INPUT SMOOTHING FOR FASTER CO-SIMULATION USING FMI

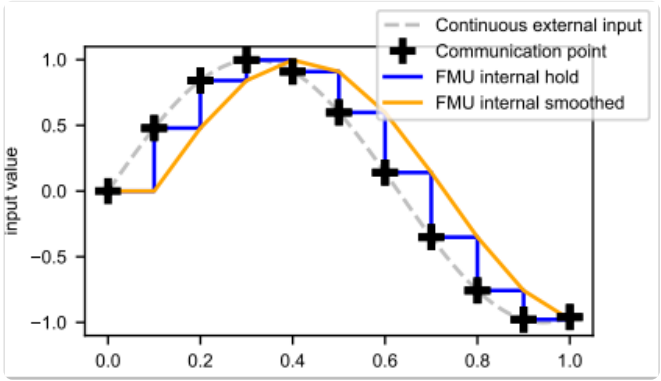
Lucerne, September 9, 2025

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Julius Aka
Oliver Lenord

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INPUT SMOOTHING FOR FASTER CO-SIMULATION USING FMI

- Purpose
  - Speed up FMI co-simulation
- Method
  - Input smoothing with optional predictor compensation
- Implementation
  - Easy to use and widely usable
  - Dymola 2025x (Refresh 1)
- Target user
  - Anyone exporting heavy co-simulation FMUs from Dymola
  - Especially when small communication intervals are required



TLK-Thermo GmbH

Universität Augsburg University

TLK ENERGY

BOSCH

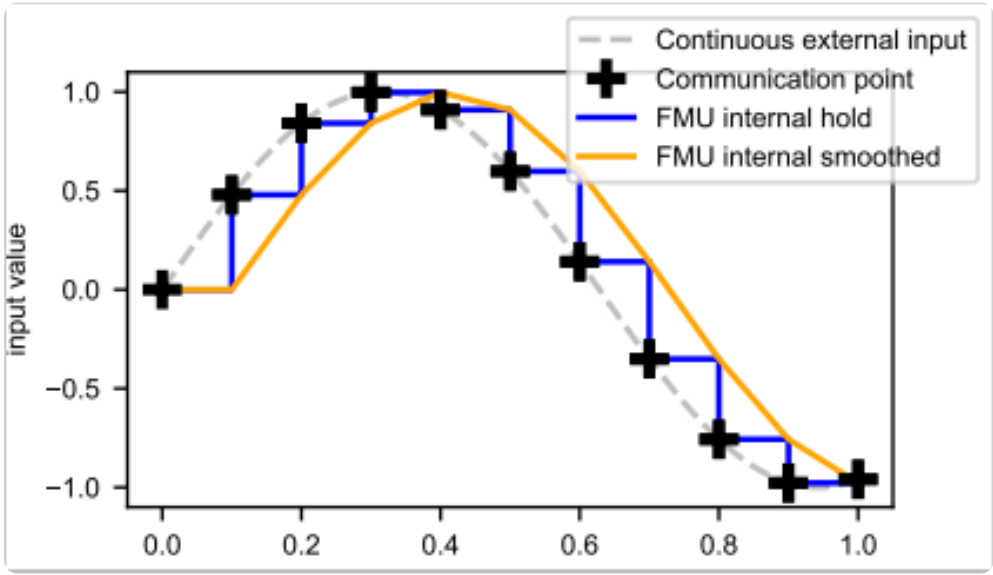
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INPUT SMOOTHING

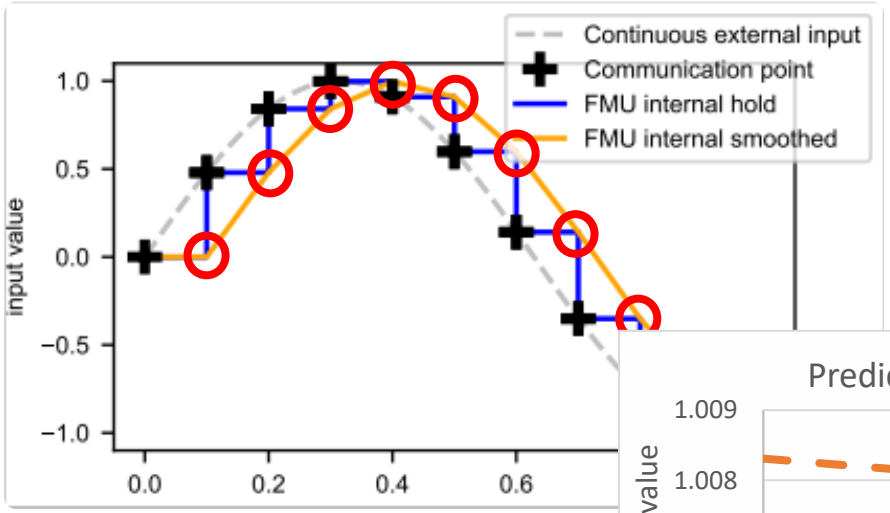
- Classical input handling
  - Zero-order hold of external input at communication points
- Dymola input smoother
  - Linear interpolation of delayed external input
  - Based on implementation by TLK-Thermo
- Continuous input signal inside the FMU
  - Avoids integrator restarts
  - Speed-up for multistep methods (CVode, Dassl, …)
- Smoother embedded inside exported FMU
  - No special co-simulation master required
  - `Advanced.FMI.UseInputSmoother`



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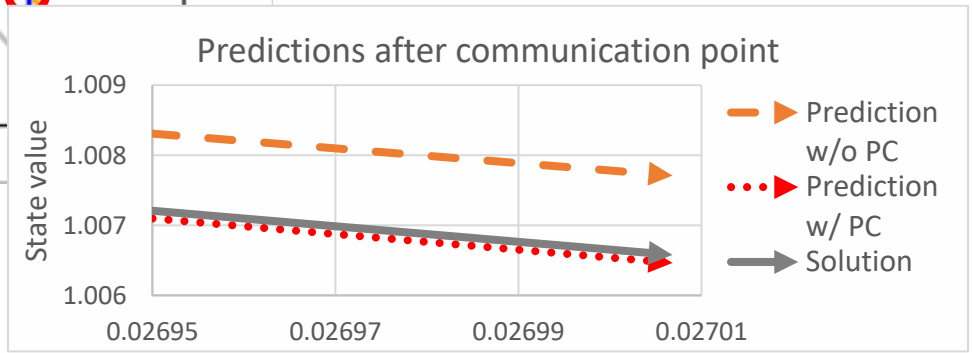
PREDICTOR COMPENSATION

- Smoothed input not continuously differentiable
  - High-order integrators expect high-order differentiability
  - Violation means bad predictors



- Modify predictor at communication points
  - Improved start guess for nonlinear solver
  - Improved error estimate
  - Fewer discarded steps, fewer nonlinear solver failures, less step size and order reduction

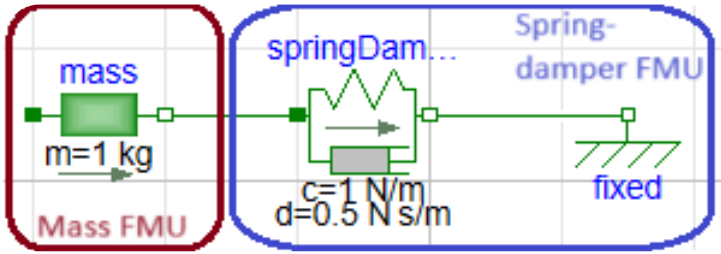
- Embedded inside exported FMU
  - Two extra model evaluation at communication points
  - `Advanced.FMI.UsePredictorCompensation`

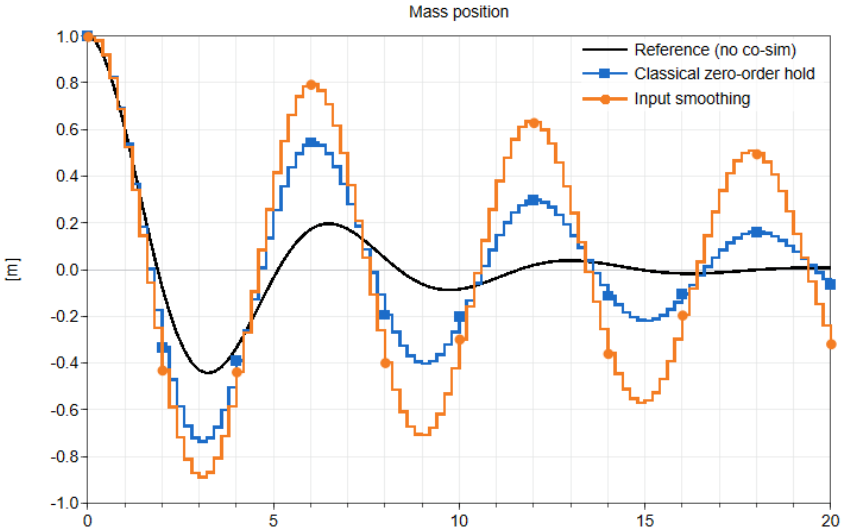


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EXAMPLE: MASS-SPRING SYSTEM

- Mass-spring-damper system split into two FMUs
  - Only mass FMU modified
- Input smoothing reduces the number of model evaluation
  - Predictor compensation further reduces evaluations





	CVODE			IDA			DASSL		
Option	f-evals	Jac-evals	PC f-evals	f-evals	Jac-evals	PC f-evals	f-evals	Jac-evals	PC f-evals
Classical	5471	499		5958	4960		5042	4543	
IS	2708	40		4715	1030		2653	534	
IS & PC	853	14	996	2692	916	996	1481	259	996

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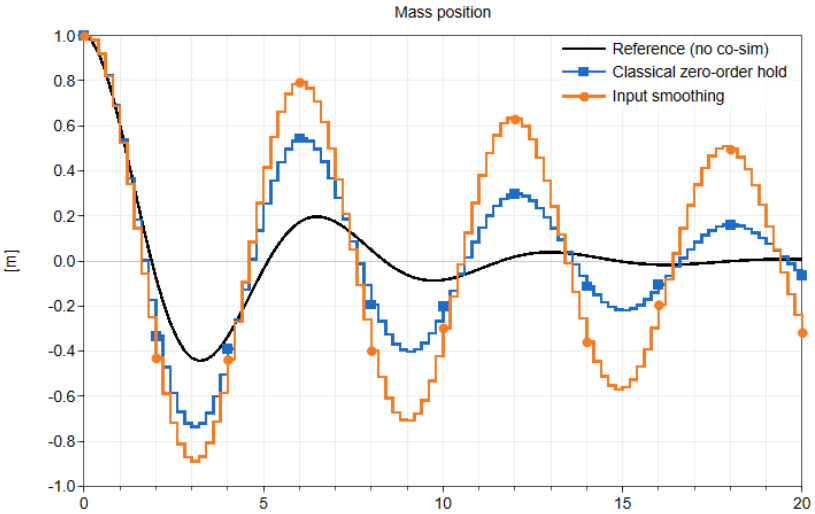
OVERVIEW AND CONTEXT

- Co-simulation challenges
  - Stability – Input smoothing worsens stability
  - Accuracy – Input smoothing does not help
  - Efficiency – Input smoothing may improve
  - There seems to be no all-purpose solution

- Contribution
  - Easy to use, yet widely usable
    - › No special master required, nor any model manipulations
    - › Non-physical, purely mathematical
    - › Based on a well-known idea
  - Handling discontinuous derivatives

- Some alternatives
  - Runge–Kutta methods
  - Transmission line modelling

- Greatest performance gains when
  - Exported FMU is computationally heavy
  - Communication interval is small
  - Co-simulation stability not a major issue



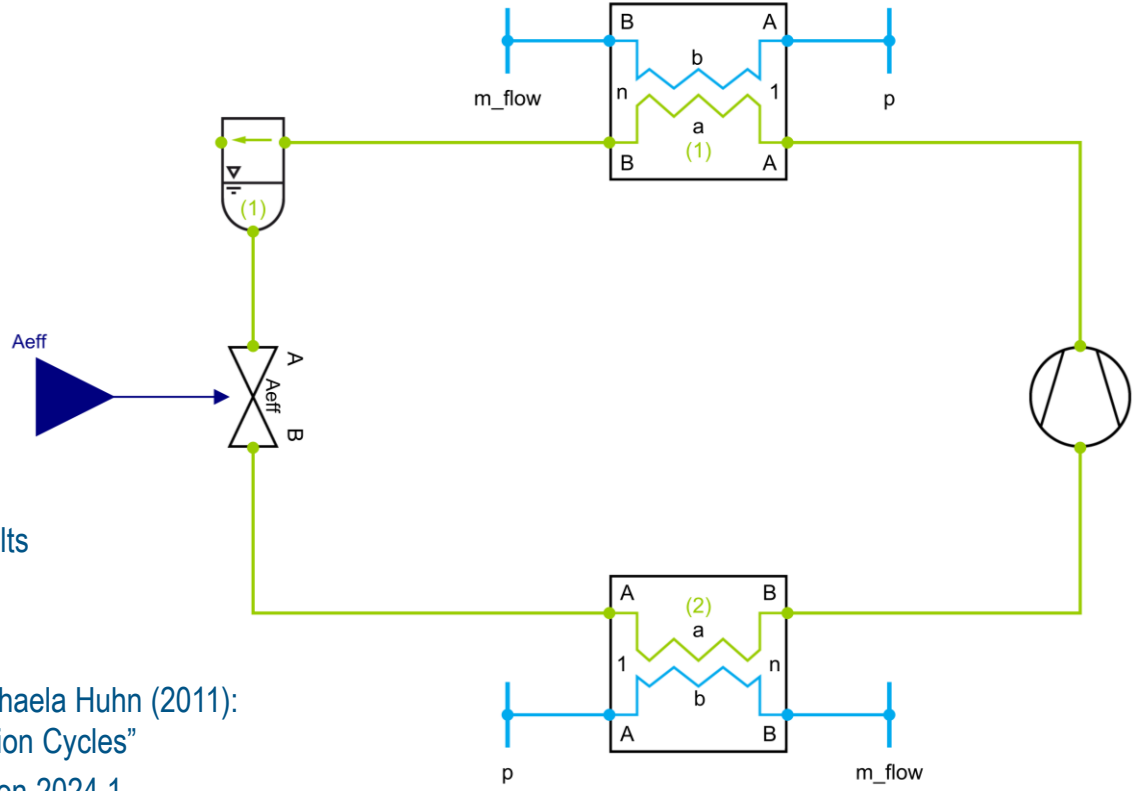
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HIL SIMULATION OF A HEAT PUMP

- Model
  - Domestic heat pump
    - › Vapor compression cycle
  - Using the TIL Suite
  - Used for HIL simulation
    - › Fixed synchronization rate with noisy input

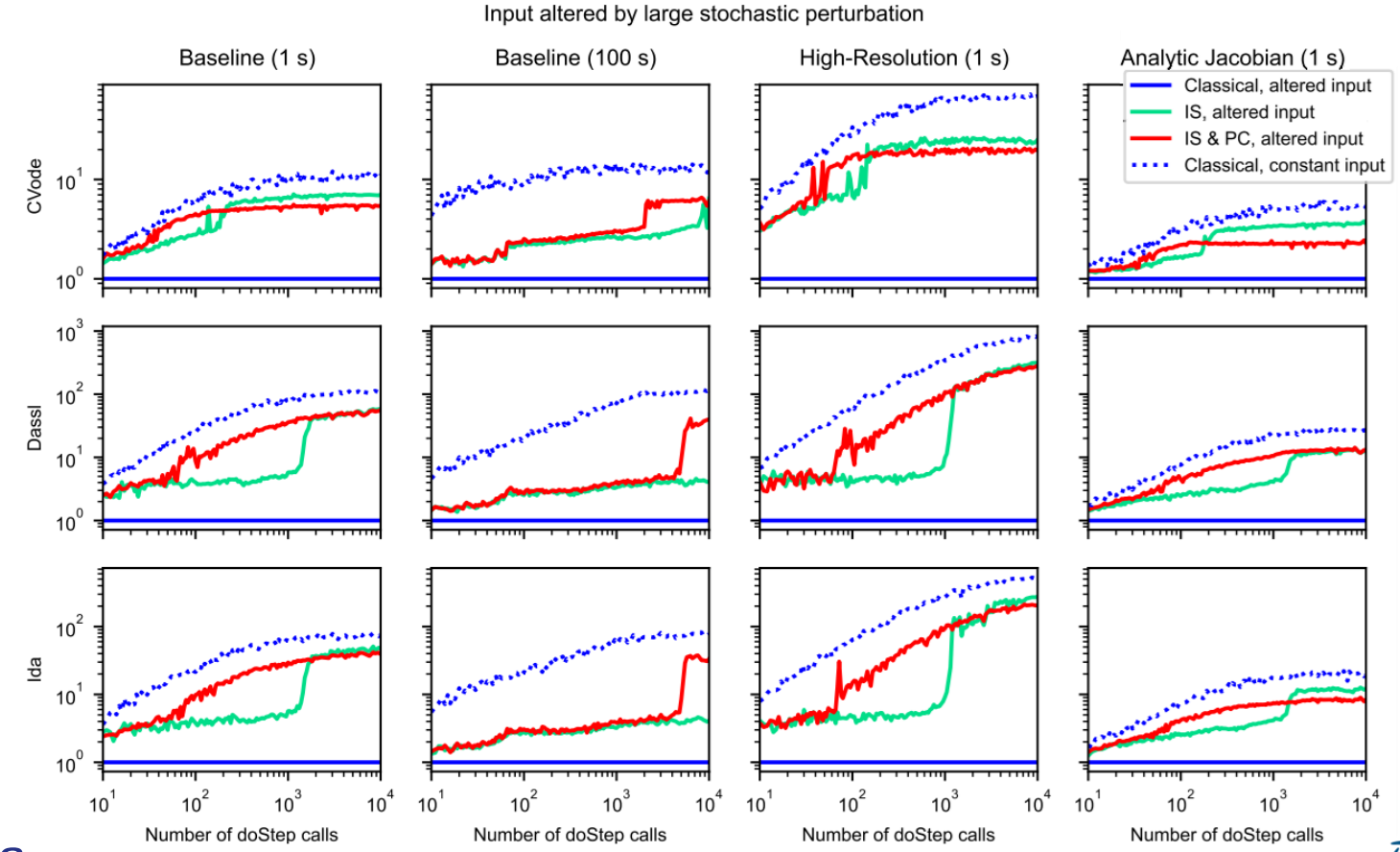
- Experiment setup
  - Whole model exported to FMU
  - Valve opening area as noisy input
  - 17000 simulations, see article for more results

- References
  - Schulze, Christian, Manuel Gräber, and Michaela Huhn (2011): “Real-Time Simulation of Vapour Compression Cycles”
  - TLK-Thermo GmbH (2024). *TIL Suite.* Version 2024.1



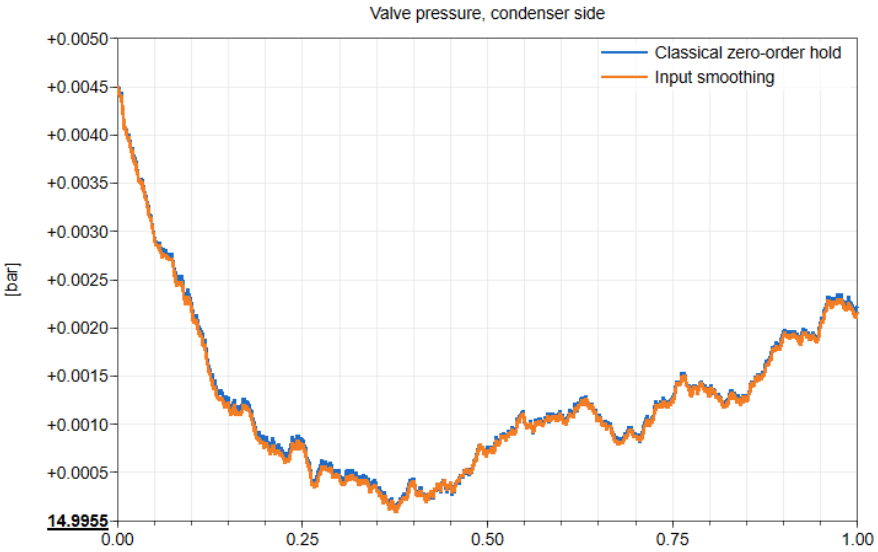
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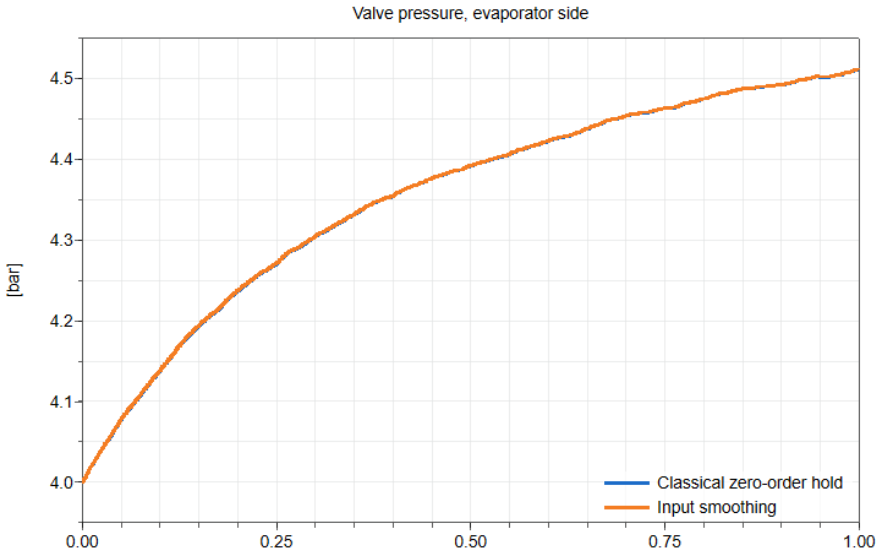
HIL SIMULATION OF A HEAT PUMP, SPEED-UP FACTOR



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HIL SIMULATION OF A HEAT PUMP, RESULT COMPARISON

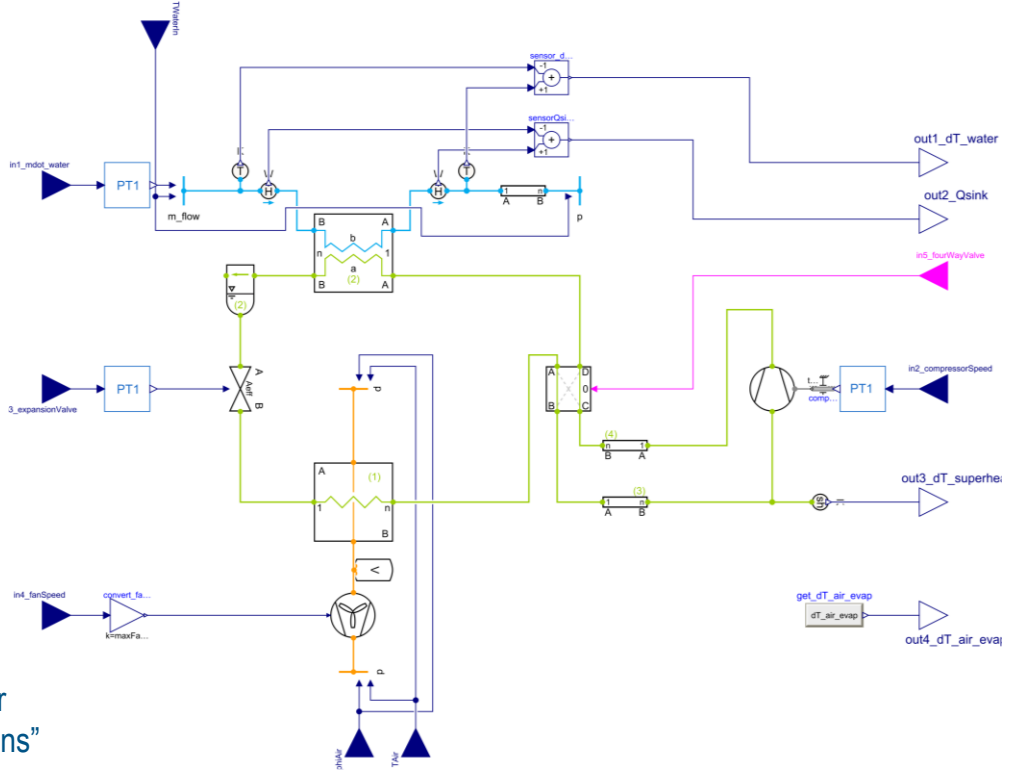




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HEAT PUMP SIMULATION DATA FOR TRAINING SURROGATE MODELS

- Model
  - Detailed air-source heat pump
    - › Refrigeration cycle with controller
    - › Moist air flow with condensation and frost formation
  - Demonstrator from Bosch for the OpenSCALING project
    - › For training surrogate models using Balanced Neural ODEs
- Experiment setup
  - Heat pump with controller exported to FMU
  - Two operating points
    - › Tuned controller
    - › High-gain controller enforcing oscillations
- References
  - Aka, Julius et al. (2025). “Balanced Neural ODEs: nonlinear model order reduction and Koopman operator approximations”



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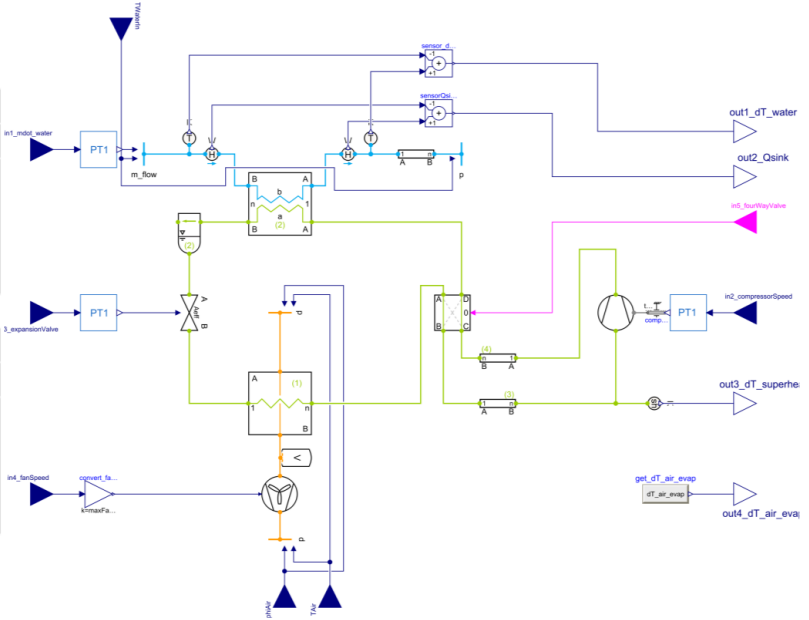
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HEAT PUMP SIMULATION DATA FOR TRAINING SURROGATE MODELS

Low Oscillations						
Option	f-evals	Jac-evals	Events	PC f-evals	CPU-time [s]	CPU-time gain
Classical	8251	4546	506		129	1
IS	1950	209	6		3.11	41.5
IS & PC	1910	222	6	998	3.27	39.5
Modelica	1038	140			2.35	54.9

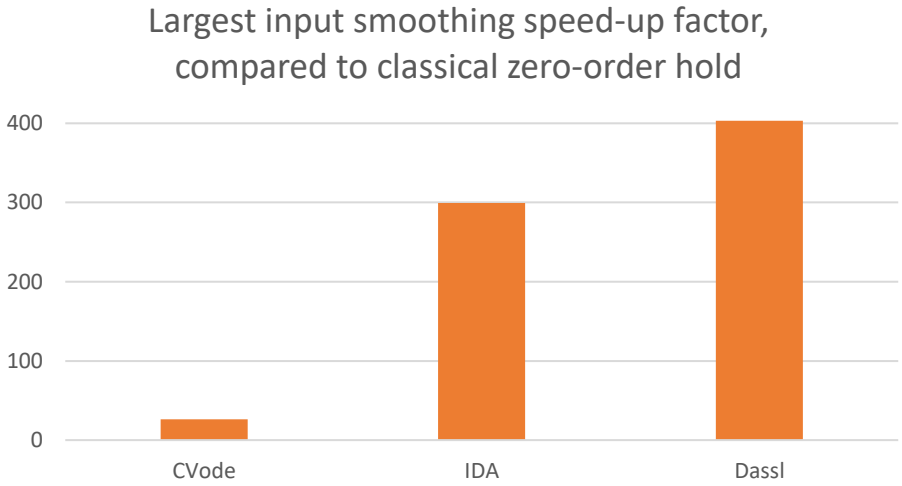
High Oscillations						
Option	f-evals	Jac-evals	Events	PC f-evals	CPU-time [s]	CPU-time gain
Classical	71939	9073	514		321	1
IS	70734	7011	16		273	1.18
IS & PC	70442	6936	16	926	255	1.26
Modelica	35343	6113			183	1.75



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CONCLUSION

- Input smoother with optional predictor compensation
  - Embedded in exported FMUs
  - No special master required, nor any model manipulations
  - May speed up FMI co-simulation
  - Available in Dymola 2025x (Refresh 1)
- Limitations
  - Does not solve all co-simulation problems
  - Worsens stability
- Thermo fluid applications
  - Often 10 times faster and sometimes 100 times faster
- Future work
  - Applications with several FMUs using input smoothing



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