Traditional Energy Applications

Supporting the energy transition with simulation technology

Moritz Hübel

WORK EXPERIENCES:

April 2019 – Present

Modelon Deutschland GmbH, Germany

Energy Simulation Expert and Industry Team Lead Energy

Feb 2012 – Mar 2019

University of Rostock and Research Center for Thermodynamic GmbH, Rostock, Germany

Team and project leader for modeling and simulation projects focusing on optimization of products from thermal power plants and energy systems.

EDUCATION:

Dec 2013 – Nov 2016

Doctoral Thesis (Dr.-Ing.) with an industrial partnership

Subject: Improving Transient Operation and Ancillary Services through Dynamic Power Plant Simulation

Industry: Vattenfall R&D and M&G, Germany and Sweden

Academic: Institute for Technical Thermodynamics (LTT), Rostock, Germany

Oct 2006 – Dec 2011

Graduated in Mechanical Engineering (Dipl.-Ing.)

Mechanical Engineering (specialized in Energy Systems)

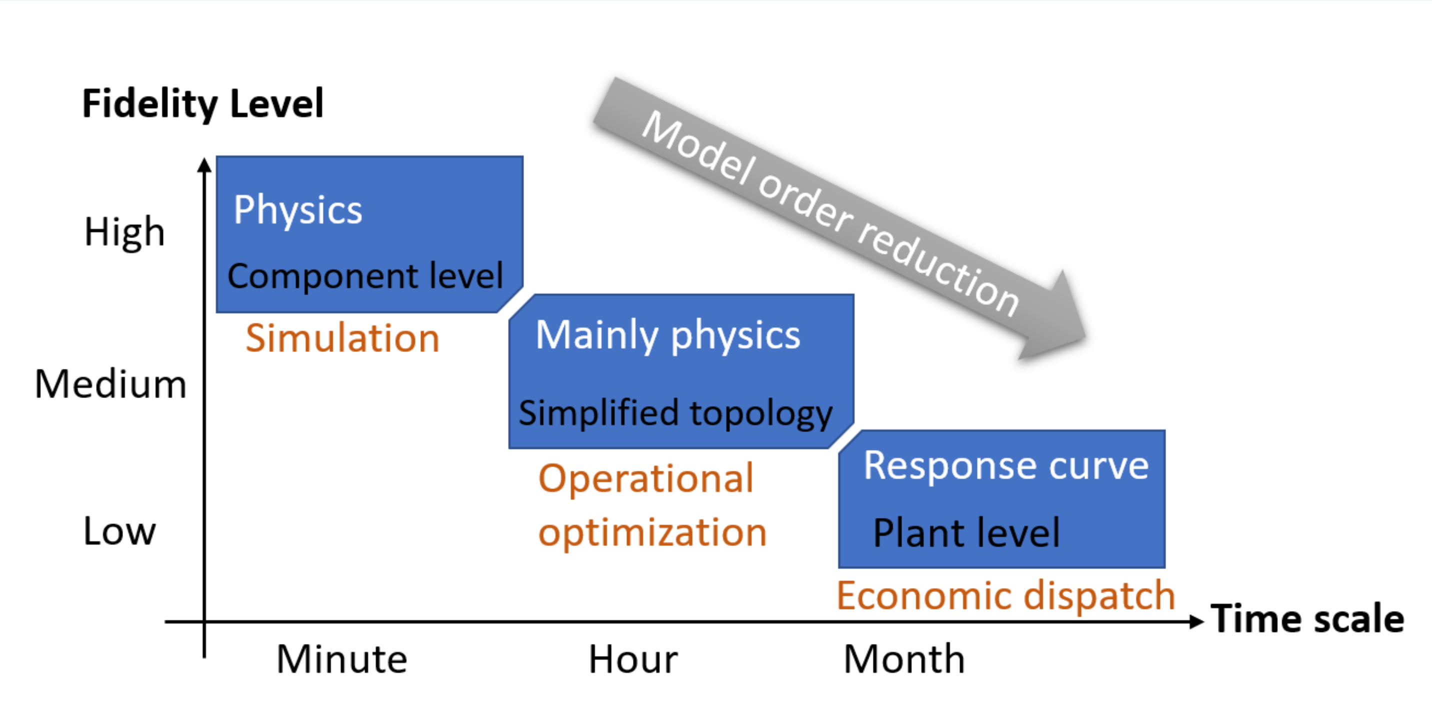
Faculty of Mechanical Engineering, University of Rostock, Germany

Outline

- Process system models for power cycles
  - Fundamentals
  - Component and system model validation techniques
  - Best practices, tips and tricks
  - Integrating controls
- Use-case examples
  - Power cycle design workflow
  - Geometry based turbomachinery modeling

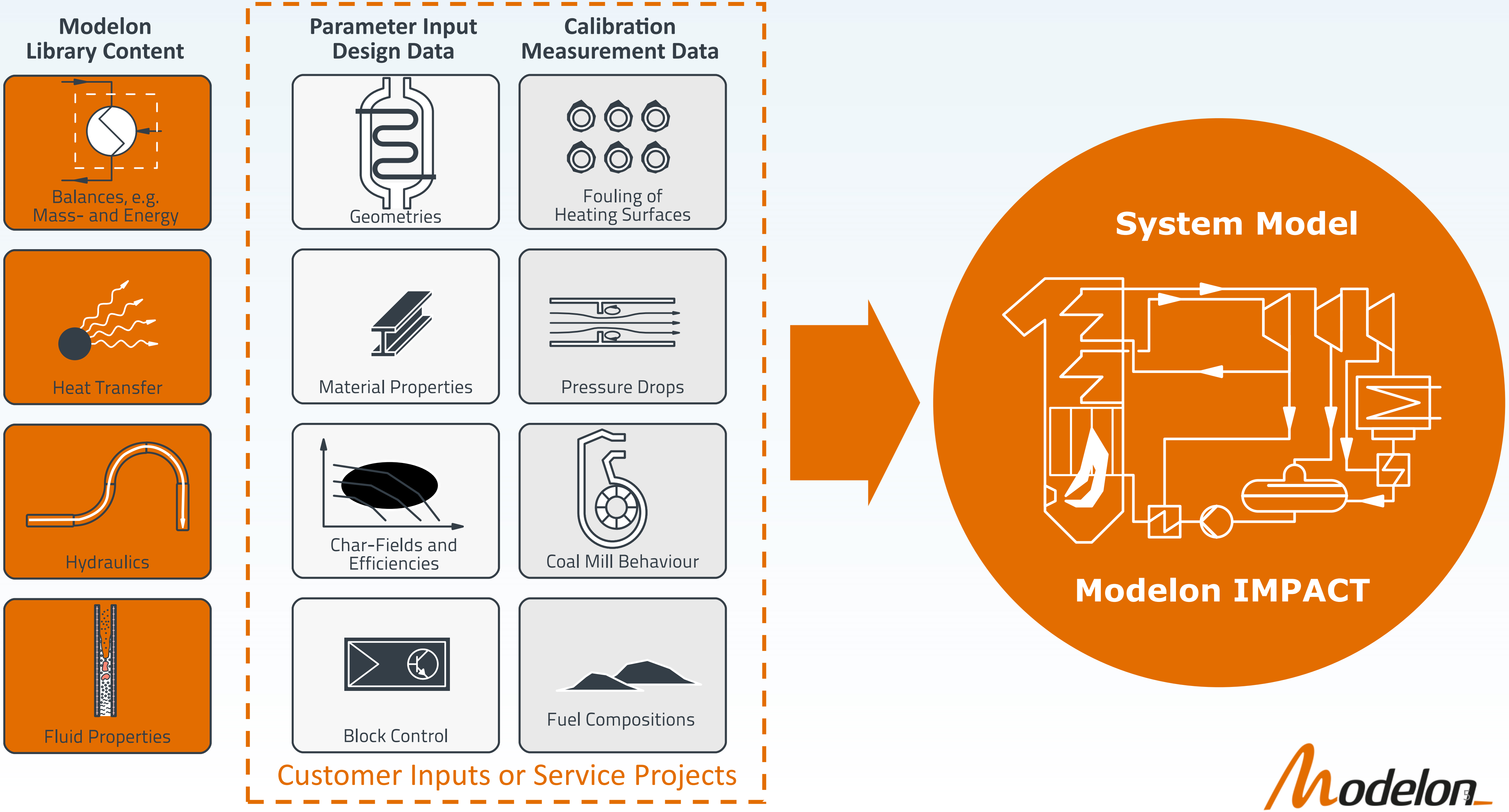
Fit for purpose modelling

Acknowledge the need for models of various fidelity levels



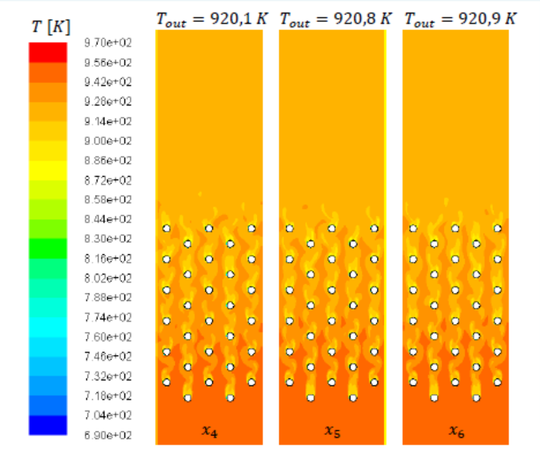
Complex models → **Complex analysis**

Workflow – Energy system Model development



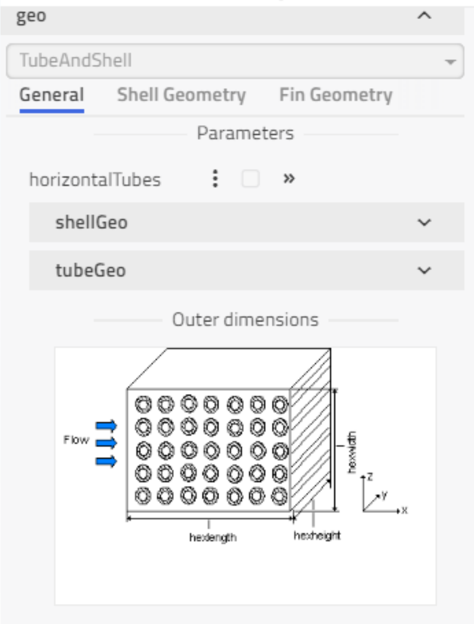
Verify component models on test bench work as needed, Calibrate if necessary

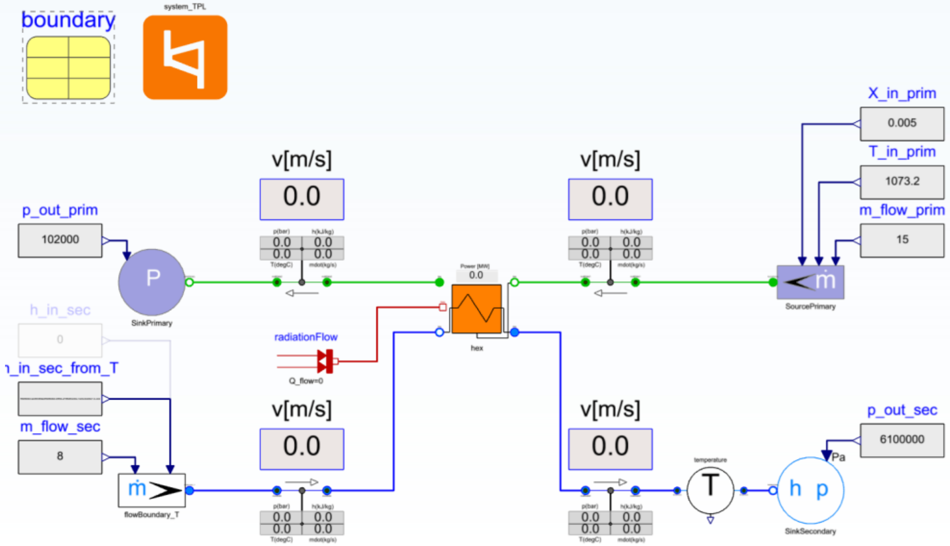
- Compare against measurement data, other tools or hand calculations.
- Add one component after the other to your system and repeat!



	Heatflow [MW]	Deviation [%]
Reference (Measurment)	28.17	-
TPL HX (F_user=0.9)	28.33	0.55
TPL HX (F_user=1.0)	32.93	16.88
CFD	29.39	3.96

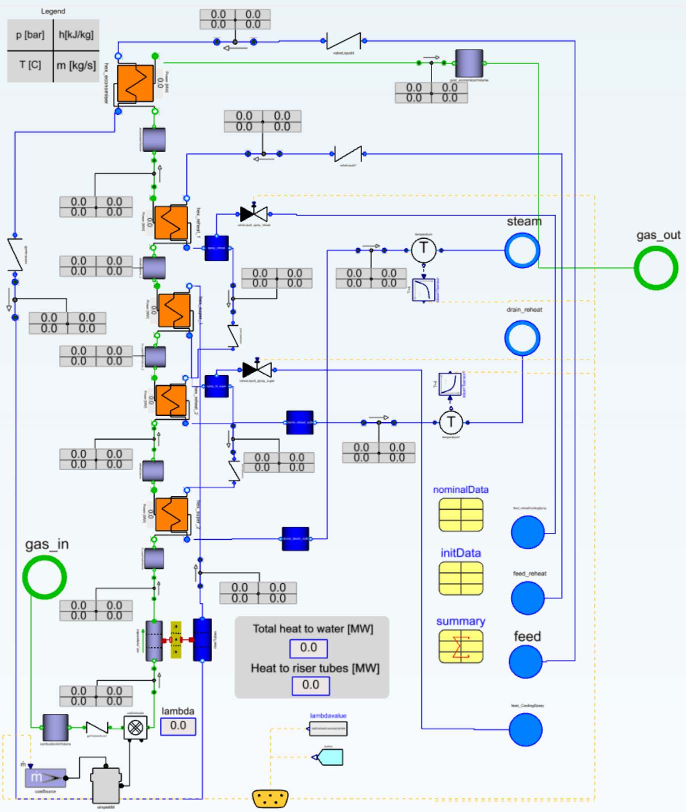
Masterthesis P. Toellner 2014, University of Rostock

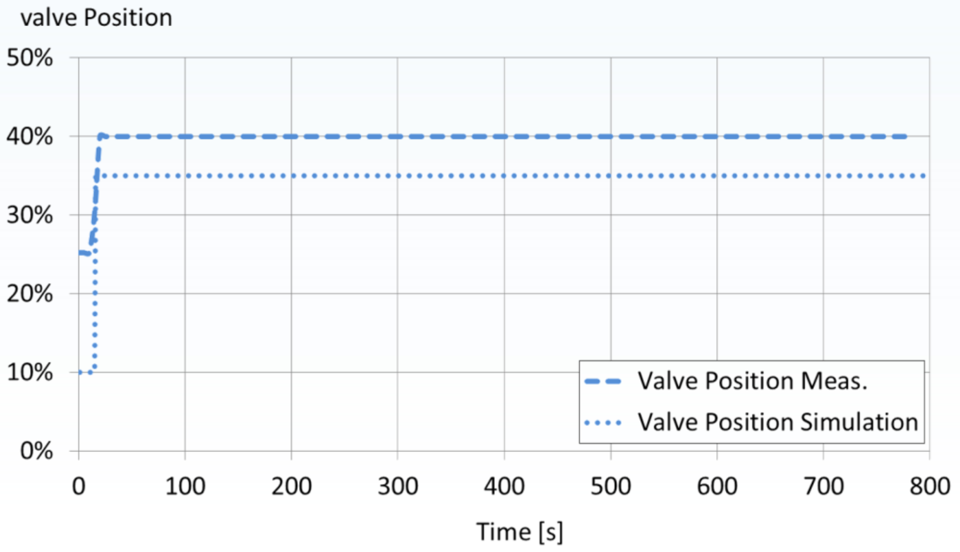


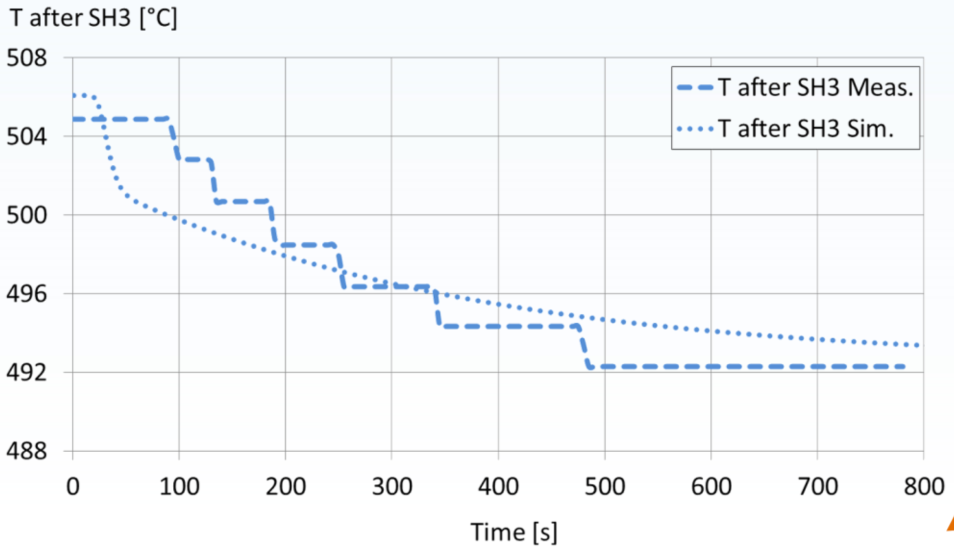


Verify dynamics on component level

- Temperature after Superheater after Opening of injection cooler
- Simulated opening has been fitted to match amplitude of temperature change, not tried to match valve characteristics
- Low discretization of measurements/sampling with large dead bands leads to steps.

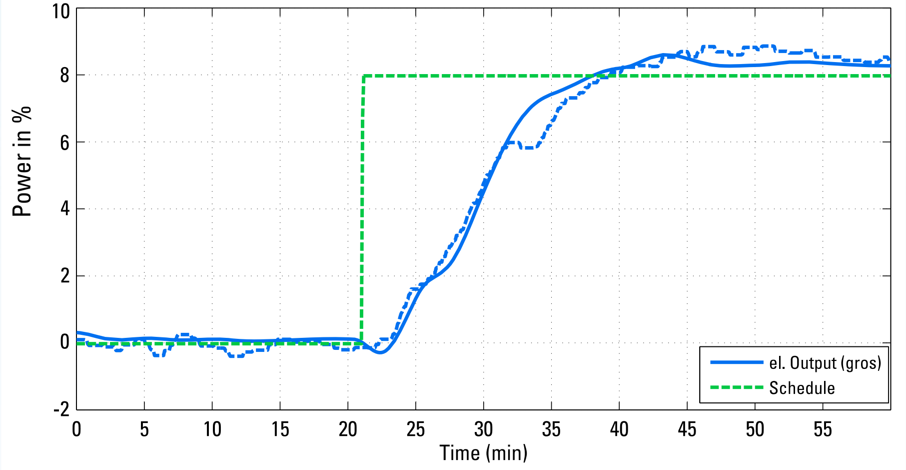




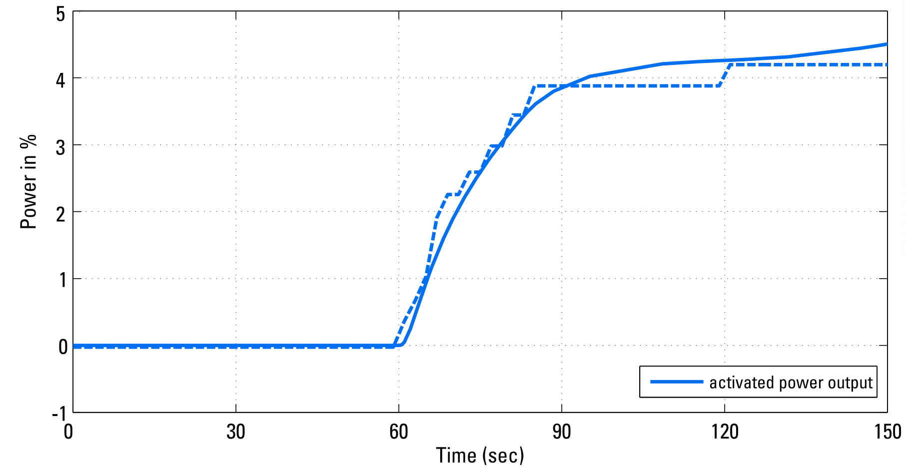


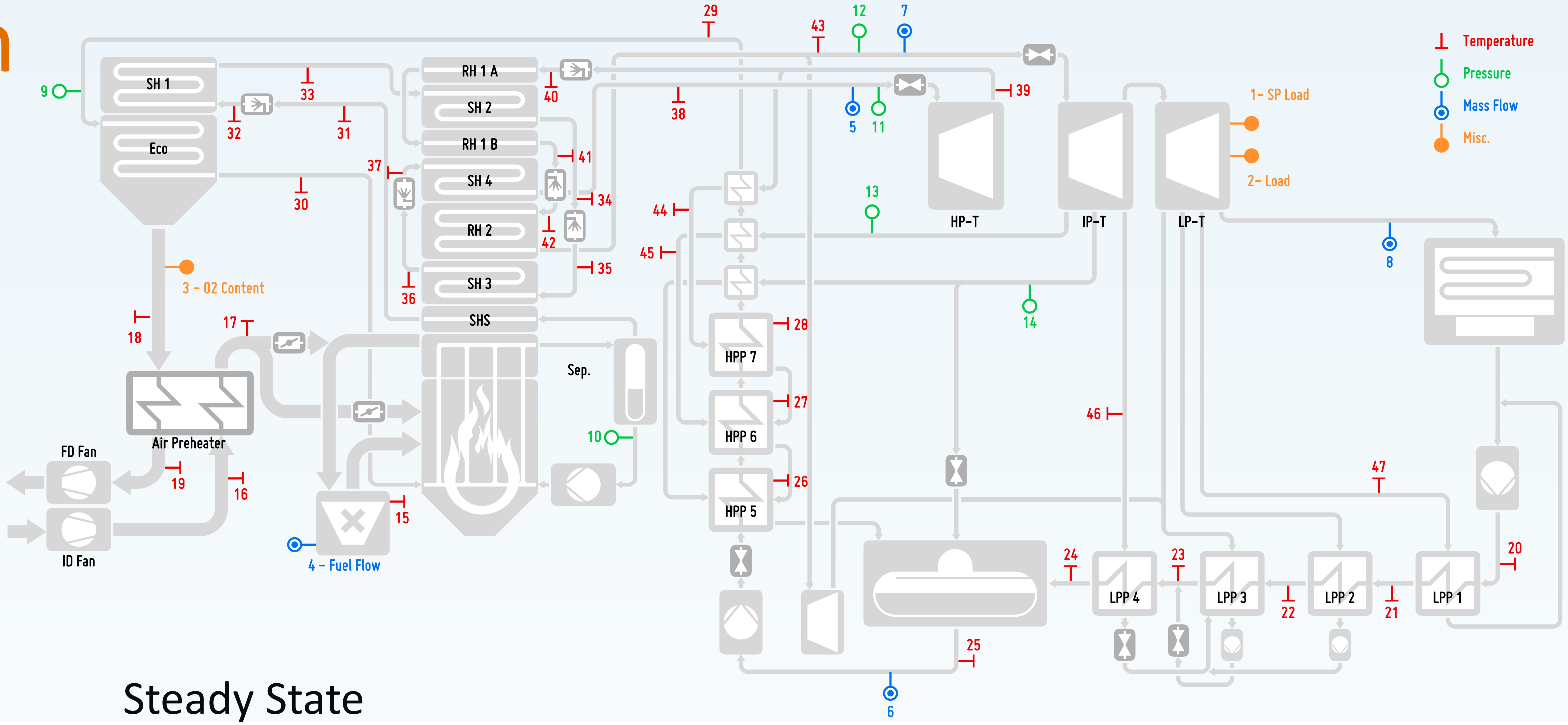
System model validation

Closed Loop (Schedule)

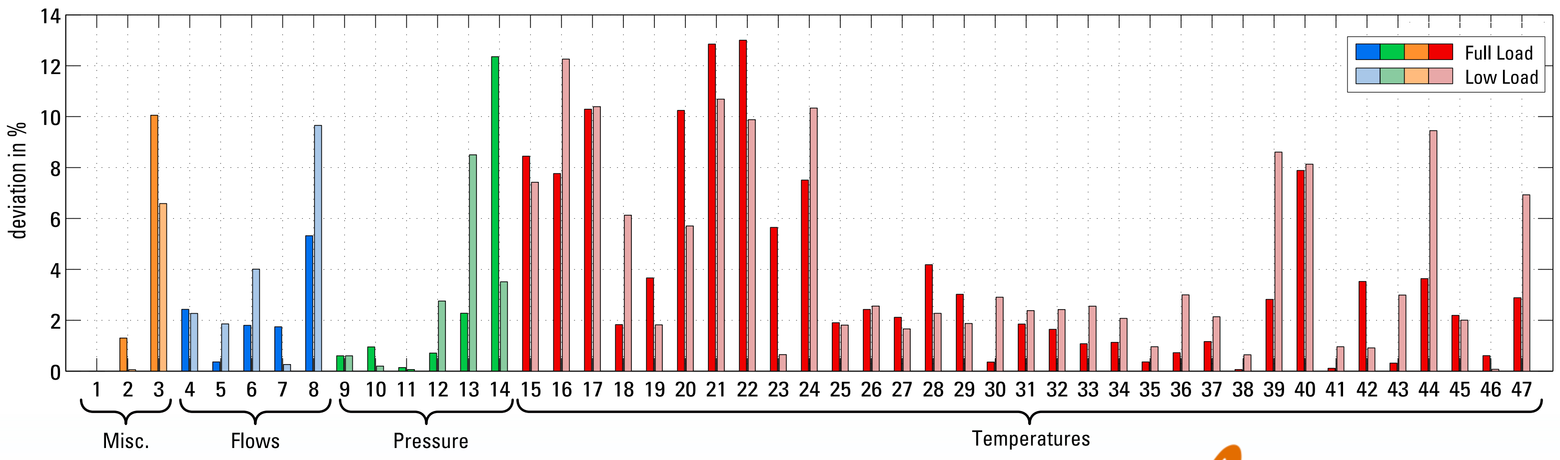


Open loop (Primary Control)





Steady State



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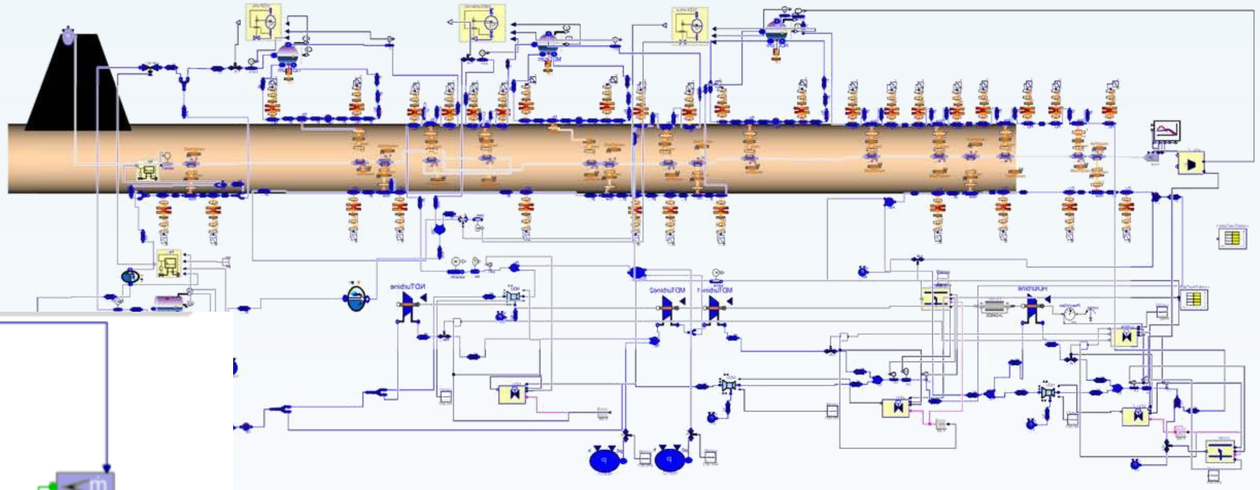
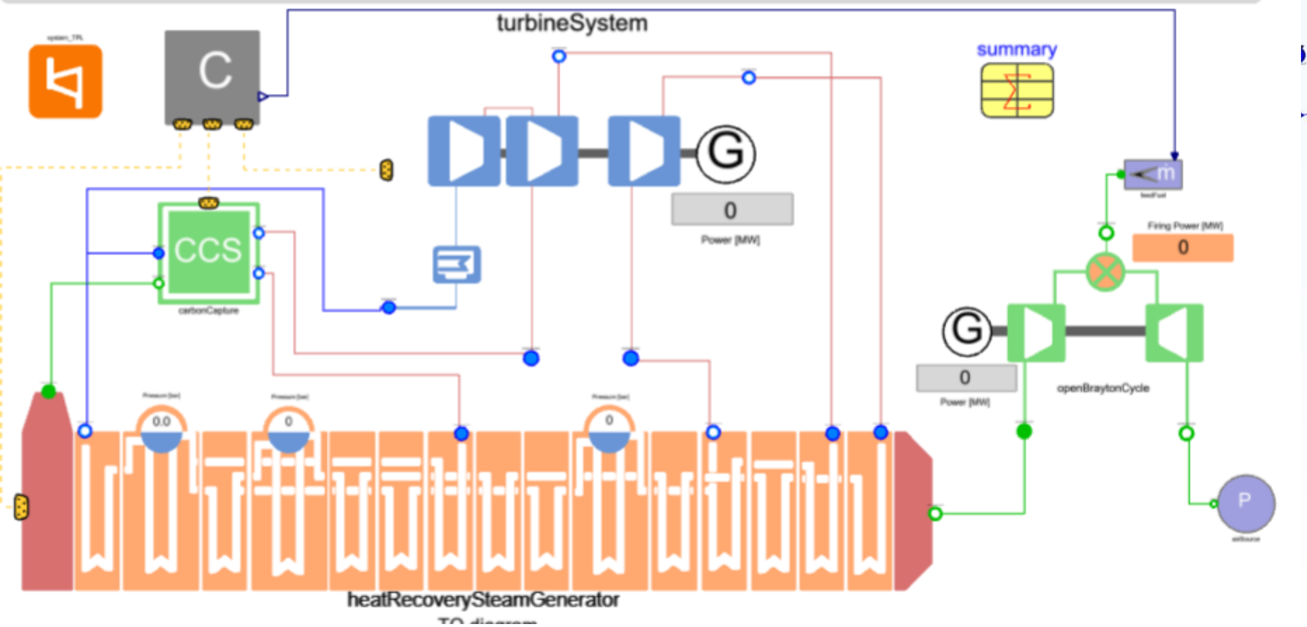
Outline

- Process system models
  - Fundamentals
  - Component / System model validation techniques
  - Best practices, tips and tricks
  - Integrating controls
- Use-case examples

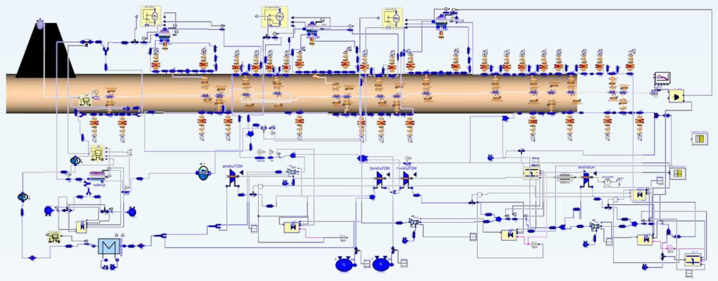
Best practices, tips and tricks

- Flat vs. Deep





Best practices, tips and tricks

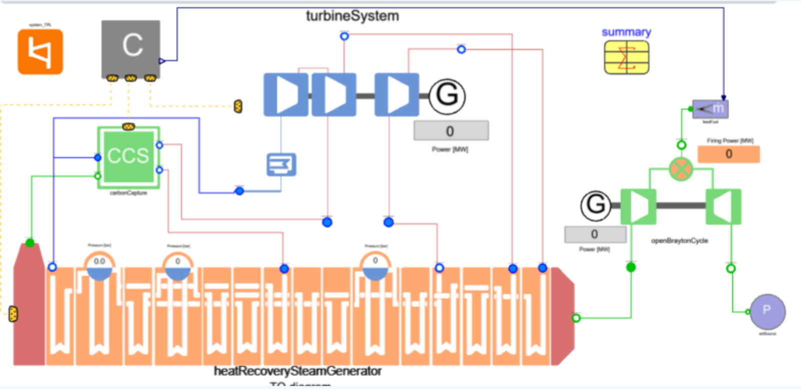


- Why flat?
  - Less time needed to implement a model
  - Model is easy to understand and analyze with knowledge of the corresponding system - up to a certain size.
  - Details of the structure can quickly be changed by advanced users

When to use more	When to use less
Only one advanced user	Multiple users want to collaborate
Very early stage of system structure design	Standardized system structures exists
All scenarios in question and be derived from few inputs	demand to use subsets of the model

Modelon

Best practices, tips and tricks

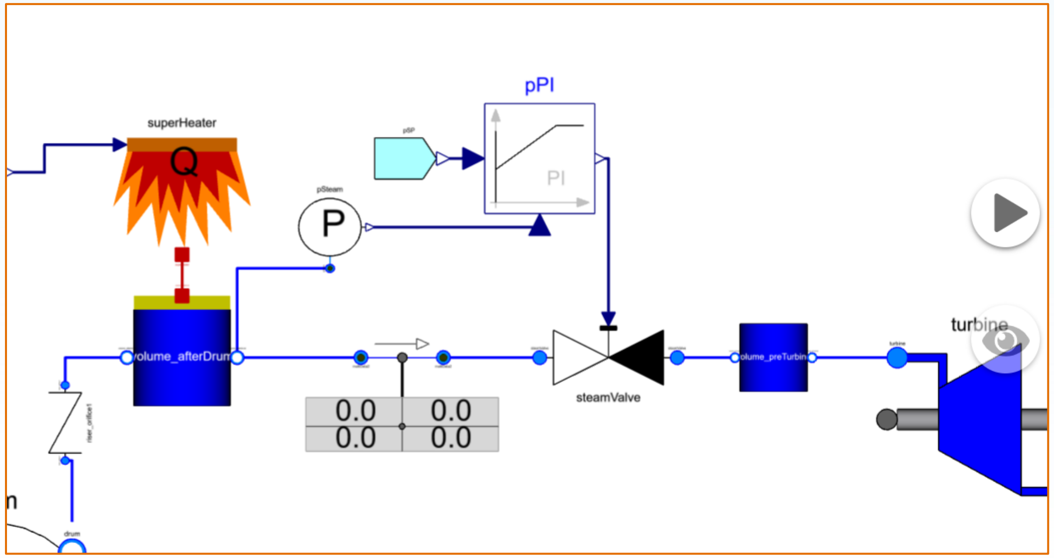


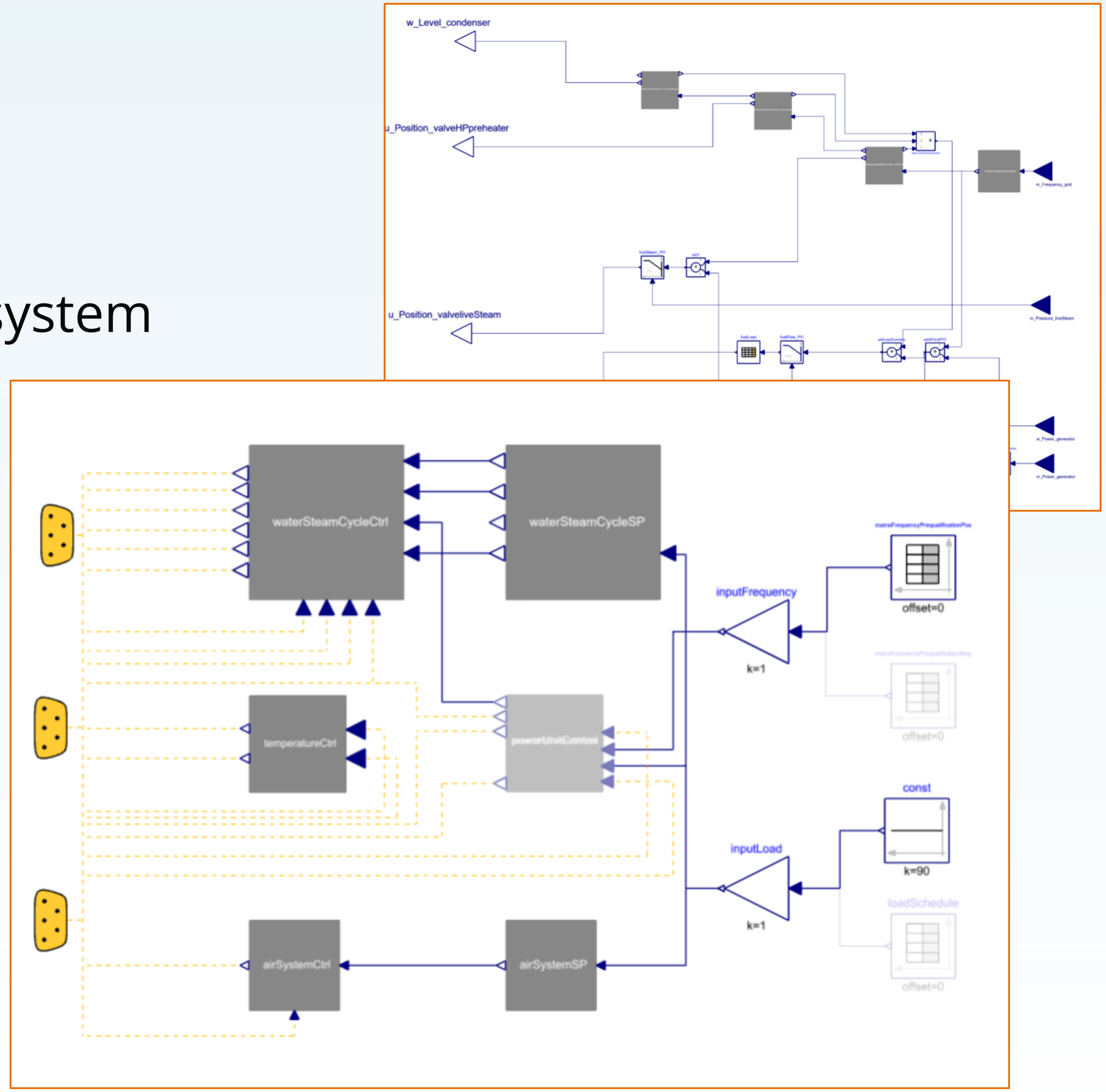
- Why deep?
  - General assumptions and fidelity can easily be changed by users depending on available templates created by advanced users
  - Multiple users can collaborate on a single system model

When to use more	When to use less
Multiple users want to collaborate	Only one advanced user
Standardized system structures exists	Very early stage of system structure design
Frequent demand to use subsets of the model	All scenarios in question and be derived from few inputs

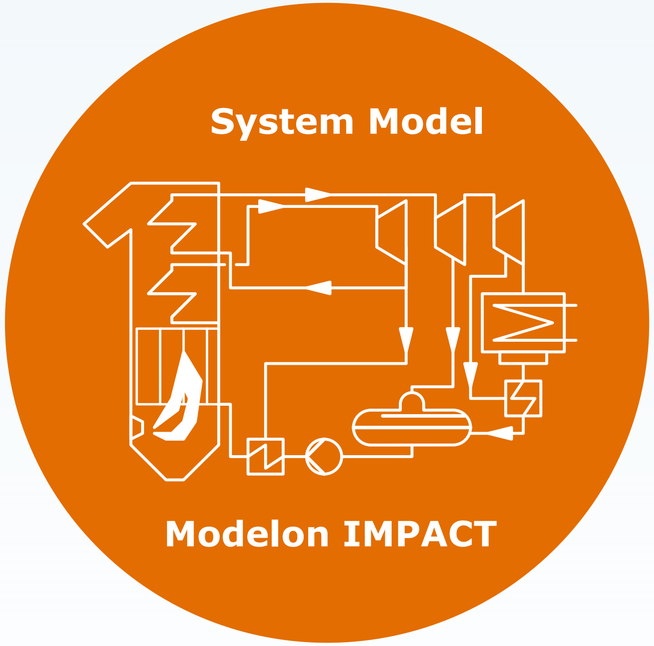
Control Integration

- Local controllers vs. centralized control system
- Expandable connectors

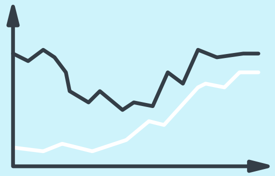


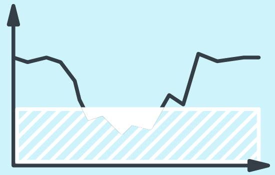


Creating value with dynamic simulation

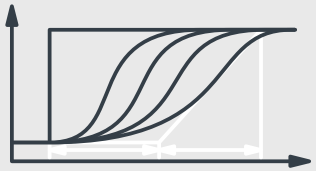


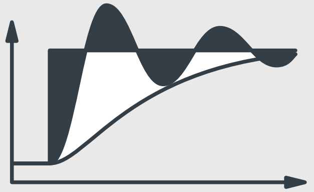
Simulation Results


Dynamic Behaviour of States and Processes


Violation of Safety Thresholds

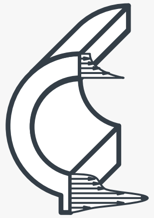
Improving Control Design


Determination of Step Responses

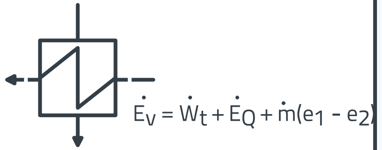

Control Quality

Calculation of Lifetime Consumption

Pressure and Temperature Differences


Stress and Strain

Exergetic Process Analysis



Exergy- Balances on Subcomponents


Calculation of Losses and Impact on Efficiency

Use-Case / DEMO

Integrated Steam turbine design

ELSEVIER

Energy Reports

Volume 8, Supplement 9, November 2022, Pages 1381-1393

TMREES22-Fr, EURACA, 09 to 11 May 2022, Metz-Grand Est, France

Design and off-design system simulation of concentrated solar super-critical CO2 cycle integrating a radial turbine meanline model

Michael Deligant [a], Moritz Huebel [b], Tchable-Nan Djaname [a], Florent Ravelet [a], Mathieu Specklin [a], Mohamed Kebdani [a]

Show more

Modelon

Context: system modelling & turbomachines

System modelling

- Complex components interactions
- Unsteady and transient behavior

- MODELICA language
  - Equation based
  - Acausal
  - High performance

Classical turbomachines models for system modeling

- Map-based
  - Experimentally assessed
  - Numerically determined (CFD 3D, 2.5D, 0/1D)
- Use bi-dimensional interpolation
- Require pre-existing machine design and available performance

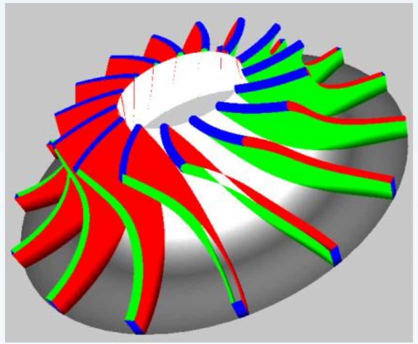
Modelon

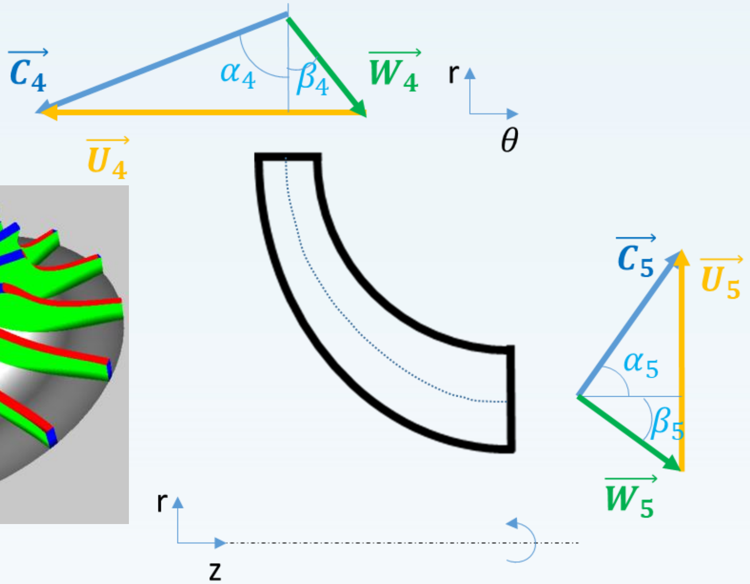
Turbine meanline model

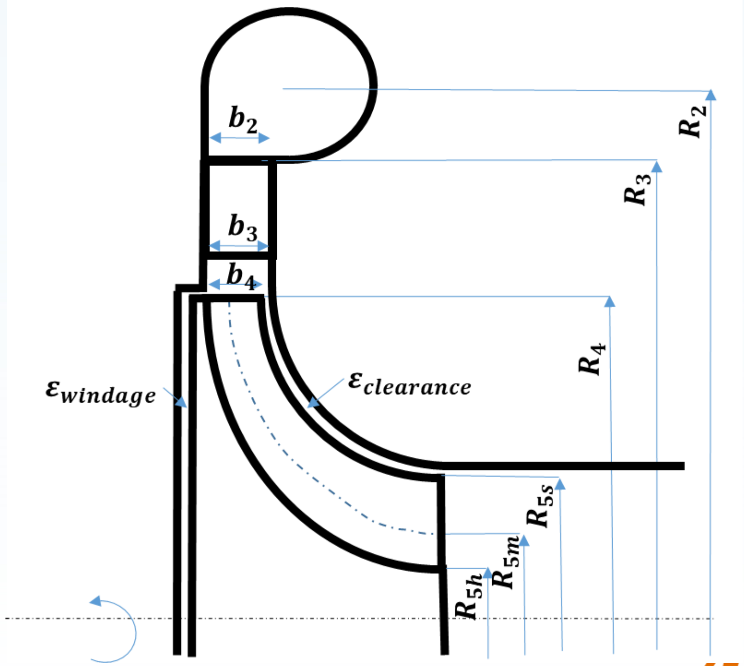
- Total enthapy drop

$$\Delta h_0 = \mathbf{U_4 C_{\theta 4} - U_5 C_{\theta 5}}$$

- Calculations based on geometrical parameters and inlet/outlet velocity triangles
- Assumptions
  - Null velocity at the turbine inlet (0)
  - Adiabatic expansion
  - Isentropic expansion in the scroll housing (0→4) with conservation of total enthalpy
  - Real gas properties
  - No inertia
- Implementations constraints
  - Limitation of the range of solutions for α_4 and α_5





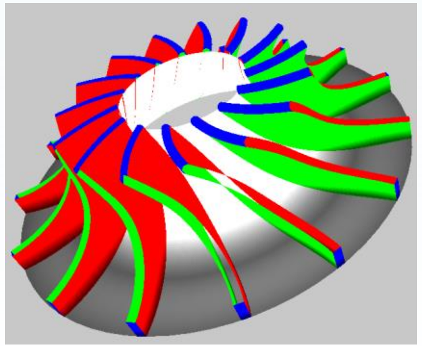


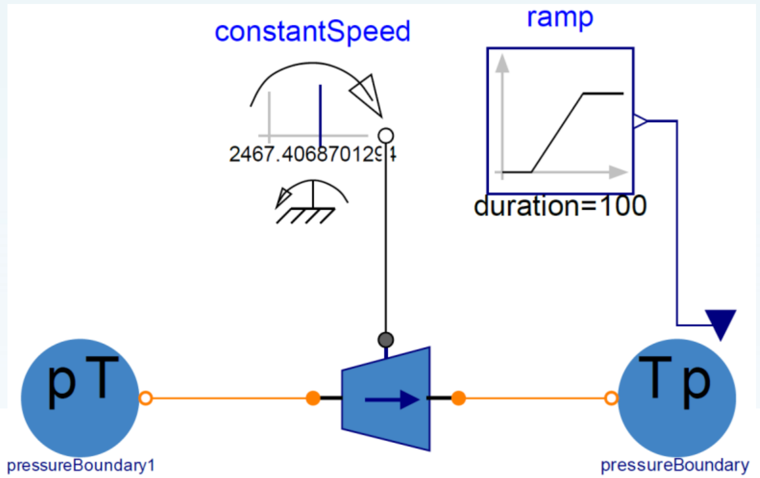
Design and performance prediction of a sCO2 turbine

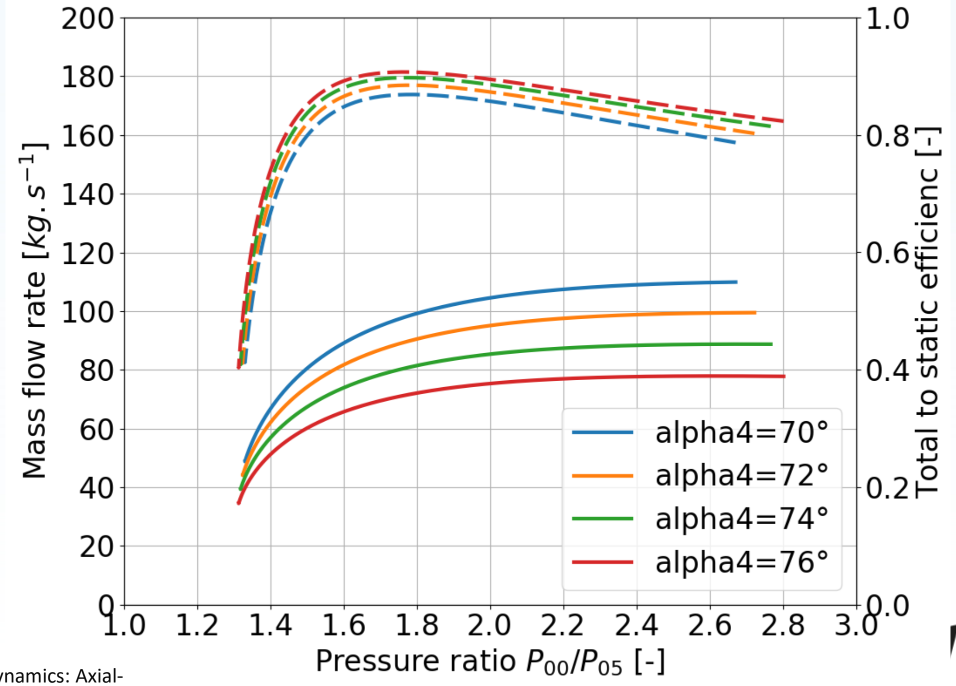
- Design of a 8.7MW turbine
  - Inlet conditions: 205 bar, 525°C
  - Outlet conditions: 86bar
  - Mass flowrate: 84 kg/s
  - Specific speed $\Omega = 0.422$
  - ➔N=23562rpm

Geometrical parameters obtained from Aungier preliminary design

Parameters	Variable	Values	Units
Inlet radius	R4	122.6	mm
Inlet tip	b4	12.31	mm
Relative inlet angle	b4	90	°
Absolute inlet angle	α_4	76	°
Outlet radius at hub	R5h	36.78	mm
Outlet radius at shroud	R5s	73.67	mm
Rotor height	Z	55.34	mm
Relative outlet angle at hub	b5h	60.35	°
Relative outlet angle at shroud	b5s	41.26	°
Number of blades	Zr	15	-



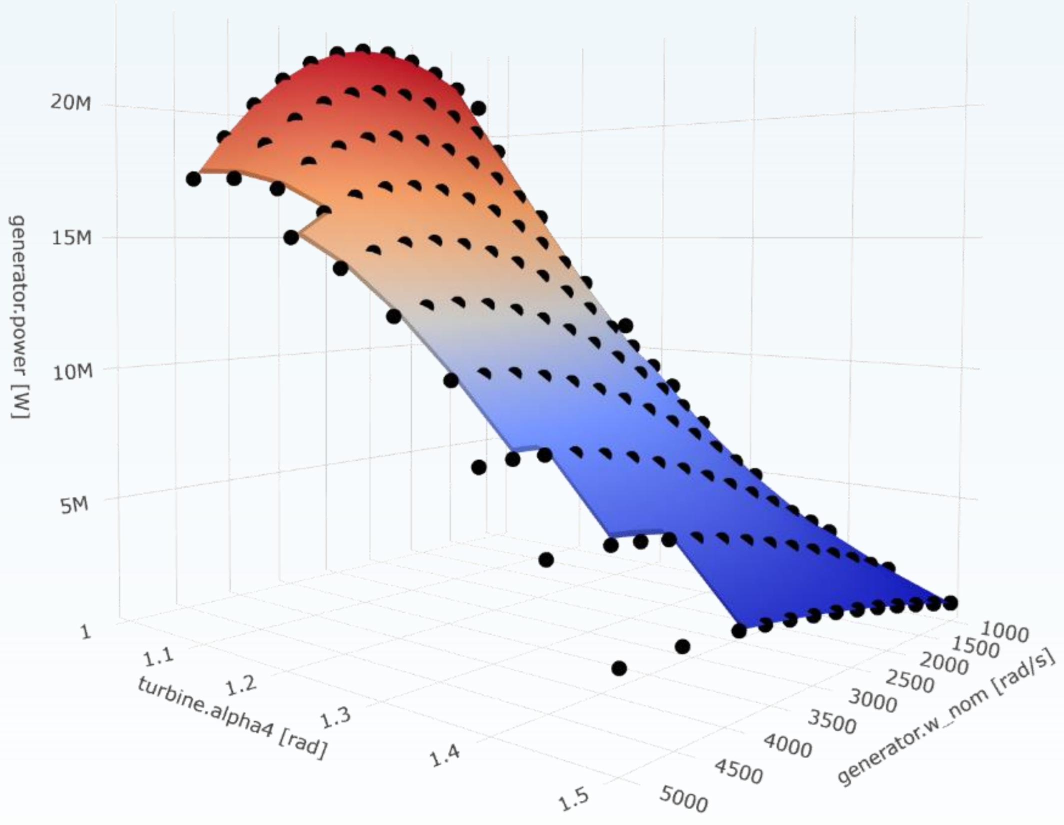




R. H. Aungier, R. Aungier, Preliminary Aerodynamic Design of Axial-Flow Turbine Stages, in: Turbine Aerodynamics: Axial-Flow and Radial-Flow Turbine Design and Analysis, 2010

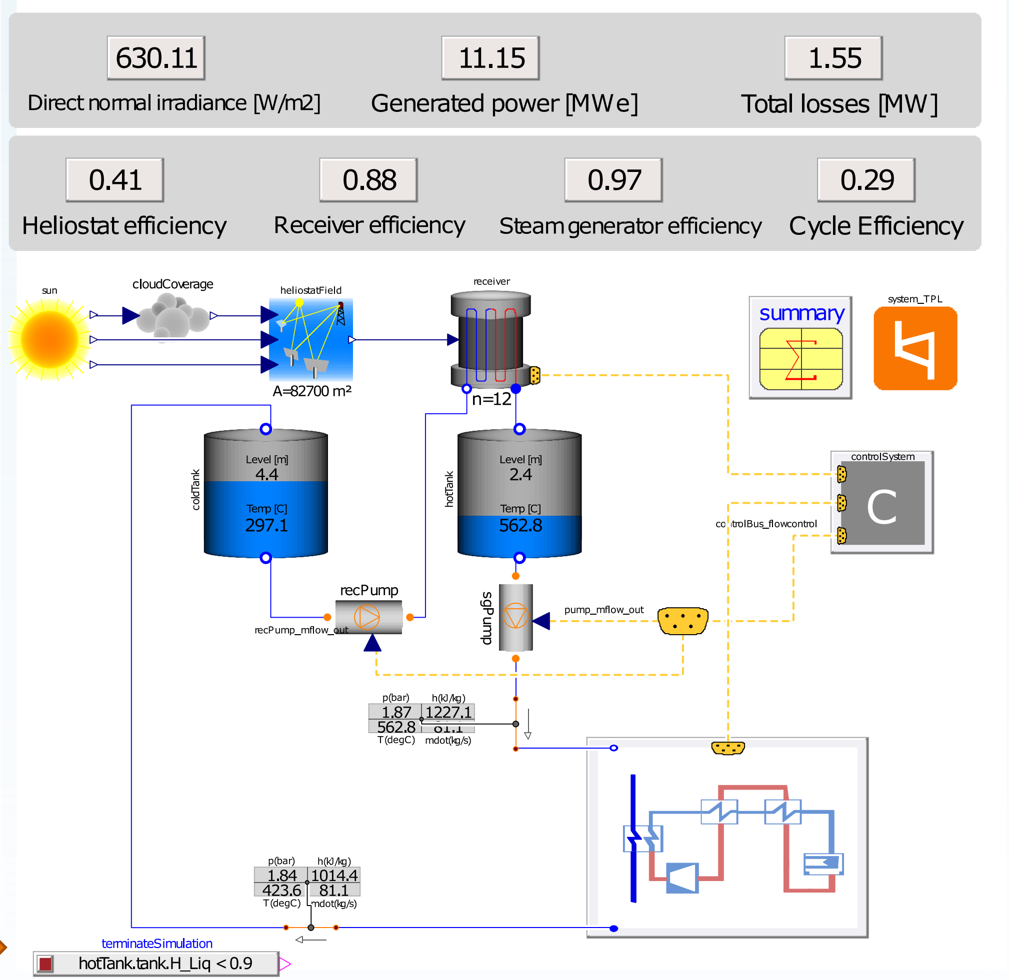
Use-Case / DEMO

Turbine Design Test Bench



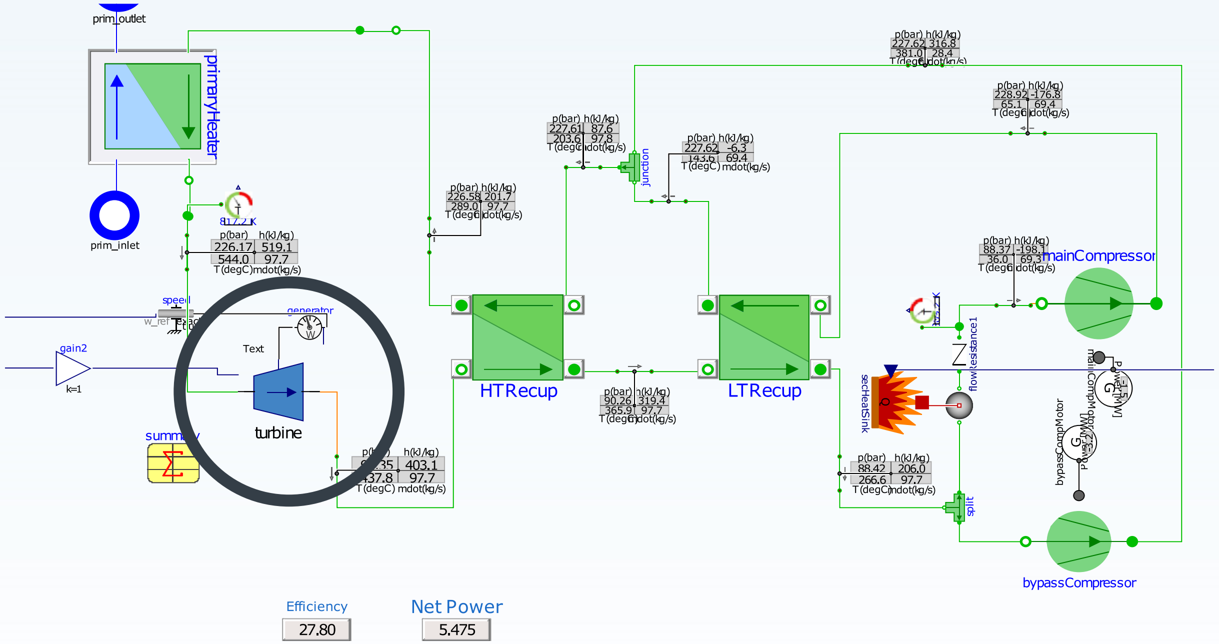
CSP plant system

- System model representing « Solar Two » test facility in California, USA
- 12.5 MW rated power output.
- Utilizing buffer storage with hot salt
- Dynamic system model based on Modelica language available in Modelon Impact simulation platform
- Power Cycle model from ThermalPower Library including both conventional Rankine and supercritical CO_2 Brayton cycle



Turbine integration into supercritical CO2 cycle

- Integrating the mean line turbine model into the supercritical CO2 cycle
- No significant performance reduction for the full plant system model compared to conventional approaches like Stodola model
- Models allows both On- and OffDesign steady-state and dynamic simulations and therefore turbine parameter optimization
- Cycle model includes:
  - Mean line turbine model
  - Geometry based heat exchanger models for primaryHeater, HTRecup, LTRecup.
  - Map-based compressor models. (mainCompressor, bypassCompressor)
  - Simple heat extraction model for the air cooler.
  - Controlled heat extraction to fix low pressure of the cycle well above the critical pressure of the CO2.

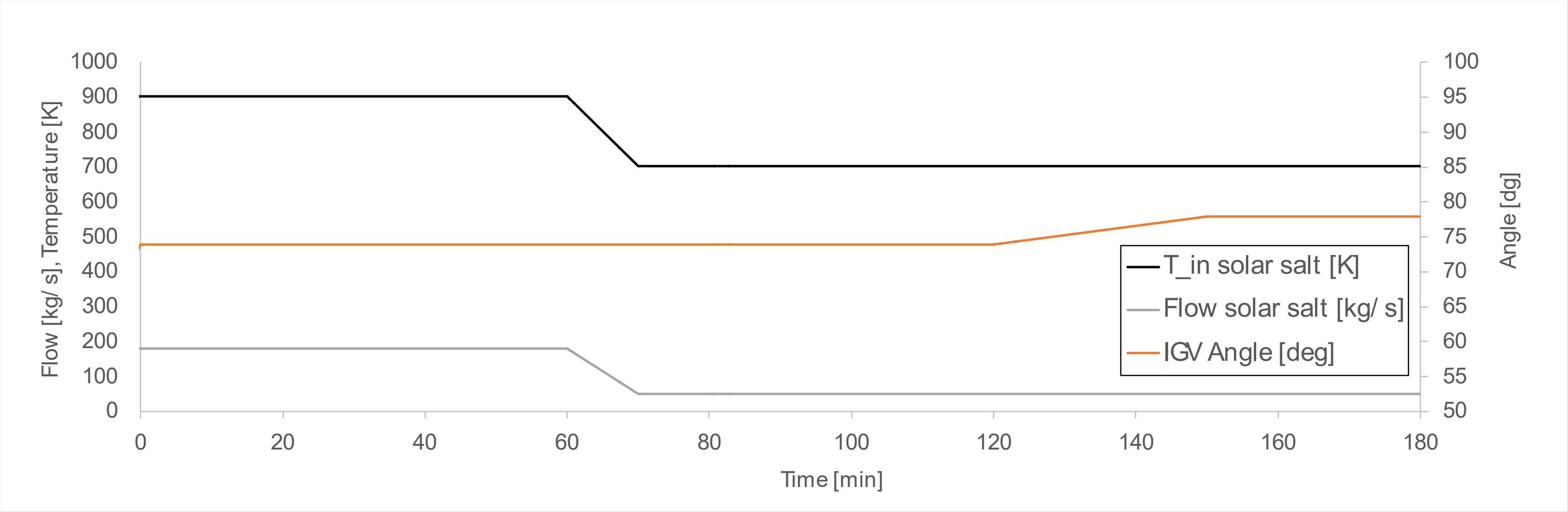


Model type	Nbr of equations	Simulation time in %
Turbine Stodola	31	100
Turbine Meanline	69	130
Solar Plant System	4252	3430

Modelon

Investigation Scenario

1. t=0 min: operation of the cycle at maximum load condition. Hot tank of the solar plant is filled with high temperature molten salt, primary heater of the sCO2 cycle receives 180 kg/s at 630 °C.
2. t=60min: negative load change. Molten salt flow drops from 180 kg/s to 50 kg/s and temperature to 470 °C.
3. t=120min: change of inlet guide-vane position. The inlet guide-vane position and therefore the alpha4 angle inside the turbine is changed from 74° to 78°.



Results: steady-state cycle

- t=0 min: operation of the cycle at maximum load condition. Hot tank of the solar plant is filled with high temperature molten salt, primary heater of the sCO2 cycle receives 180 kg/s at 630 °C.

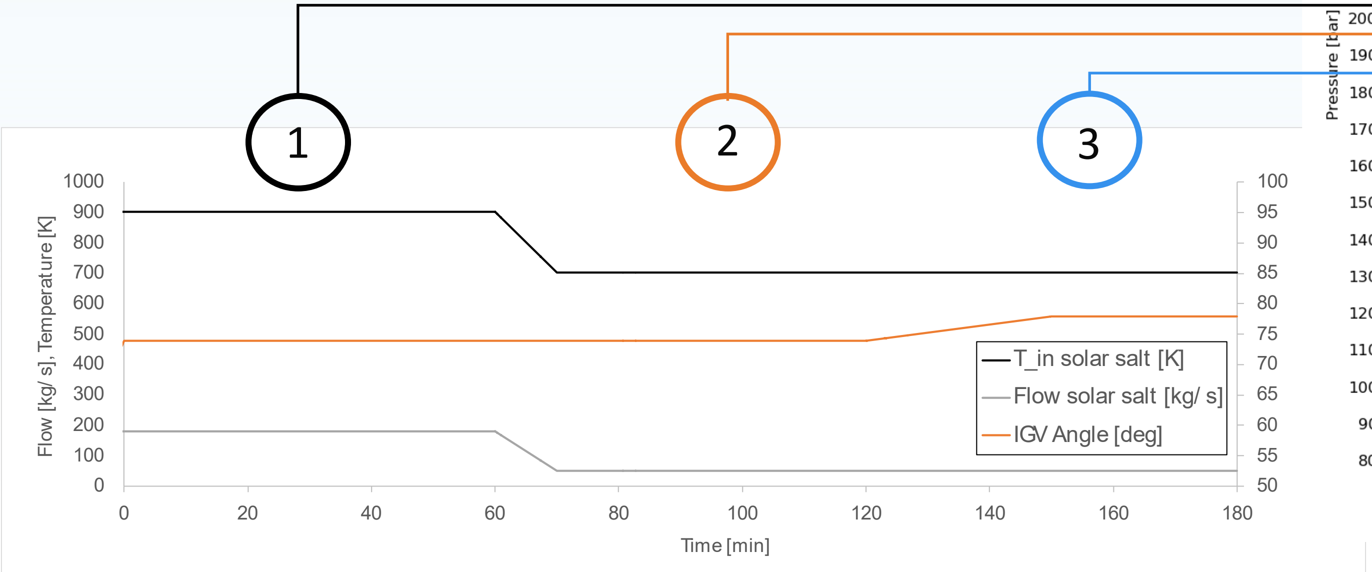
  Settled point: full-load, nominal conditions (1)

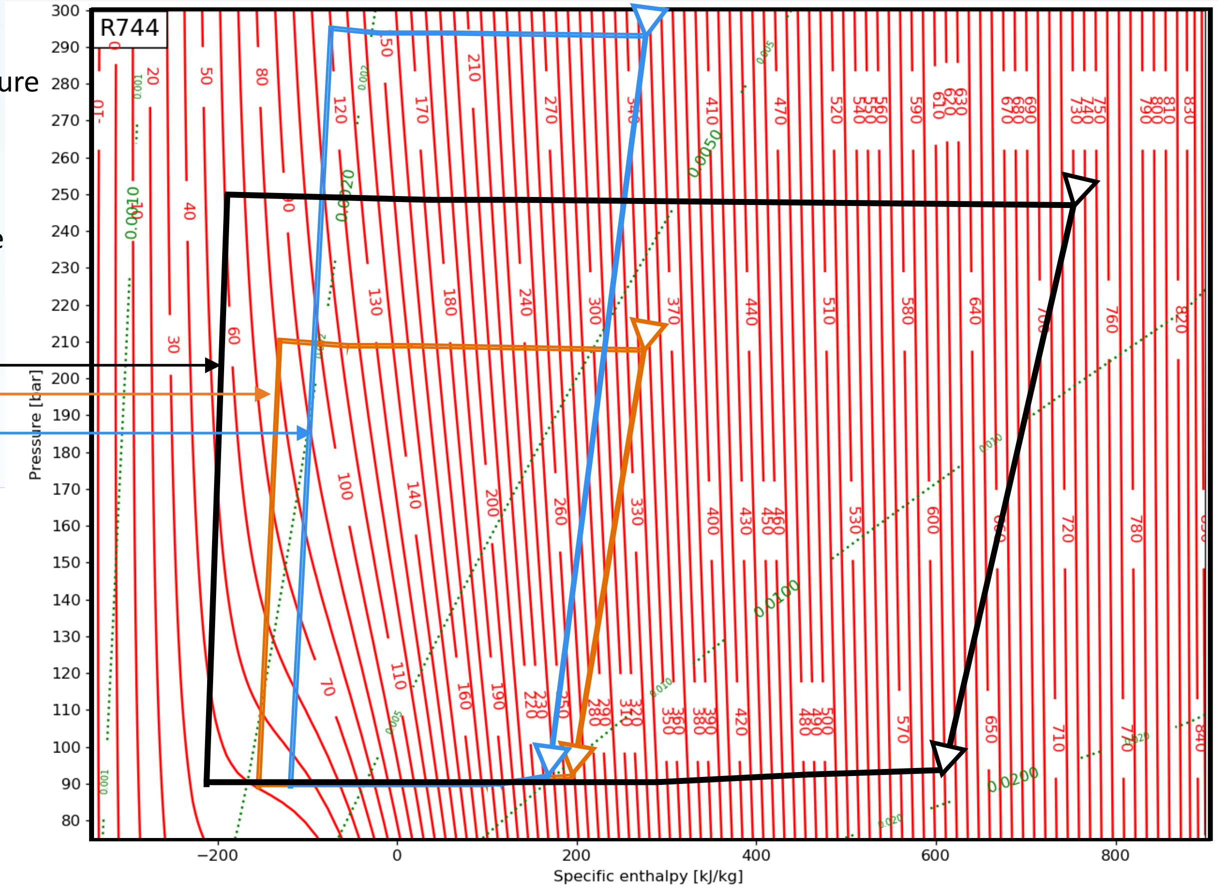
- t=60min: negative load change. Molten salt flow drops from 180 kg/s to 50 kg/s and temperature to 470 °C.

  Settled point: low-load, nominal conditions (2)

- t=120min: change of inlet guide-vane position. The inlet guide-vane position and therefore the alpha4 angle inside the turbine is changed from 74° to 78°.

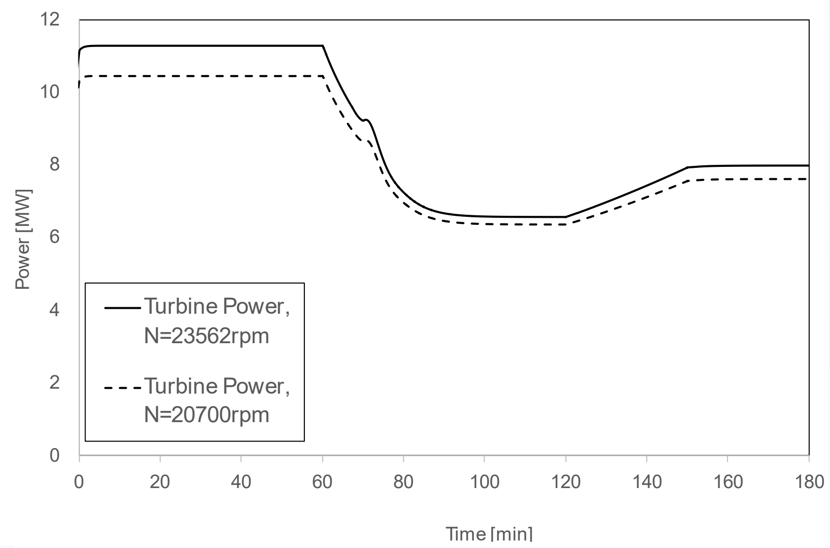
  Settled point: low-load, modified IGV angle conditions (3)

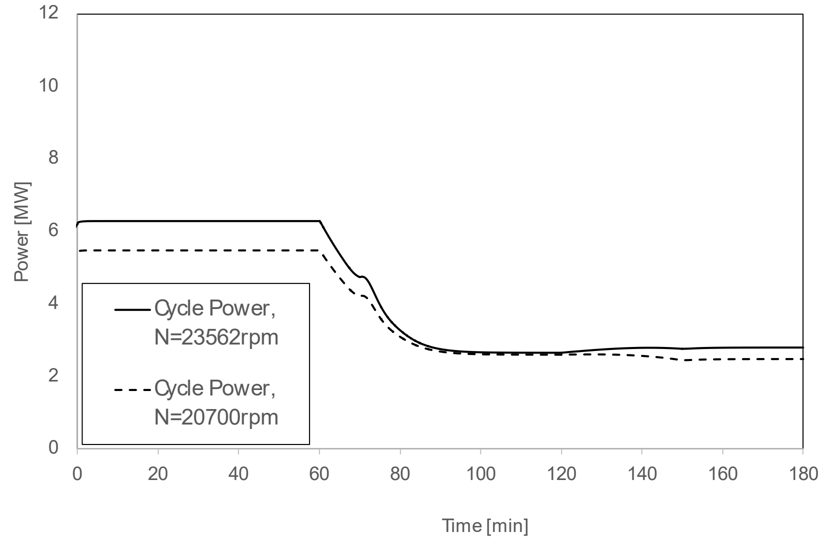




Results: transient power

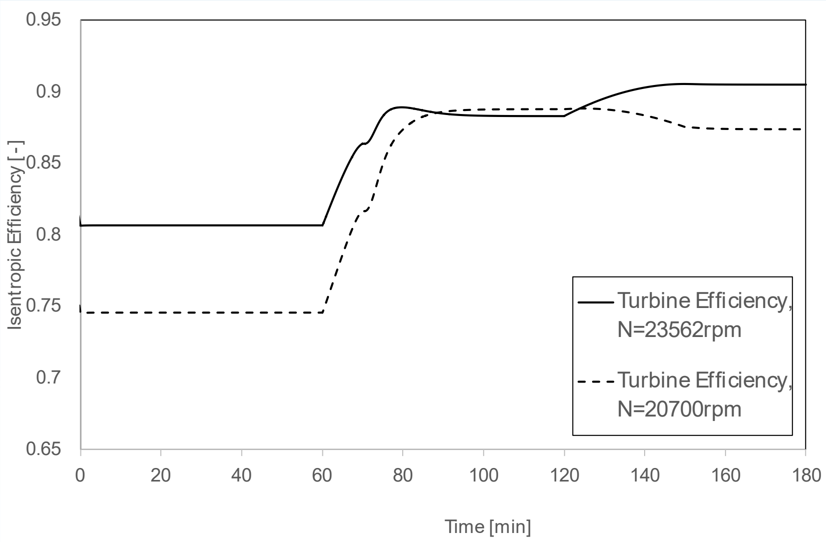
- Turbine Power:
  1. Nominal Power: highest with design speed (23562rpm)
  2. Low load: lower speed consistently resulting in less turbine power
  3. Low load, adapted IGV: leads to higher turbine power
- Net Cycle Power:
  1. In nominal point maximum net output around 6 MW for nominal speed, only 5.7MW with lower speed
  2. In low load, cycle power equal for both speeds, meaning additional turbine power at N=23562rpm is consumed by the compressors
  3. Low load, adapted IGV: Results in higher power output at nominal speed but less power for lower speed, meaning the compressors will consume significantly more power at N=20700rpm

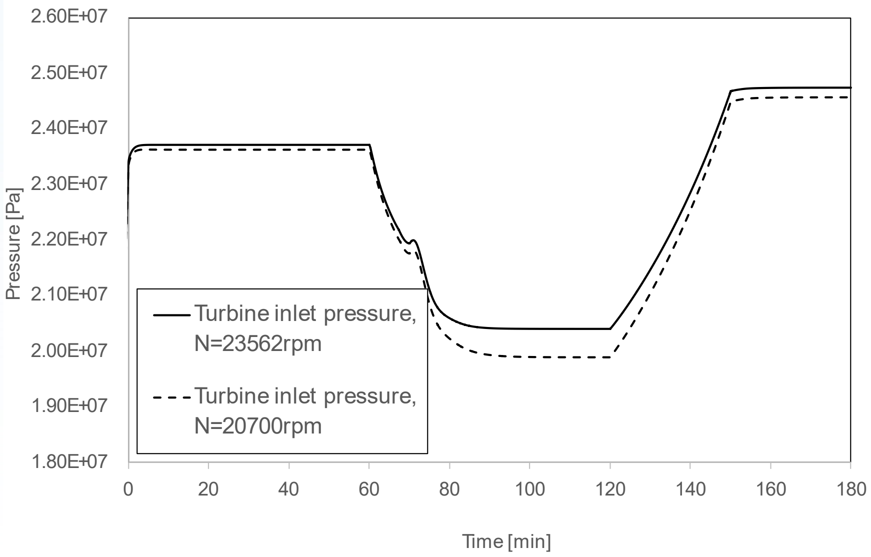




Results: efficiency and inlet pressure

- Turbine efficiency:
    1. Nominal Power: highest with design speed (23562rpm)
    2. Low load: lower speed resulting in higher efficiency
    3. Low load, adapted IGV: modification of IGV in combination with design speed gives highest efficiency.
- Turbine inlet pressure:
    1. Around 235 bar at nominal power
    2. In low load, pressure, higher pressure drop for lower speed
    3. Increasing IGV angle results in throttling and higher pressure, while this is more efficient, it may violate given component specifications for maximum pressure



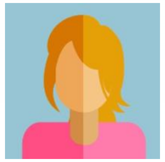


Use-Case

Design Workflow for Power Plants using Modelon Impact and App-Mode for Deployment

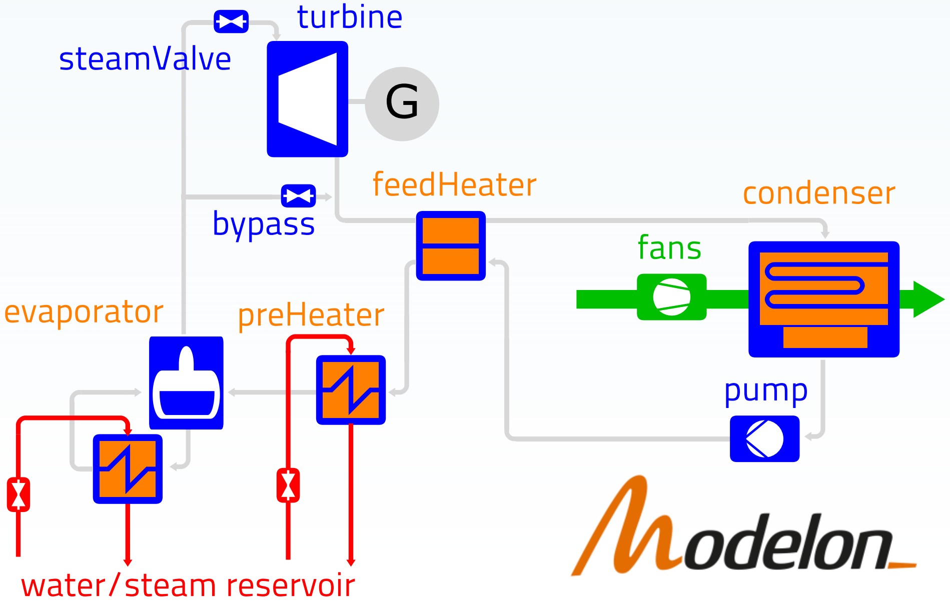
Challenge – geothermal plant design tool

- Impact user wants to design geothermal power plant systems for different sites, based on customer requests.
- Structure of the plant is typically not changing – sometime minor adaptions
- Adaption typically requires sizing of different heat exchangers, turbomachinery.
- Few advanced simulation engineers (“Asta”) in the company to develop models
- Larger number of design engineers (“Bruno”) to adapt system to customer needs



Asta

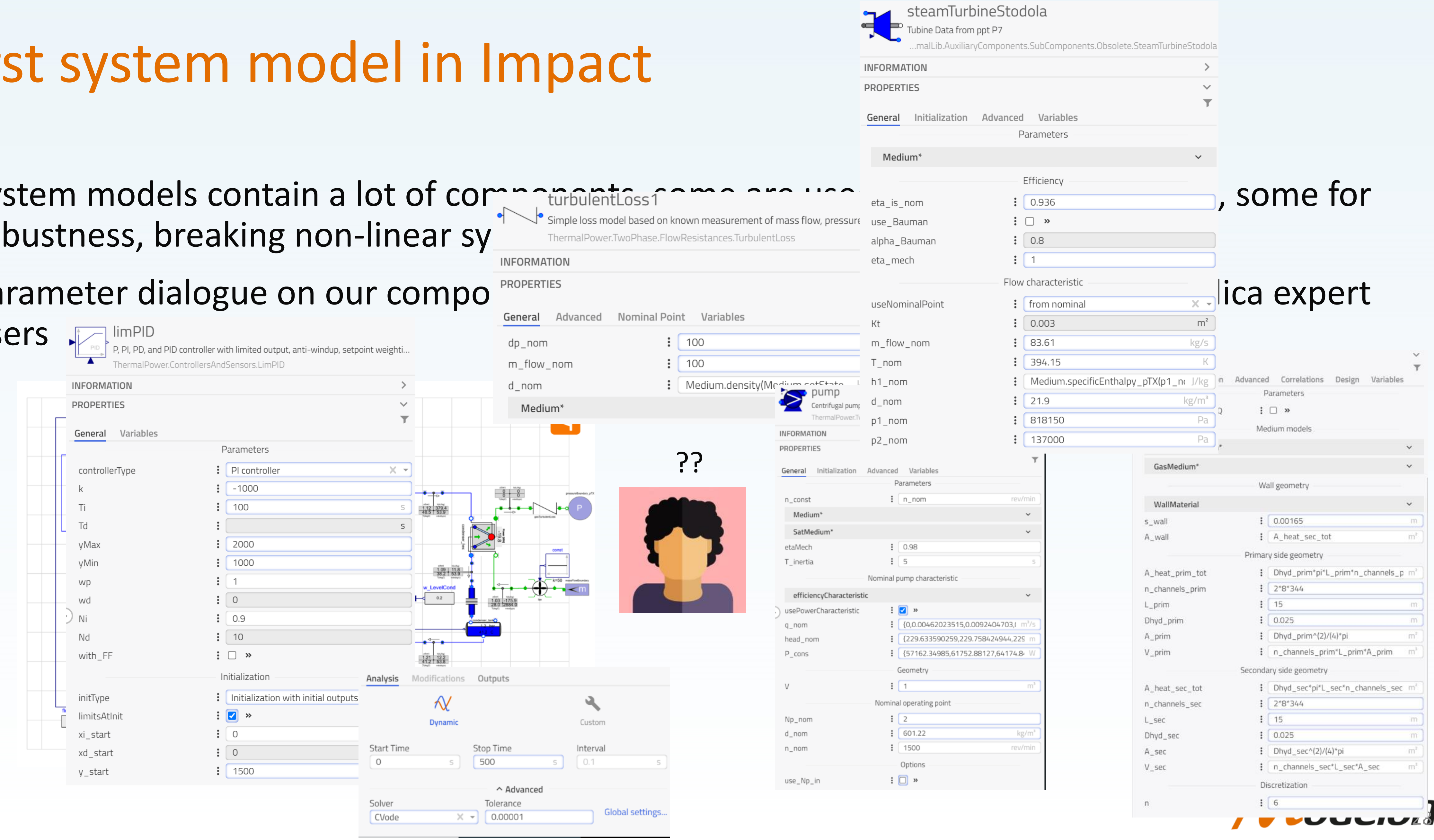
Bruno



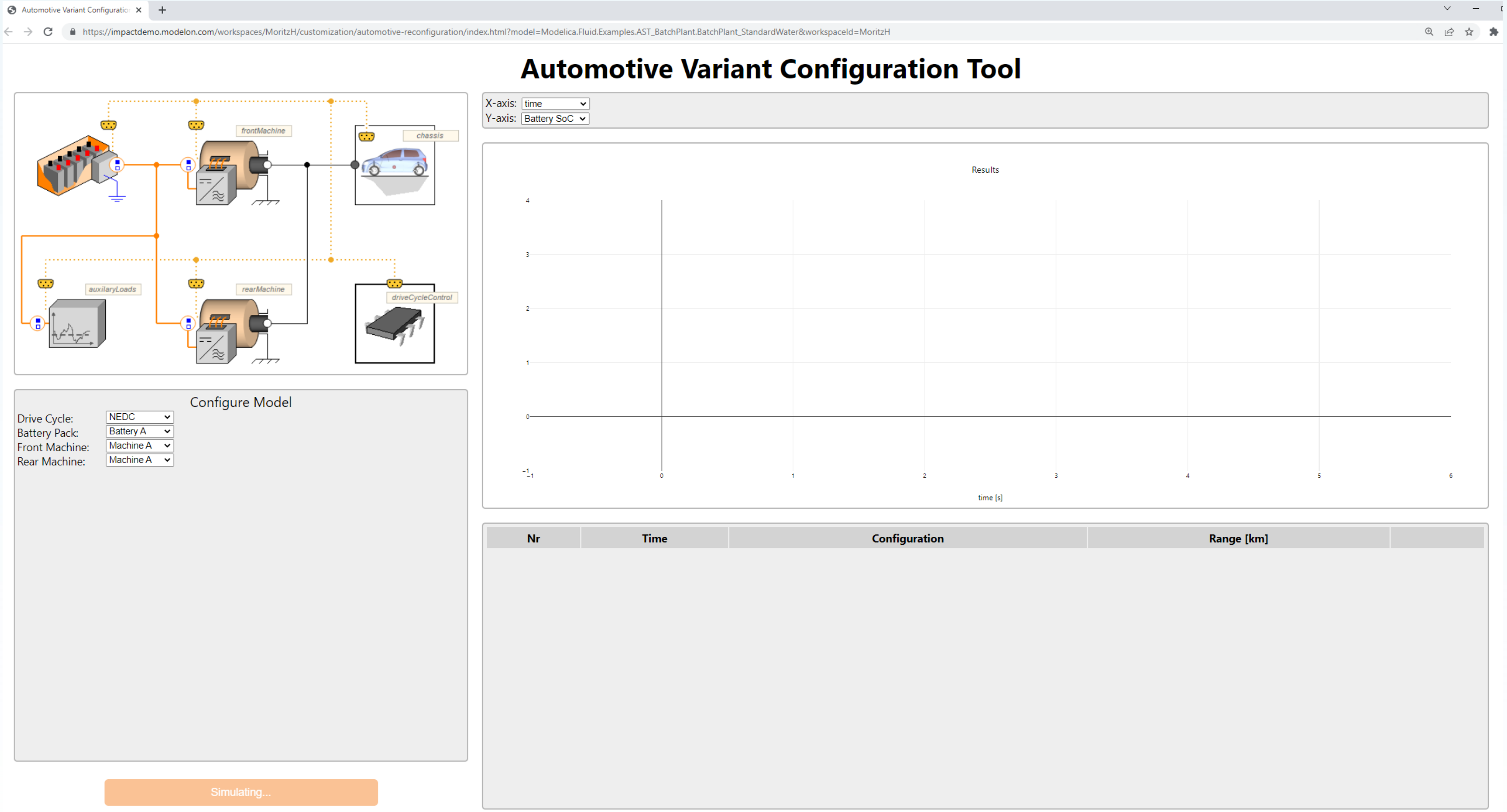
Modelon

First system model in Impact

- System models contain a lot of com … , some for robustness, breaking non-linear sy …
- Parameter dialogue on our compo … lica expert users



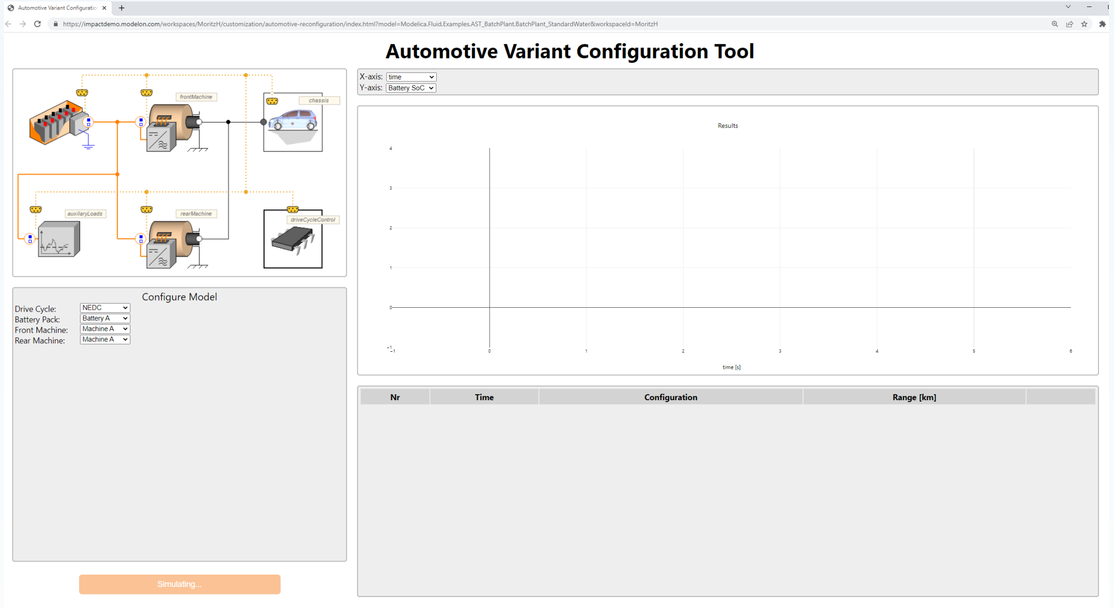
Solution 1: Web apps



Solution 1: Web apps

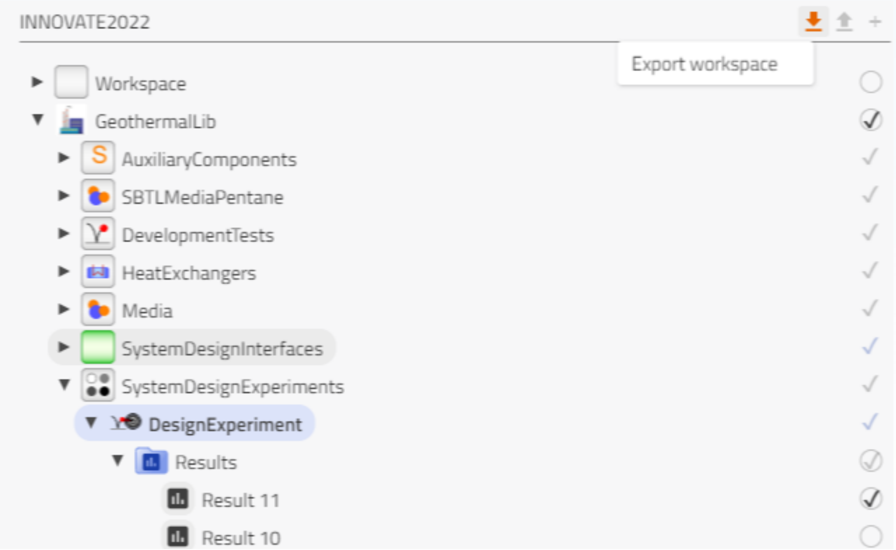
But

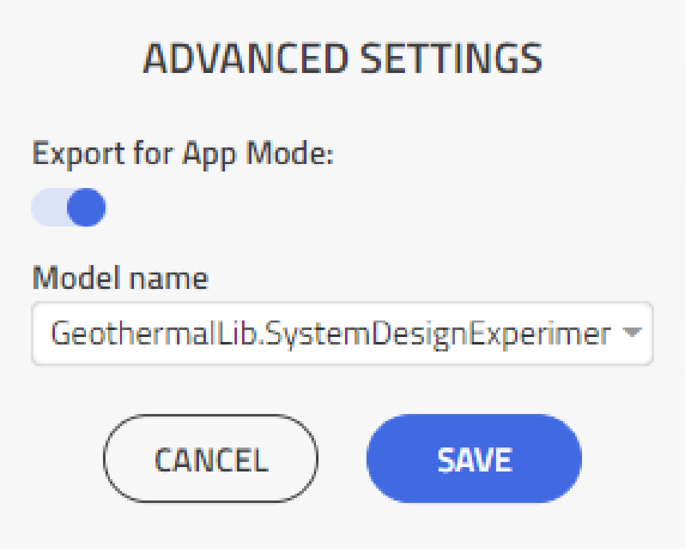
- Requires Java + Modelica experience
- Adds additional tool dependencies
- Design engineer can never start interacting with the model on a deeper level



Solutions 2: Modelica Wrapper in the deployment App

- ✓Does not require Java-experience
- ✓No additional tool dependencies
- ✓Allows scalable utilization through affordable deployment addon
- ✓User can start interacting with the model once he feels comfortable





Design Engineer View

On top level system structure is fixed. Show only design inputs that are meaningful for the design goal (performance, temperature etc.) but cannot break the model

a. Number of pipes
b. Diameters (i/o)
c. Tube length
d. Width / length / height

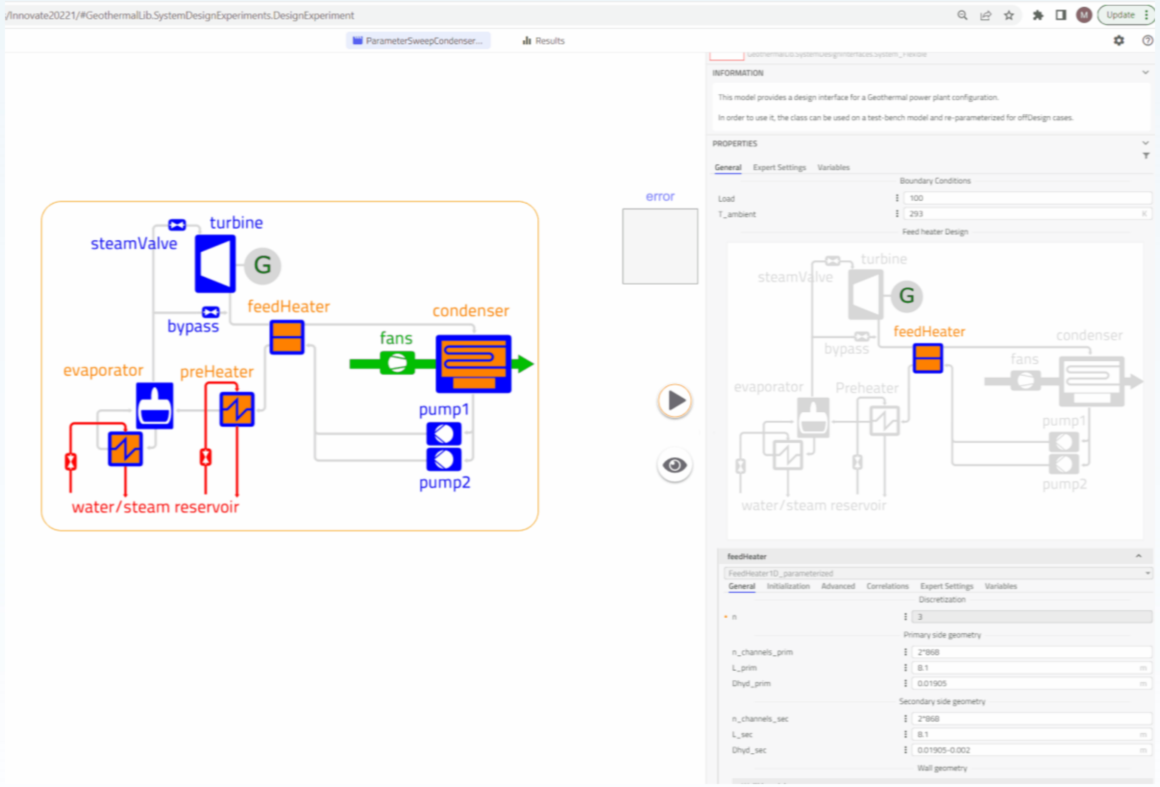
Correlations on advanced tabs (might need modifications but not in first step by design engineer)

a. Heat transfer
   i. Primary
   ii. Secondary
b. Pressure loss
   i. Primary
   ii. Secondary

More advanced settings (should typically not be modified by design engineer

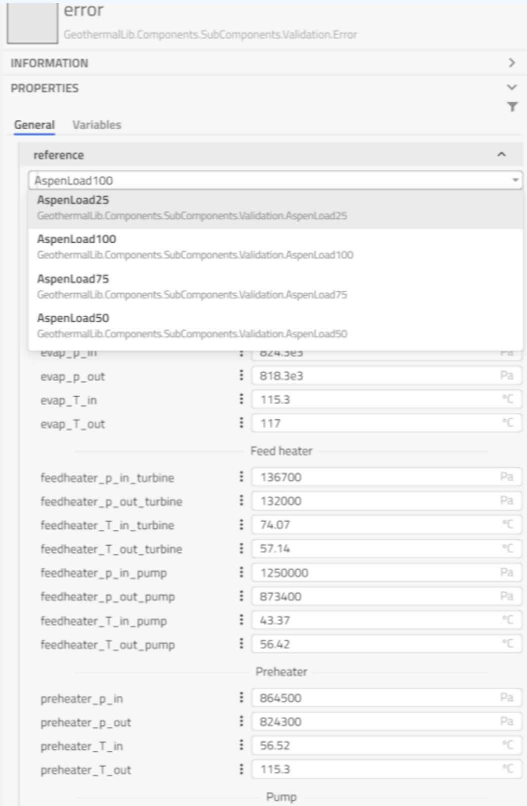
   i. Initialization
   ii. Media models
   iii. …

Target: Maximum robustness with little Modelica knowledge required

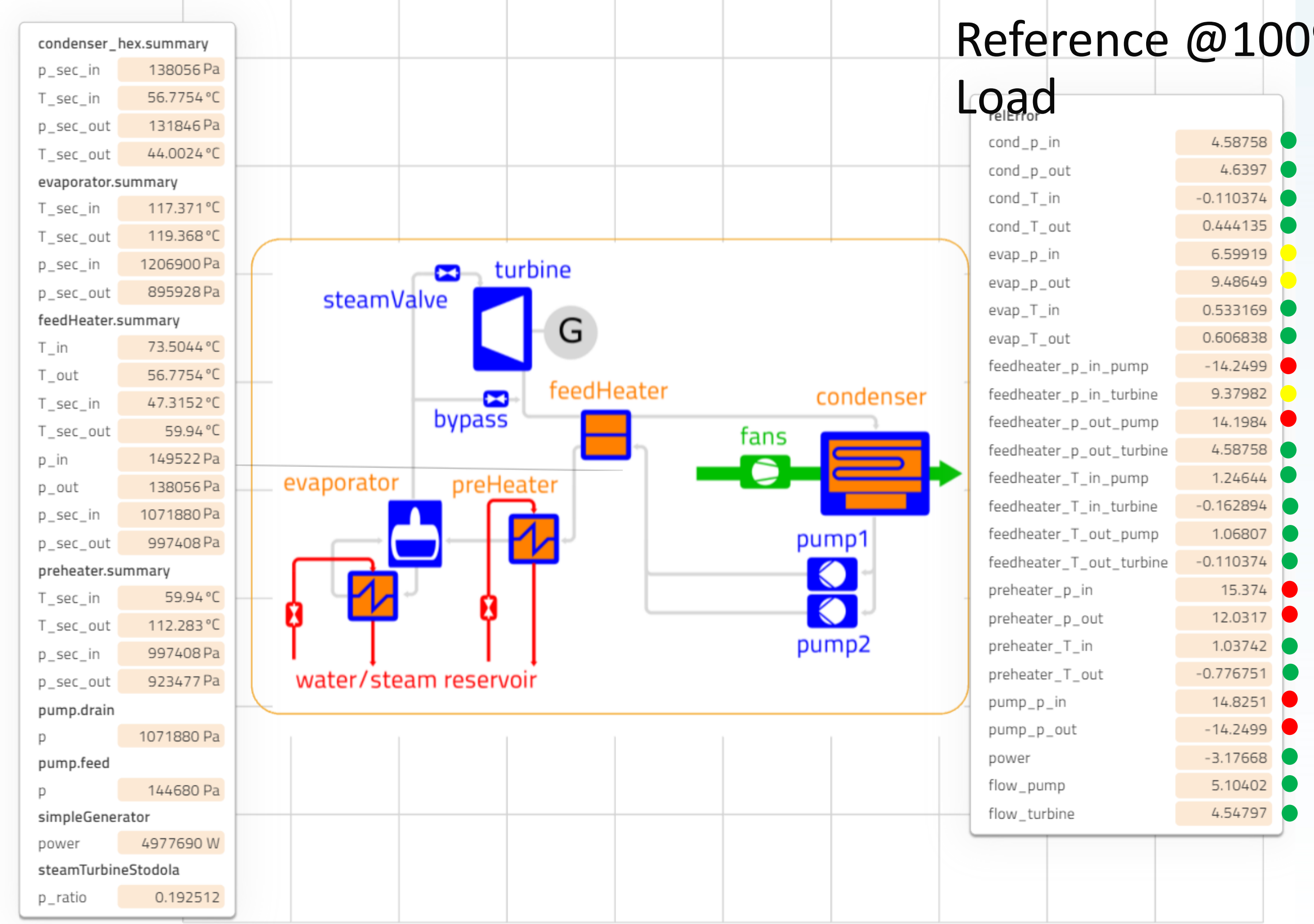


Access to stickies for easy validation

- Reference values stored in replaceable Modelica data records – allowing rapid validation and calculation of relative errors

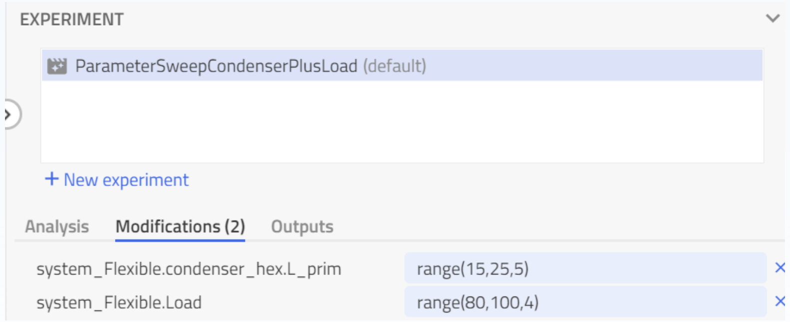


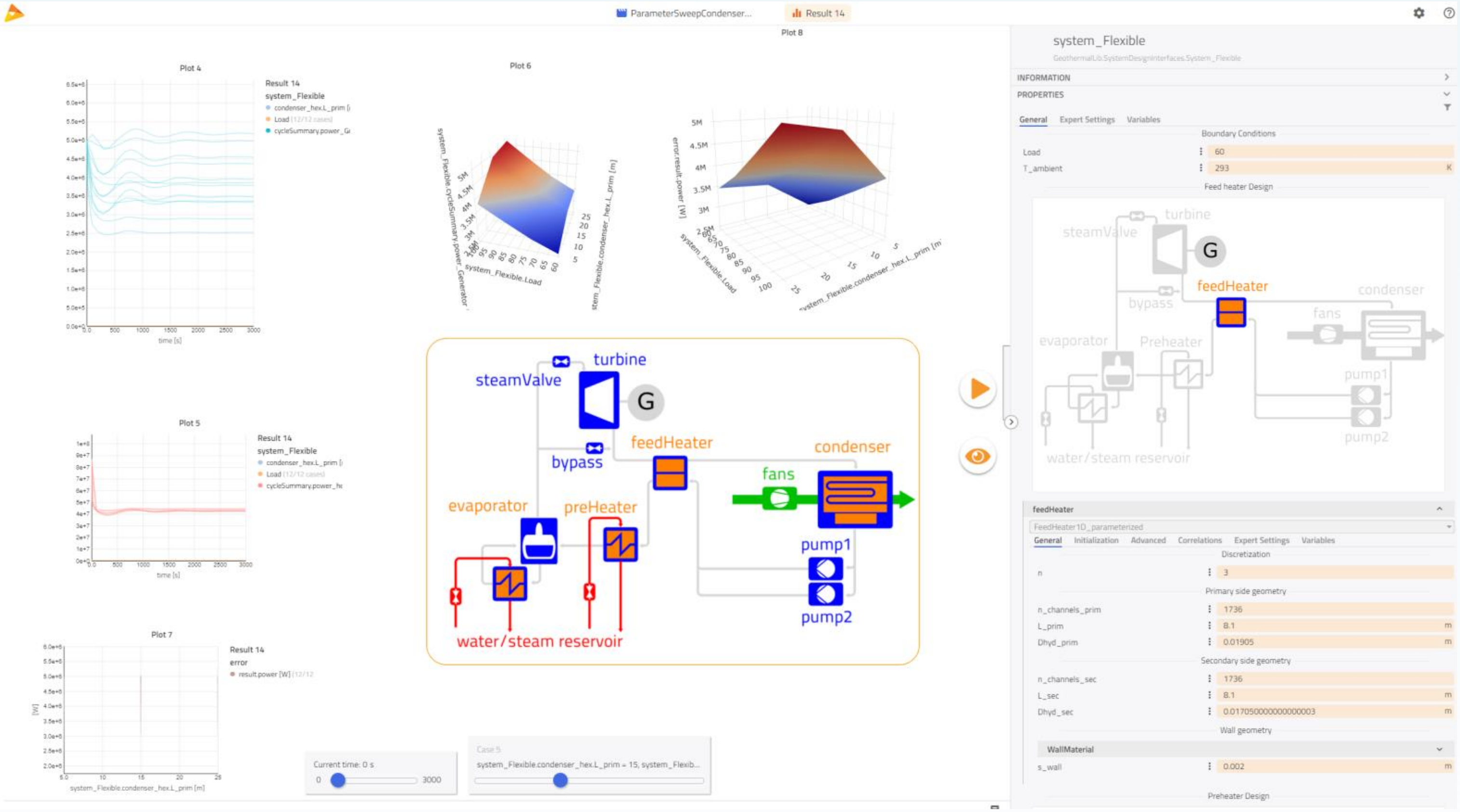
% deviation from Reference @100% Load



SYSTEM DESIGN

- Design parameter inputs available through stickies or Experiment settings
- Operators such as “range” and “choices” can be used to generate parameter sweep experiments





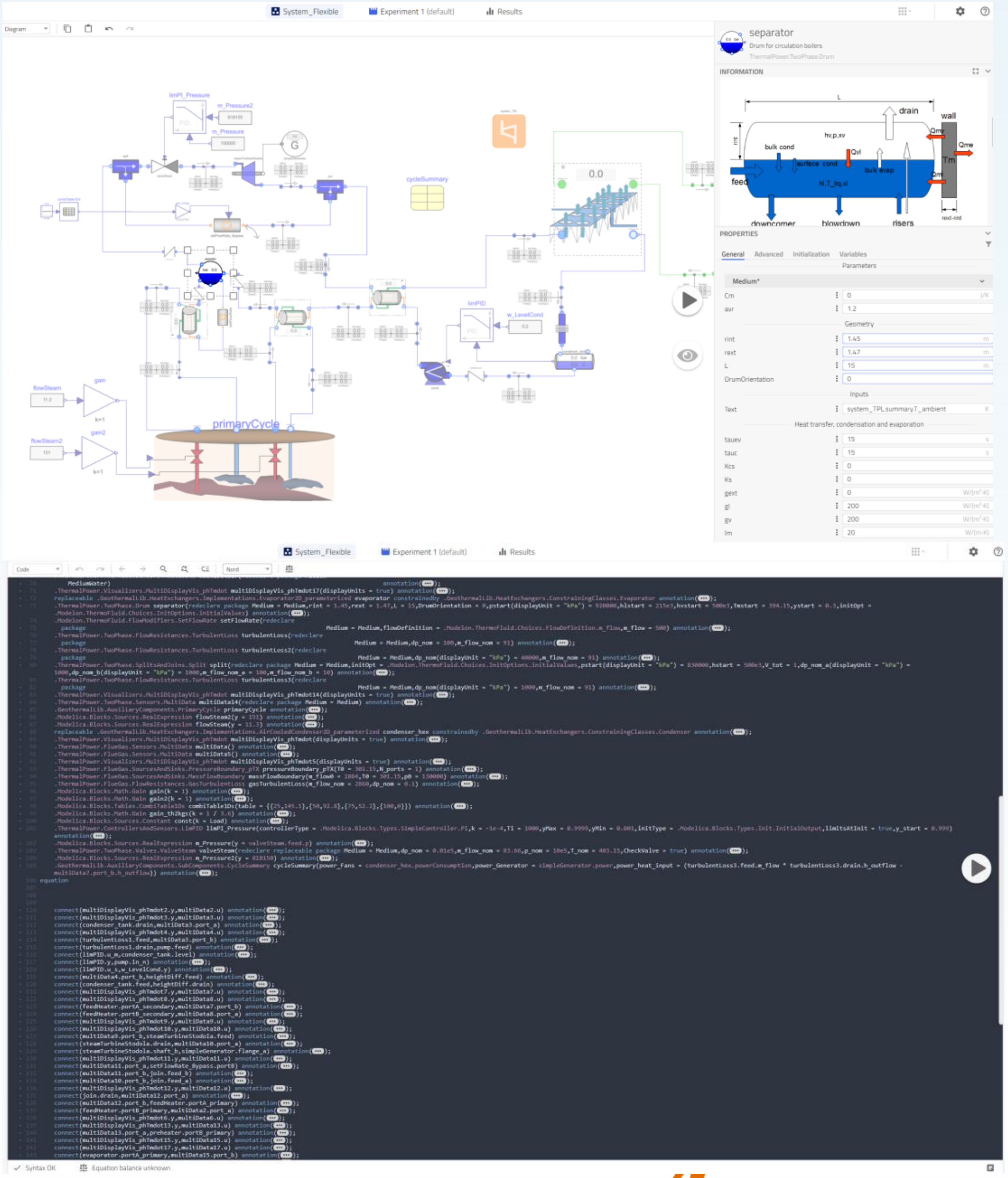
Modelica expert: Geothermal Plant Model

Expert Modelica user can configure system in an easy way:

- Drag&Drop and connect components
- Modify any parameter
- Write Modelica code

…

- Target: maximum flexibility, convenient usage



Conclusion

- Traditional technology is evolving
- Interacting markets require more advanced strategies to design new products
- Value of complex simulation models can be increased by better deployment for a broader audience.
- Integrated tooling allows
  - Better component design due in real system environment
  - Better system design for more efficient, more flexible more robust operation