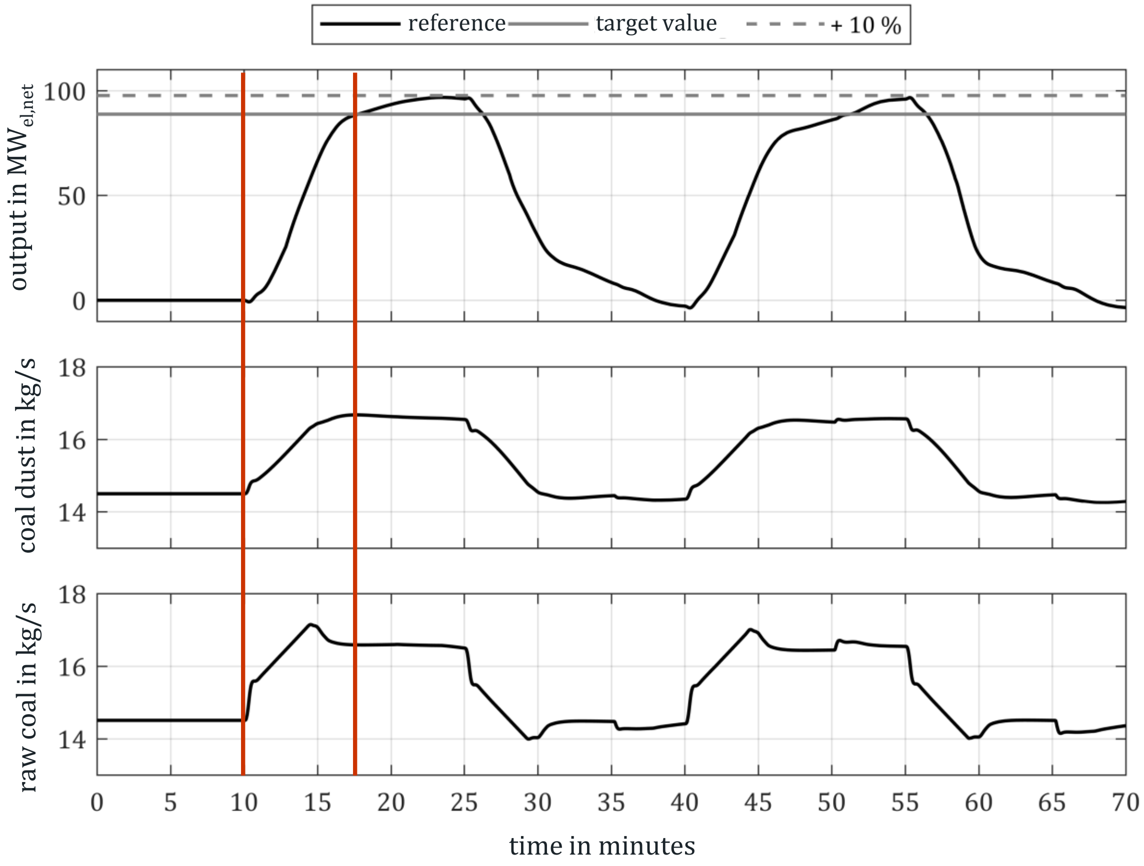
Source: Niemczyk (2010)

- **Roller-Bowl-Mills**
  - Raw coal supply via conveyor belt
  - Grinding coal between bowl and rolls
  - Transport and drying of the coal dust by hot primary air
  - Classifying of the coal dust and separation in fine and coarse particles
  - <u>Each process takes place in a specific part of the mill</u>

Application of the Mill Model

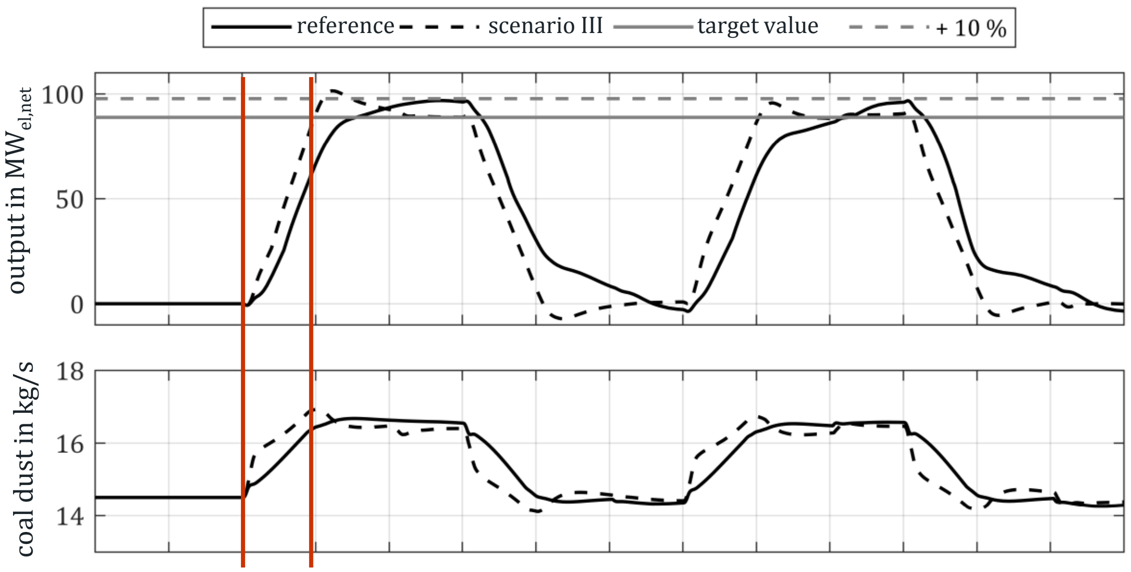
- **Scenario**
  - Pre-qualification test to provide secondary control reserve
  - Repeated load step of 90 $MW_{el,net}$
- **Boundaries reference scenario**
  - **Grinding pressure** and **classifier speed** constant
  - **Primary air mass flow** in dependence of **conveyor speed** without overdrive

Δt = 466 s to reach target value



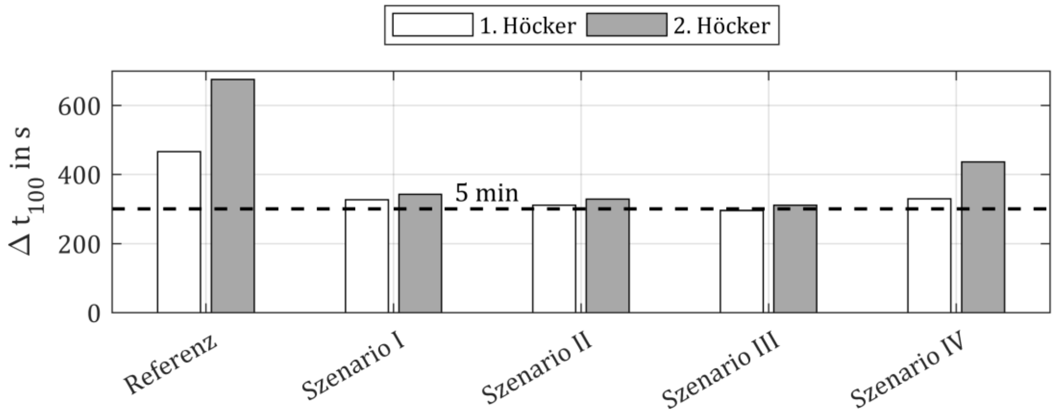
Application of the Mill Model

- **Boundaries scenario III**
  - Overdrive **grinding pressure** by max. 6 %
  - **Primary air mass flow** and **classifier speed** controlled in dependence of conveyor speed, no overdrive



Δt = 296 s to reach target value

- **Additional scenarios**
  - Scenario I: standard control
  - Scenario II: overdrive primary air mass flow
  - Scenario IV: double load gradient



Summary

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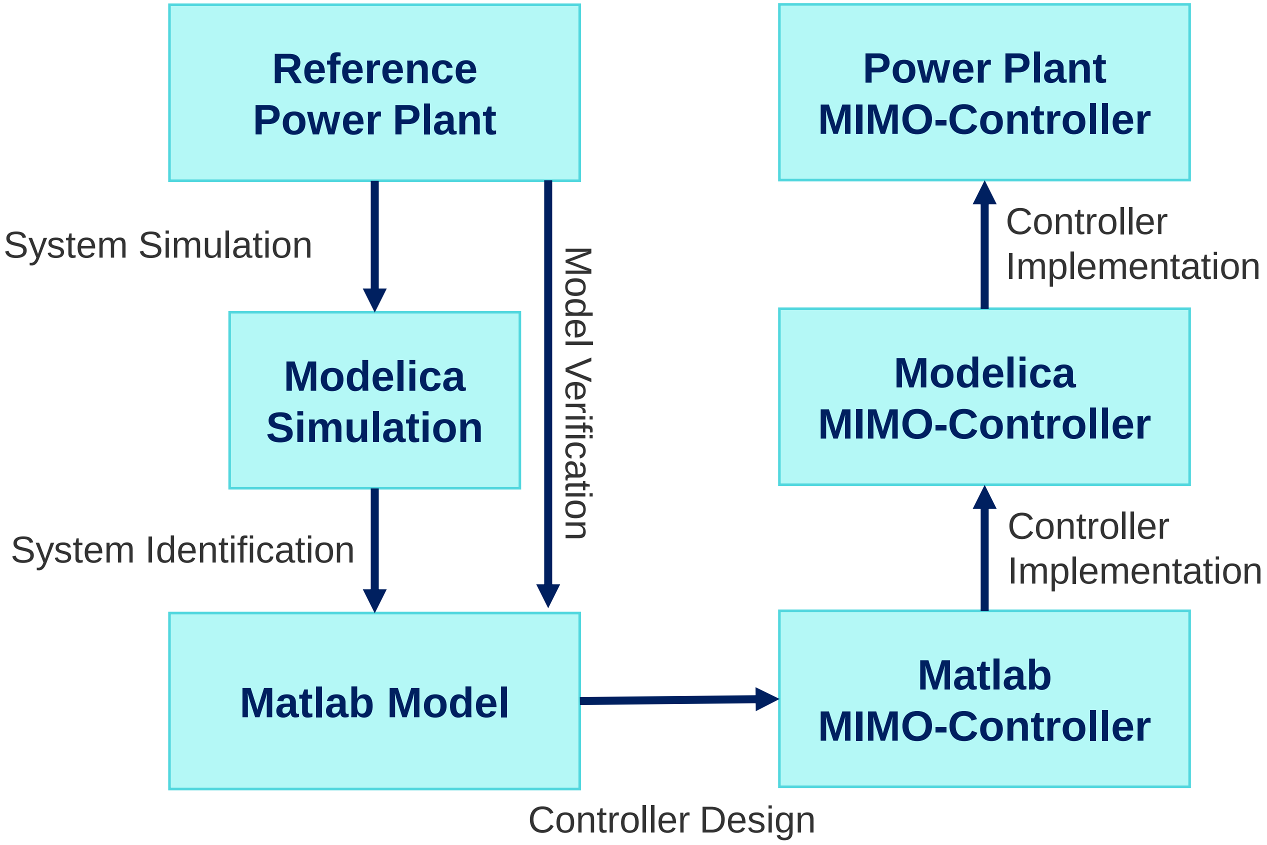
- **Complete model of a hard coal fired power plant**
  - Including control systems and step chains
  - Modularized approach using expandable connectors
  - Capable of covering the entire load range including shut-down and start-up
  - Post-processing of stresses in thick-walled components, comparison of different scenarios

- **Physically-motivated mill model**
  - Modelling sub-processes within a hard coal mill using physical equations
  - Evaluating the potential of mill control for fast load changes
  - Fully compatible with ClaRa-Library

Additional Work

- **Advanced control systems**
  - Institute of Control Systems
  - Multi-input-multi-output controller (MIMO)
  - Model predictive control (MPC)
  - Simulation data from Modelica
  - Controller design in MATLAB/Simulink
  - Co-Simulation using FMI



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DYNSTART

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