Coupling Strategy Between CATHARE and MODELICA

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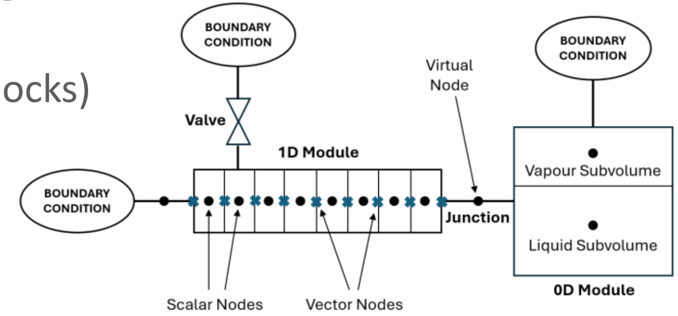
CATHARE 3 - Introduction

CATHARE 3 – Introduction

CATHARE 3 is a well-assessed French thermal-hydraulic system code used for nuclear safety analyses

The CATHARE 3 development started with the NEPTUNE project [1] in 2002

- Object-oriented modelling strategy (models made by different blocks)
- Different type of blocks available (0D, 1D, 3D, Valves…)
- Two-phase model used by default
- Each block comes with its heat structure model
- Other modules can be enabled (e.g., core neutronics)



1D vapour – liquid continuity eqs.

$$A\frac{\partial \alpha_v \rho_v}{\partial t} + \frac{\partial A \alpha_v \rho_v w_{x,v}}{\partial x} - A\Gamma_v = 0$$

$$A\frac{\partial \alpha_l \rho_l}{\partial t} + \frac{\partial A \alpha_l \rho_l w_{x,l}}{\partial x} + A\Gamma_v = 0$$

CATHARE Official website: https://cathare.cea.fr/

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CATHARE 3 – Transient Analyses

CATHARE 3 adopts a fully implicit discretization scheme for Thermal Hydraulic equations and semi-implicit scheme for heat transfer phenomena.

Transient calculation is divided into 3 different steps:

1) Steady-state

Time derivatives are not considered and a steady-state condition is searched by the solver

2) Stabilized transient

Steady-state condition is used to initialize a transient calculation to reach a stationary point

The achieved stationary point is used to initialize other modules, e.g., core neutronics

3) Transient

Starting from the achieved stationary point, a transient is induced in the system

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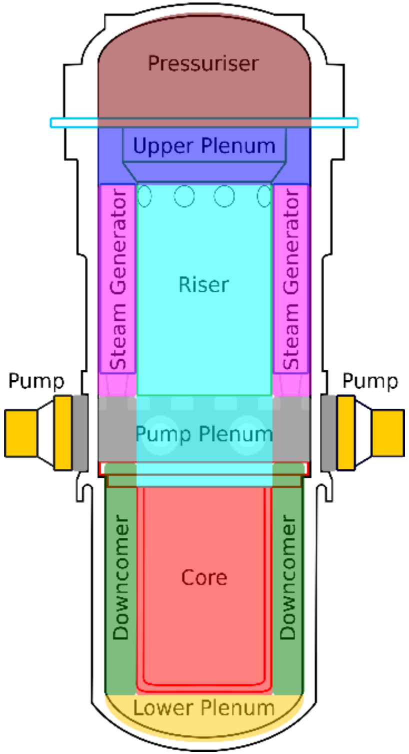
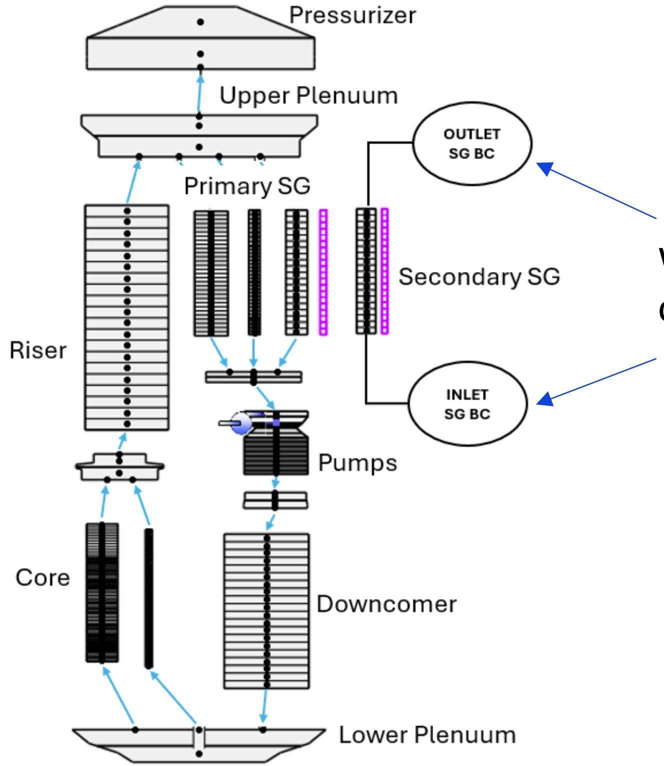
CATHARE 3 – Example of SMR CATHARE 3 Model





Will be used to perform the coupling with MODELICA

Source: ELSMOR Dataset [2]

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Model Coupling – What do We Need?

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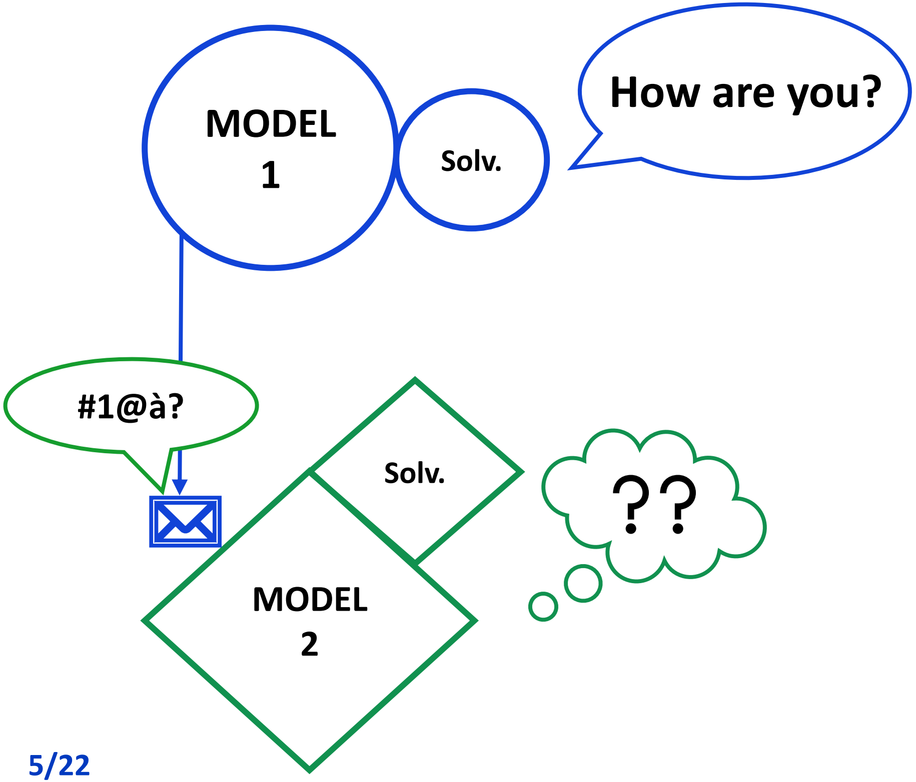
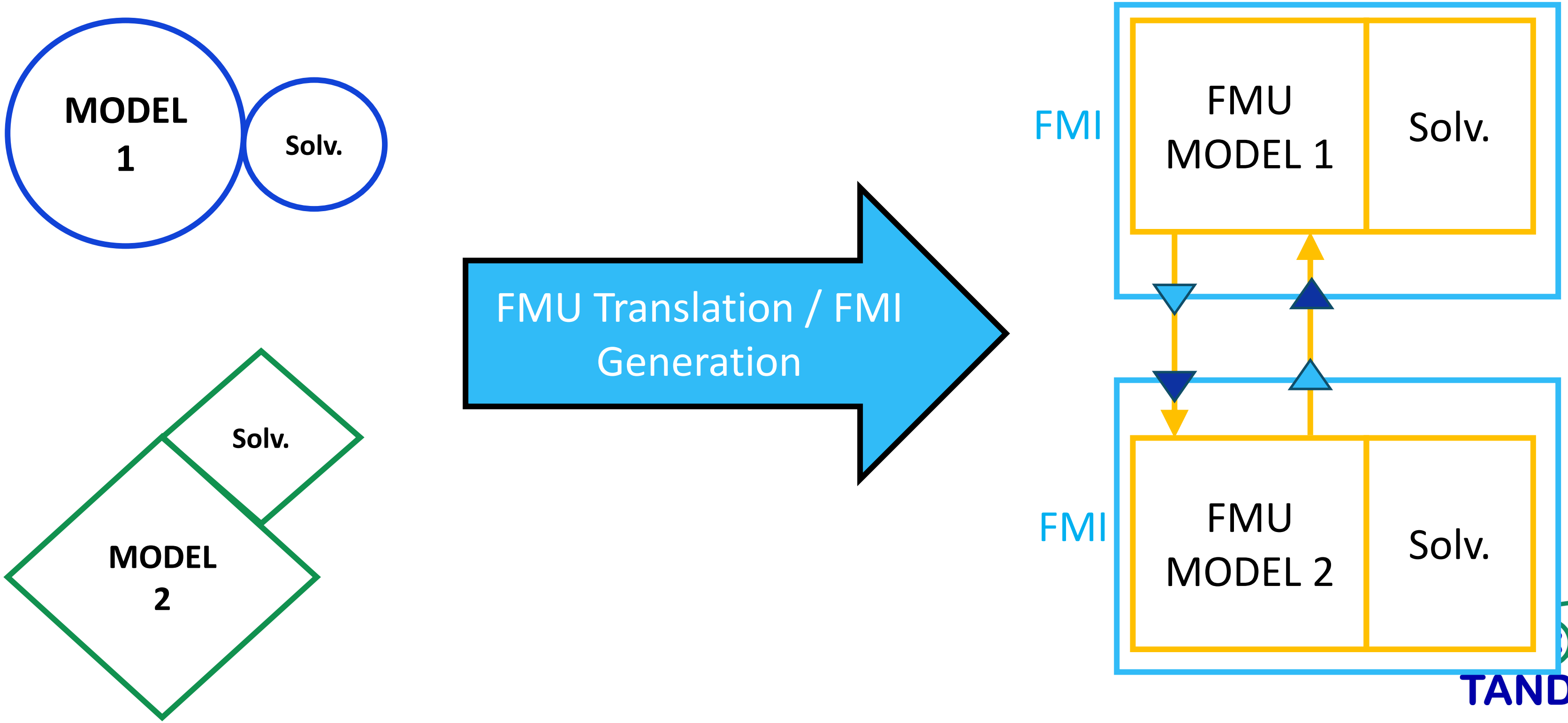
Coupling of Different Models - Background



Coupling of Different Models - Background



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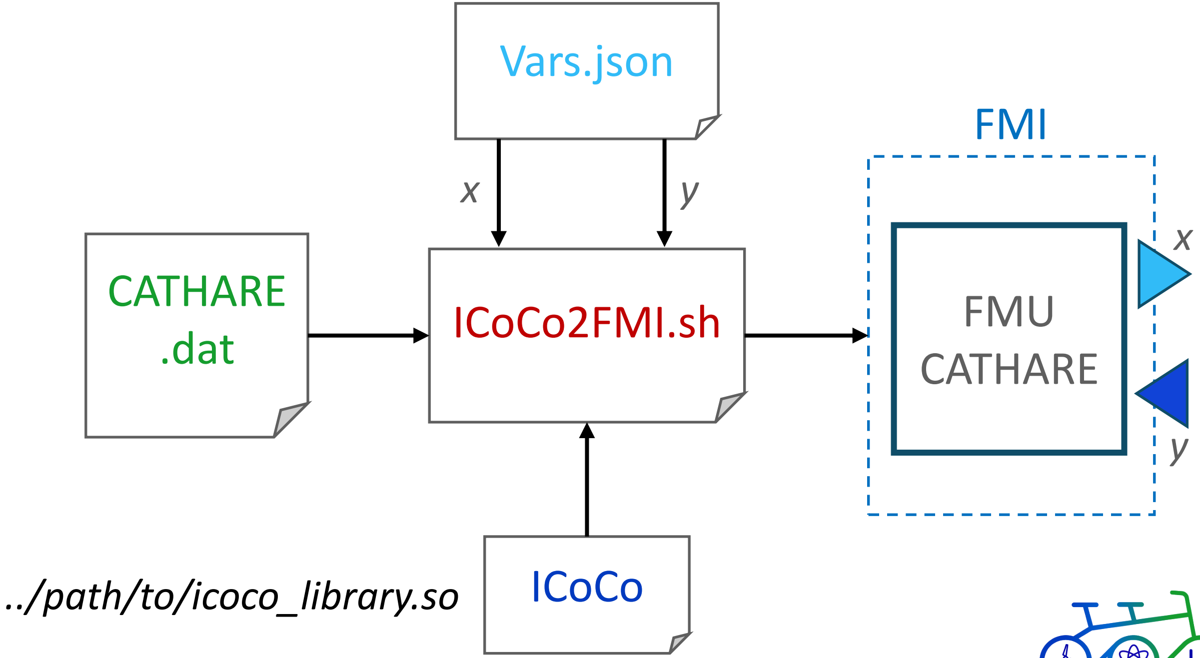
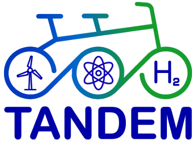
FMI Generation – CATHARE 3 Models

What do we need?

- ICoCo2FMI.sh [3]
- CATHARE 3 model
- Interface for Codes Coupling (ICoCo Library) [4]
- JSON for variable definition



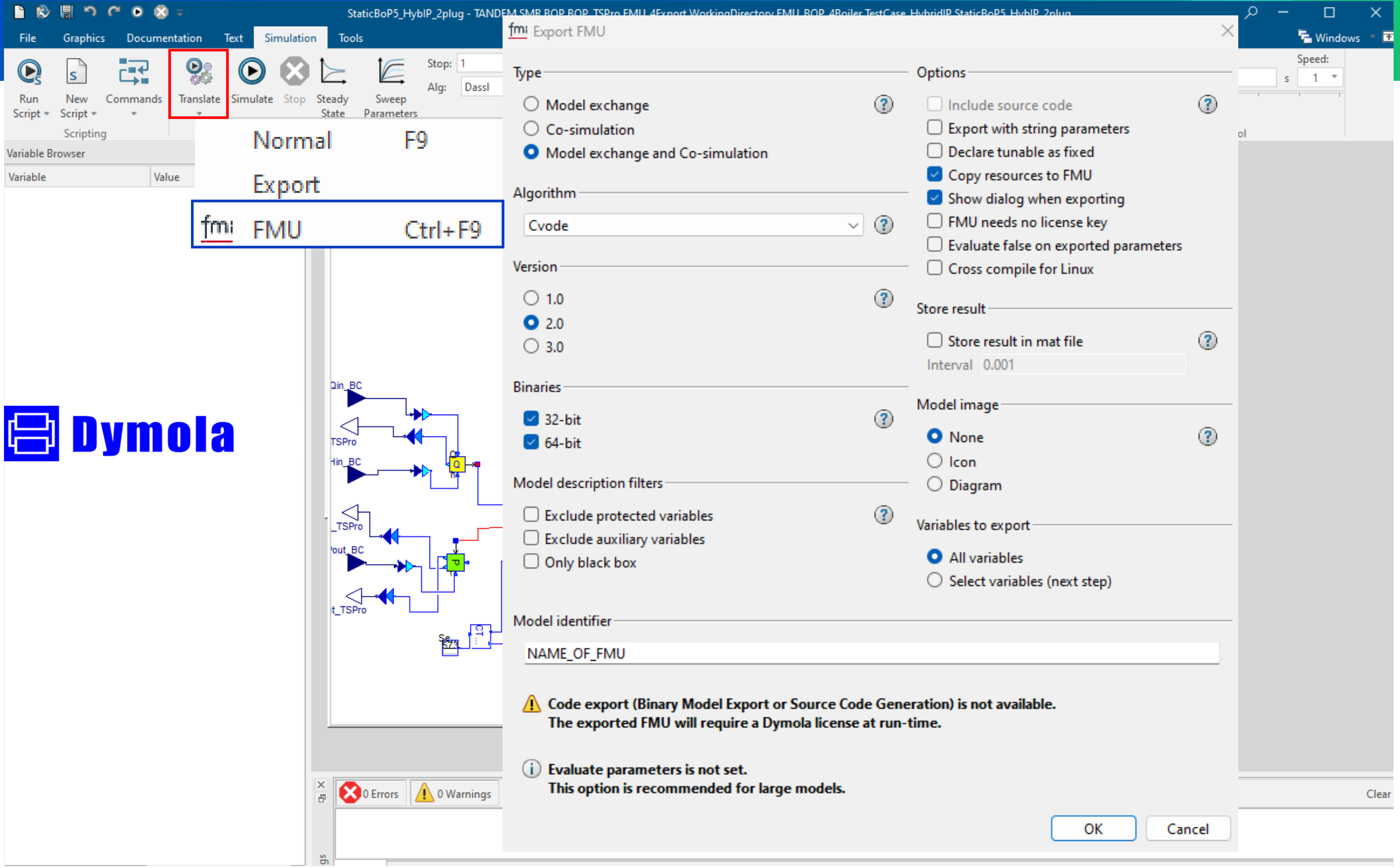


FMI Generation – MODELICA Models

Different ways

Commercial Codes (Dymola)

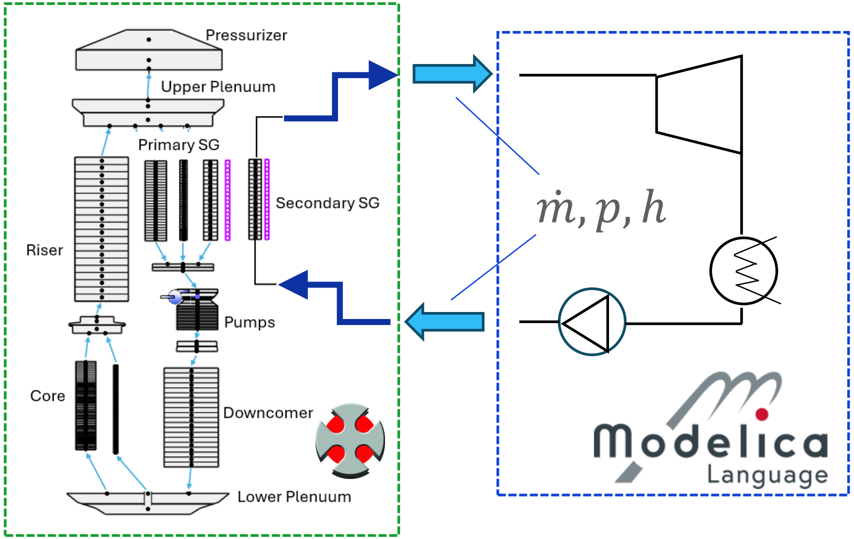
Open Source Codes (OpenModelica)

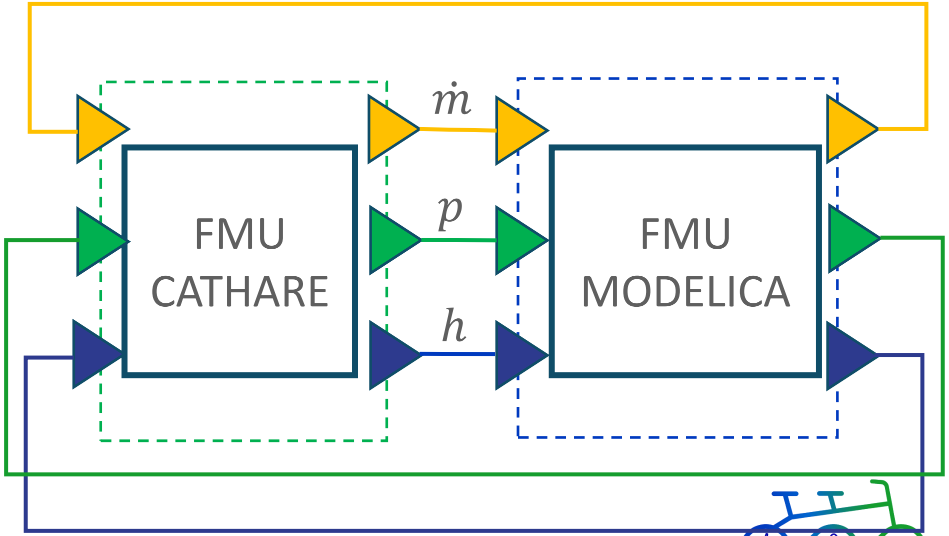


Coupling Strategy

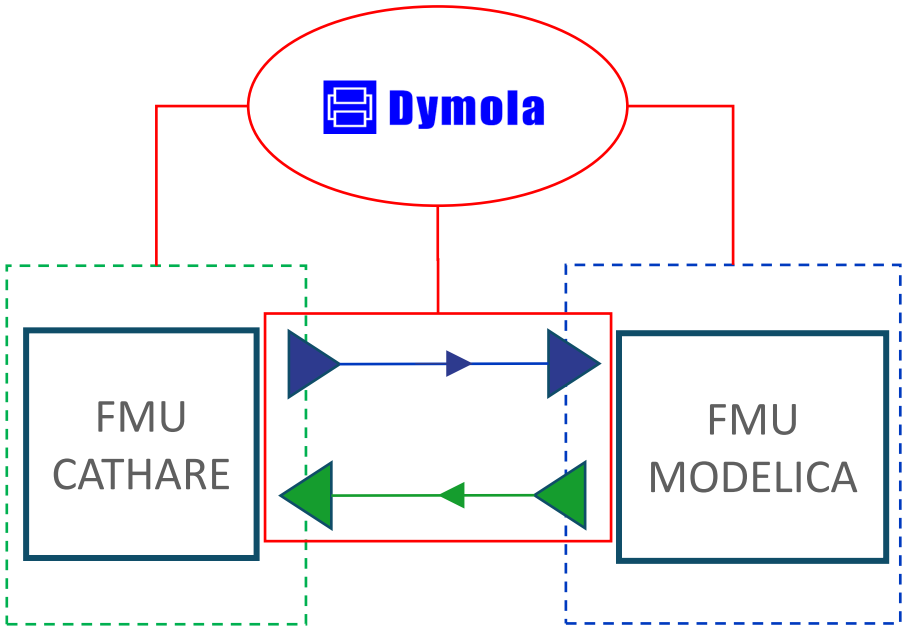
Coupling Strategy – Main Idea

Fluid Coupling between Primary Side (CATHARE 3) and Balance of Plant (MODELICA)





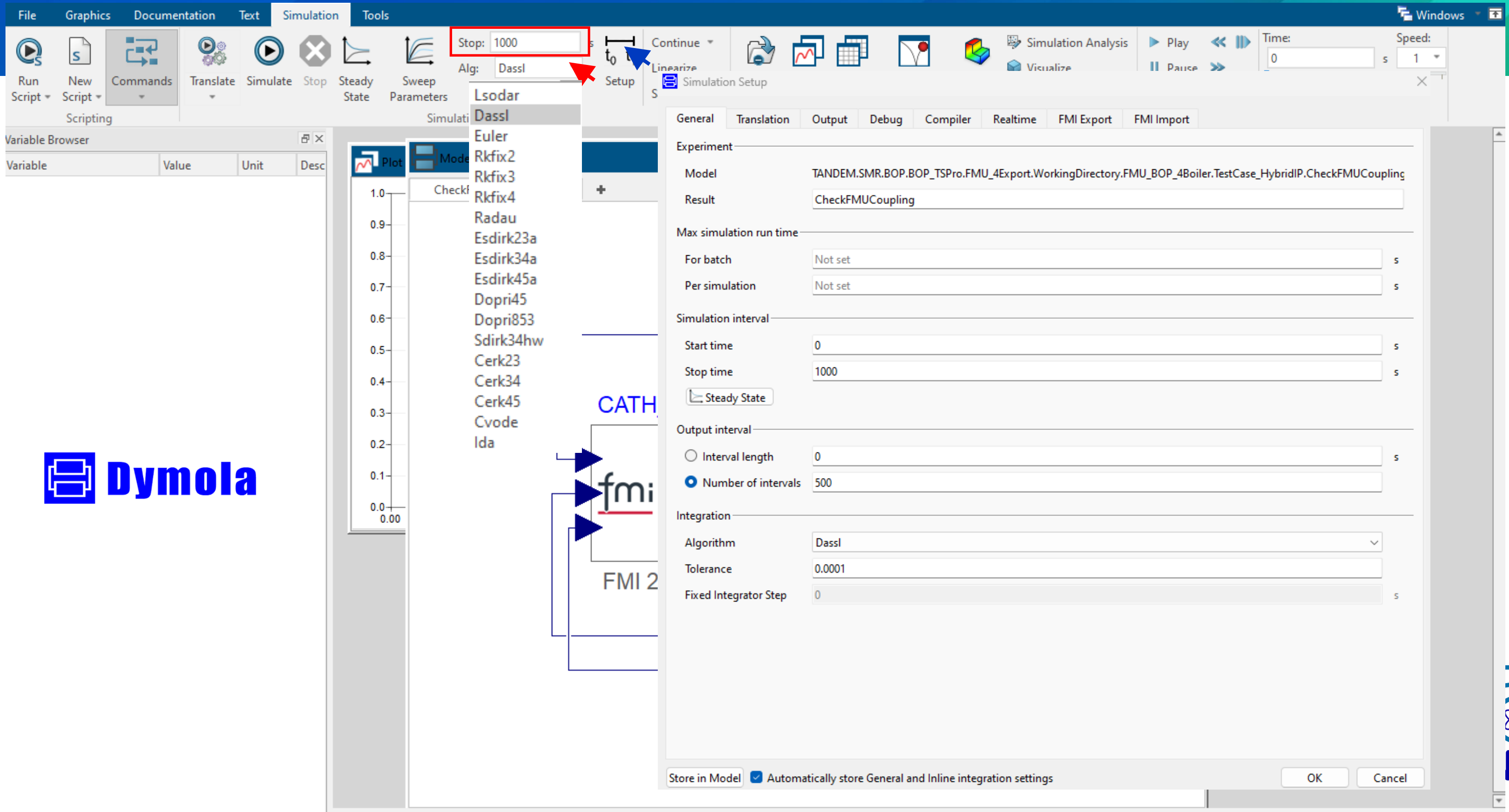
Coupling Strategy – Co-simulation Supervision



Master controls the co-simulation:

- Time-step advancement of the models
- Control of the time-step (e.g., time-step threshold)
- Collection of the outputs
- Imposition of inputs
- Simulation Environments or Python 3 coded interfaces (FMPy [4]) can be used

Coupling Strategy – Co-simulation Supervision

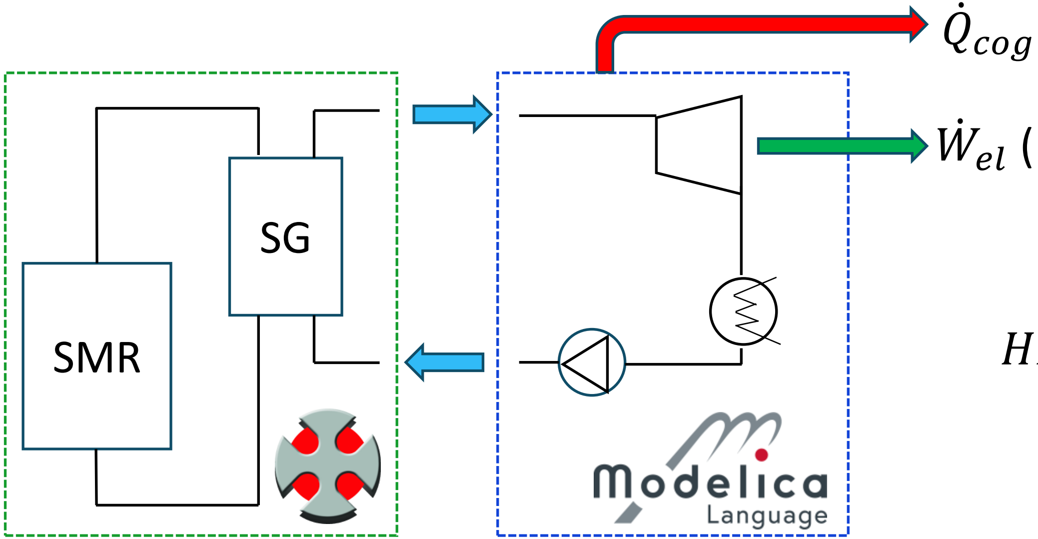


Dymola

Example – SMR/BOP Coupling

Definition of the Problem

Transition between full-electric operation to cogeneration (Heat to Power ratio 50%)



$$HPR = \frac{\dot{Q}_{cog}}{\dot{W}_{el}} \longrightarrow \dot{Q}_{cog} = 86.5\ MW$$

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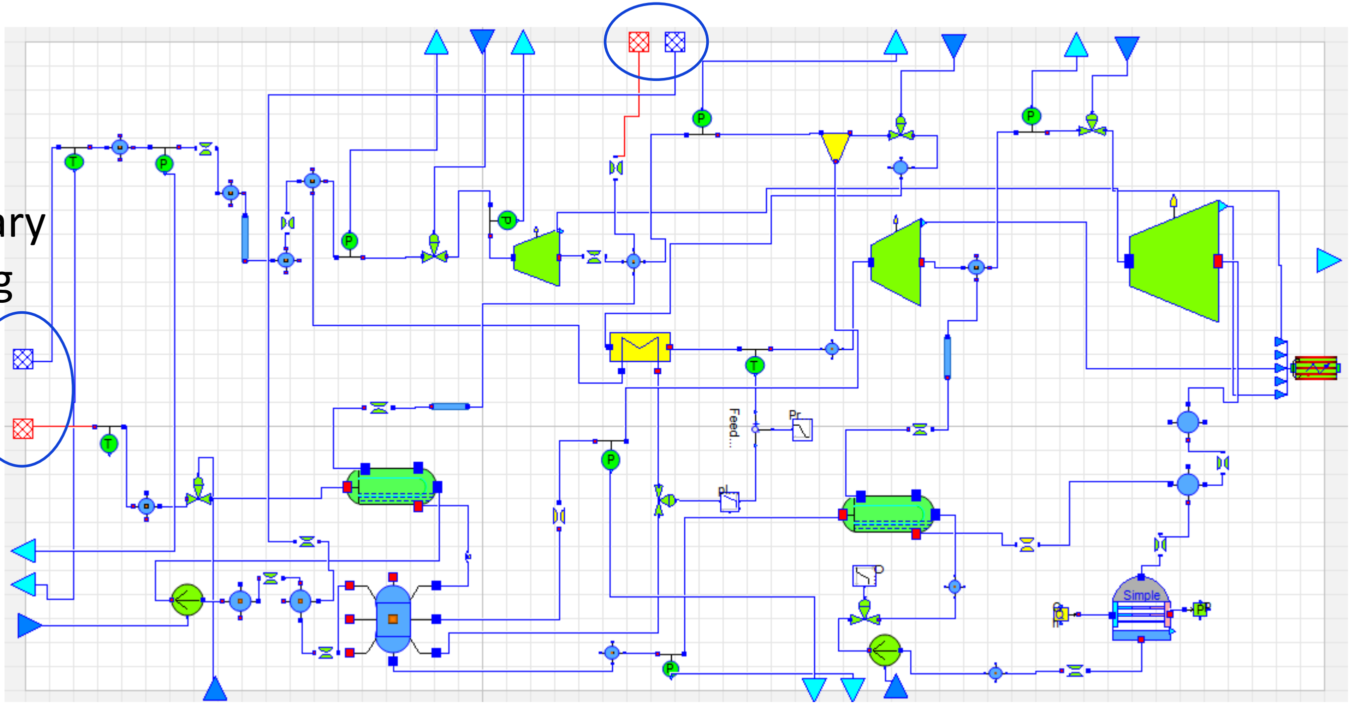
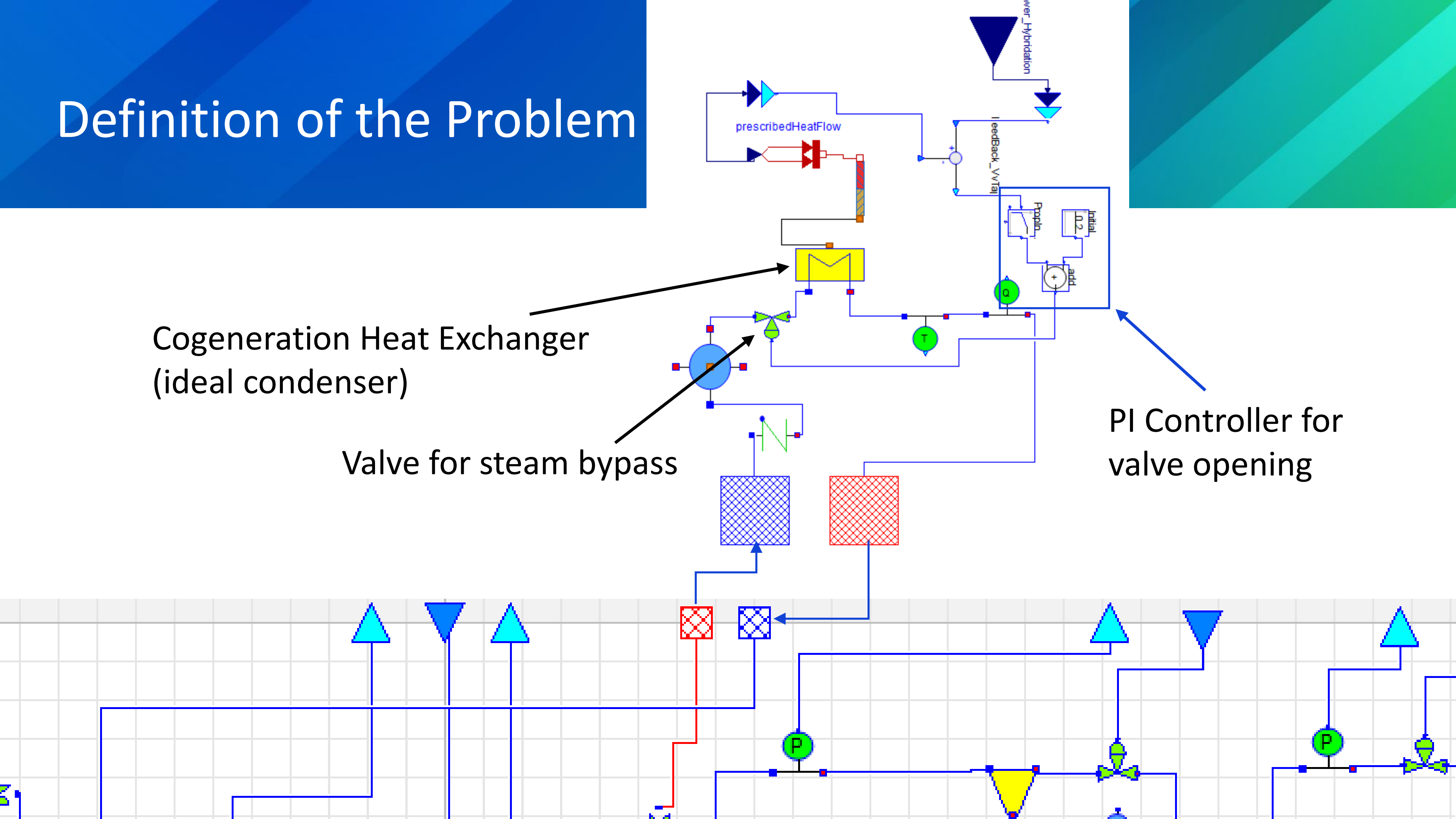
Definition of the Problem – BOP Model

Quasi-static model, i.e., <u>component dynamics is neglected</u>

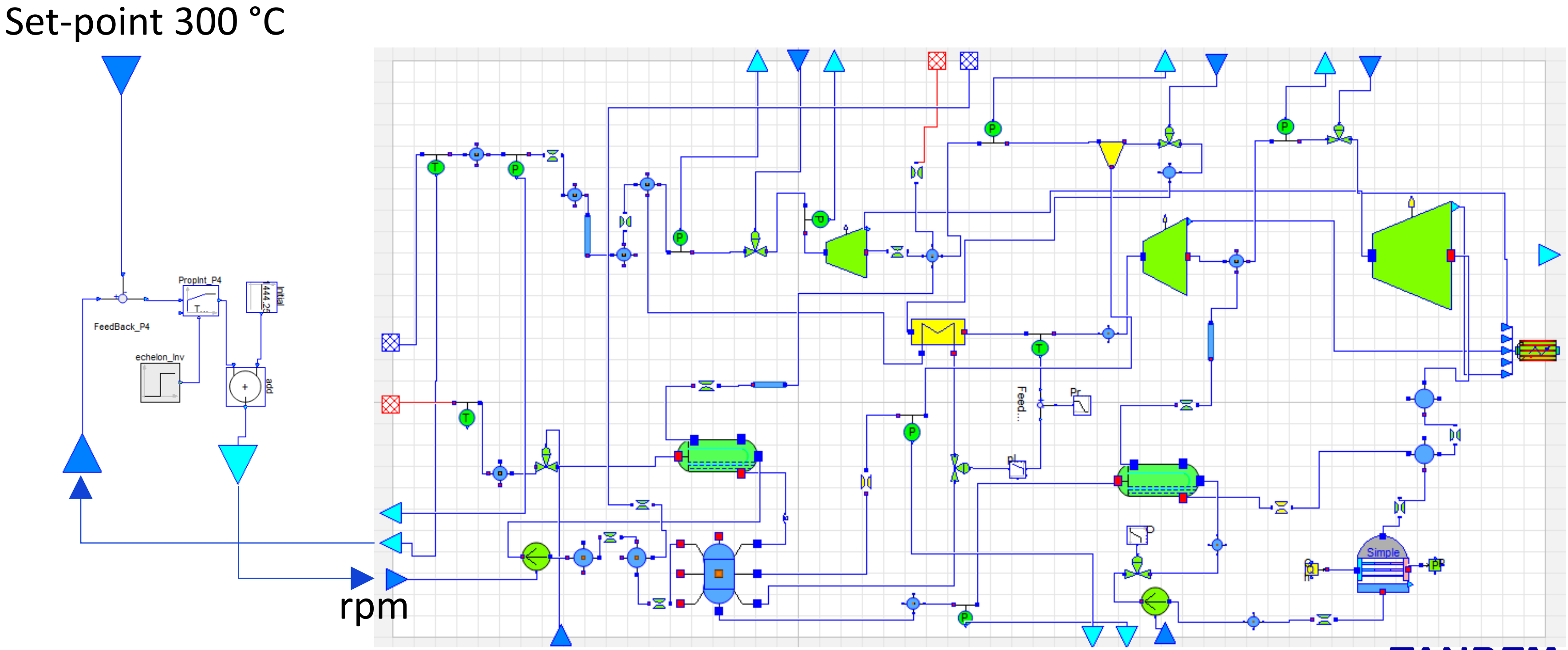
Ports for primary side coupling



Definition of the Problem



Definition of the Problem – BOP Model



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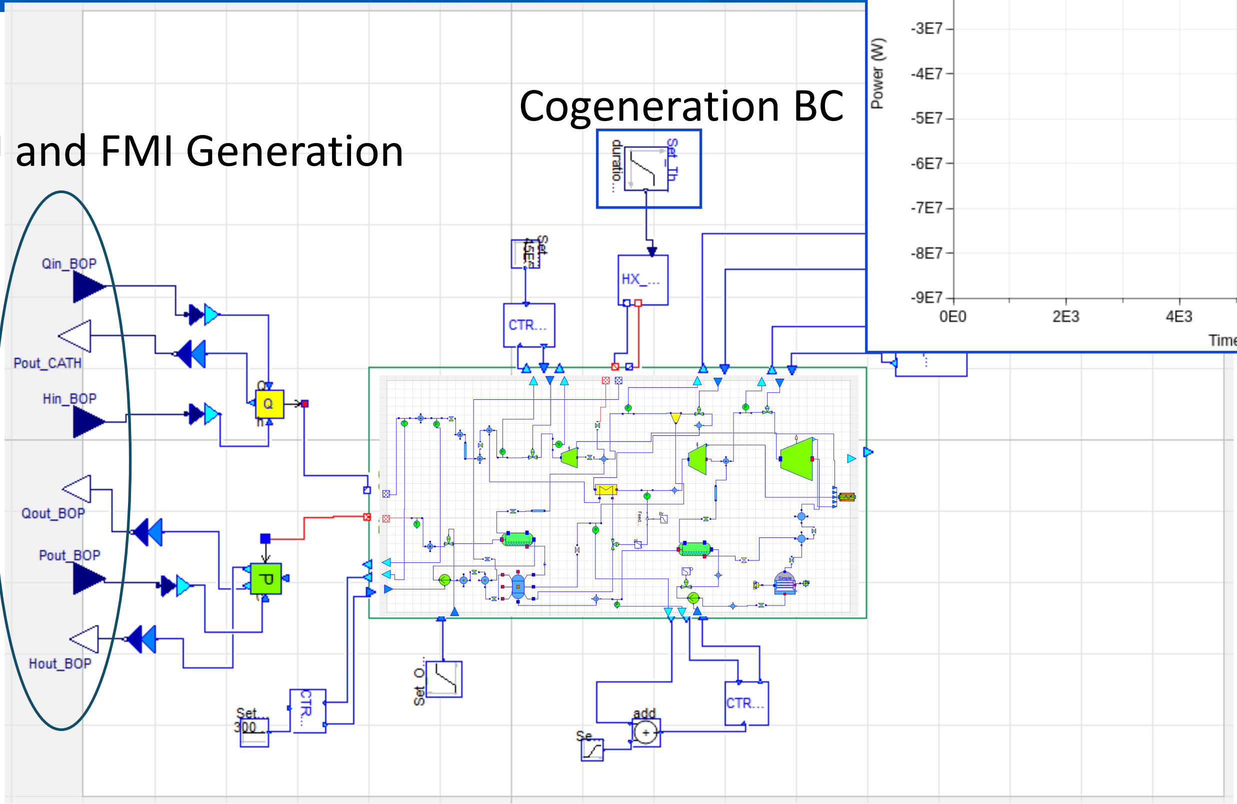
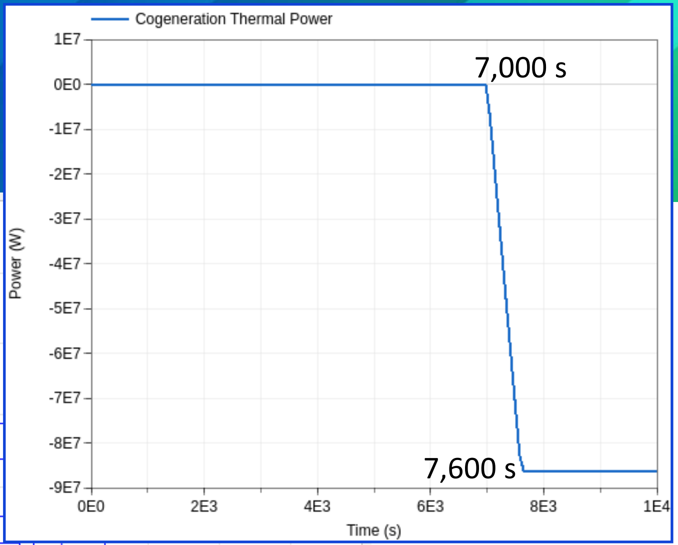
Transient Definition and Boundary Co

Ports for FMU and FMI Generation

Cogeneration BC





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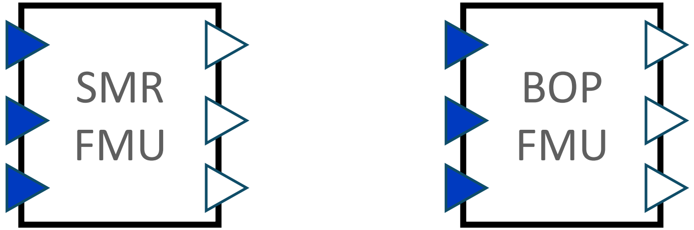
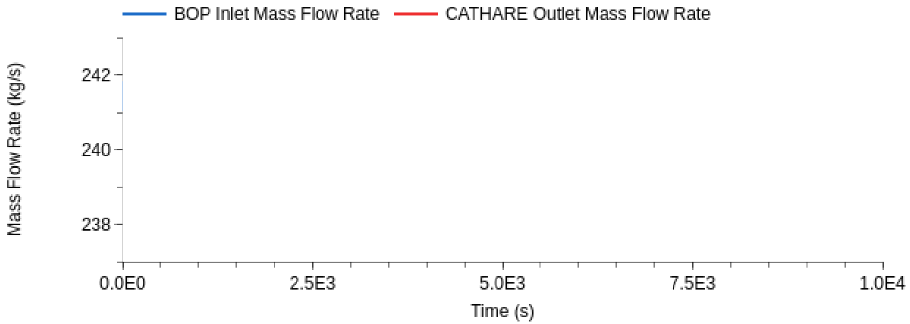
Setting up the Transient and Results Achieved

Whole transient is divided into different steps:



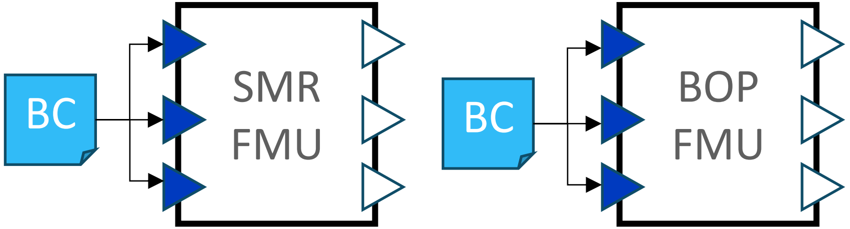


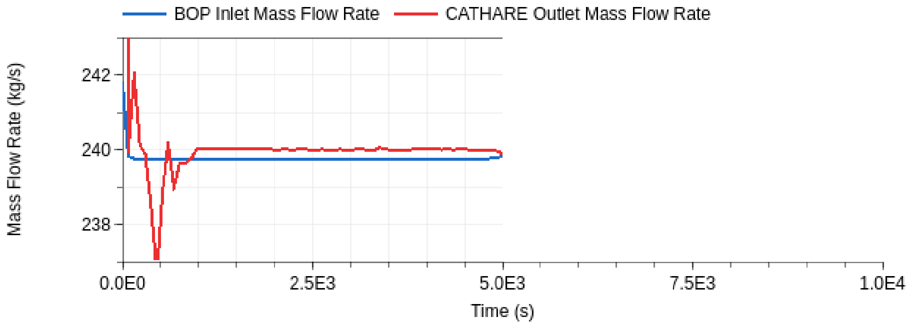
Setting up the Transient and Results Achieved

Whole transient is divided into different steps:

1) Stand alone run of models to reach stabilization

Constant BCs externally provided





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Setting up the Transient and Results Achieved

Whole transient is divided into different steps:

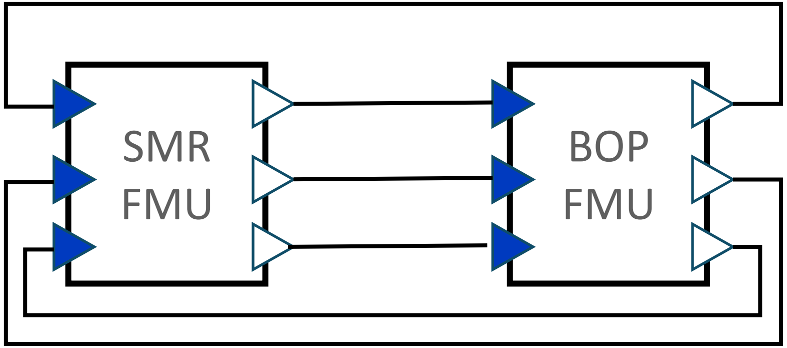
1) Stand alone run of models to reach stabilization

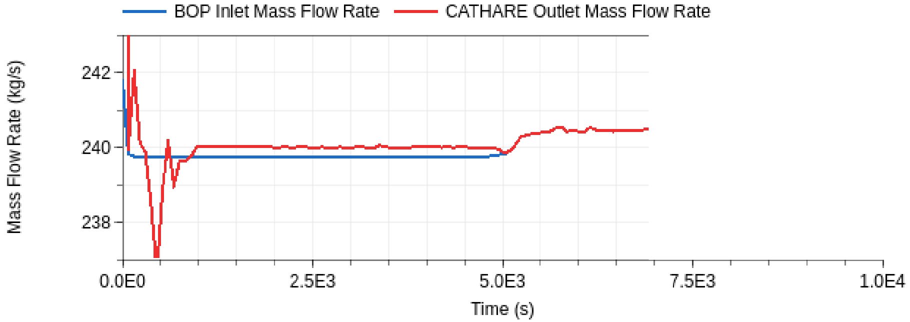
Constant BCs externally provided

2) Coupling at 5,000 seconds

Models start to exchange information

New steady state is achieved





Setting up the Transient

Whole transient is divided into different steps:

1) Stand alone run of models to reach stabilization

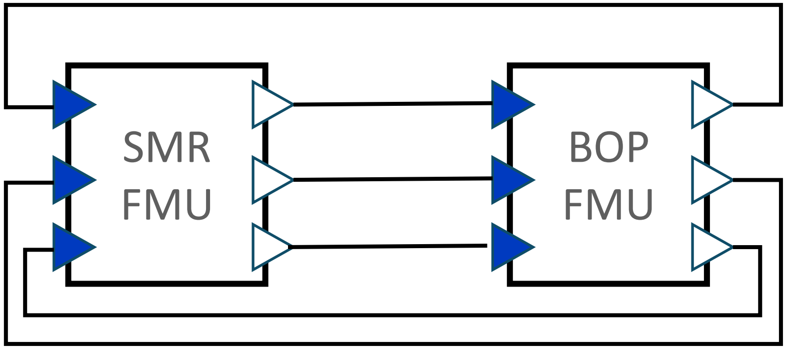
Constant BCs externally provided

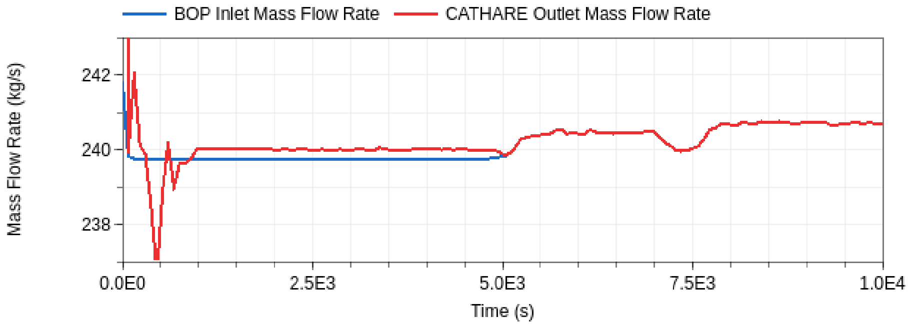
2) Coupling at 5,000 seconds

Models start to exchange information

New steady state is achieved

3) Cogeneration transient





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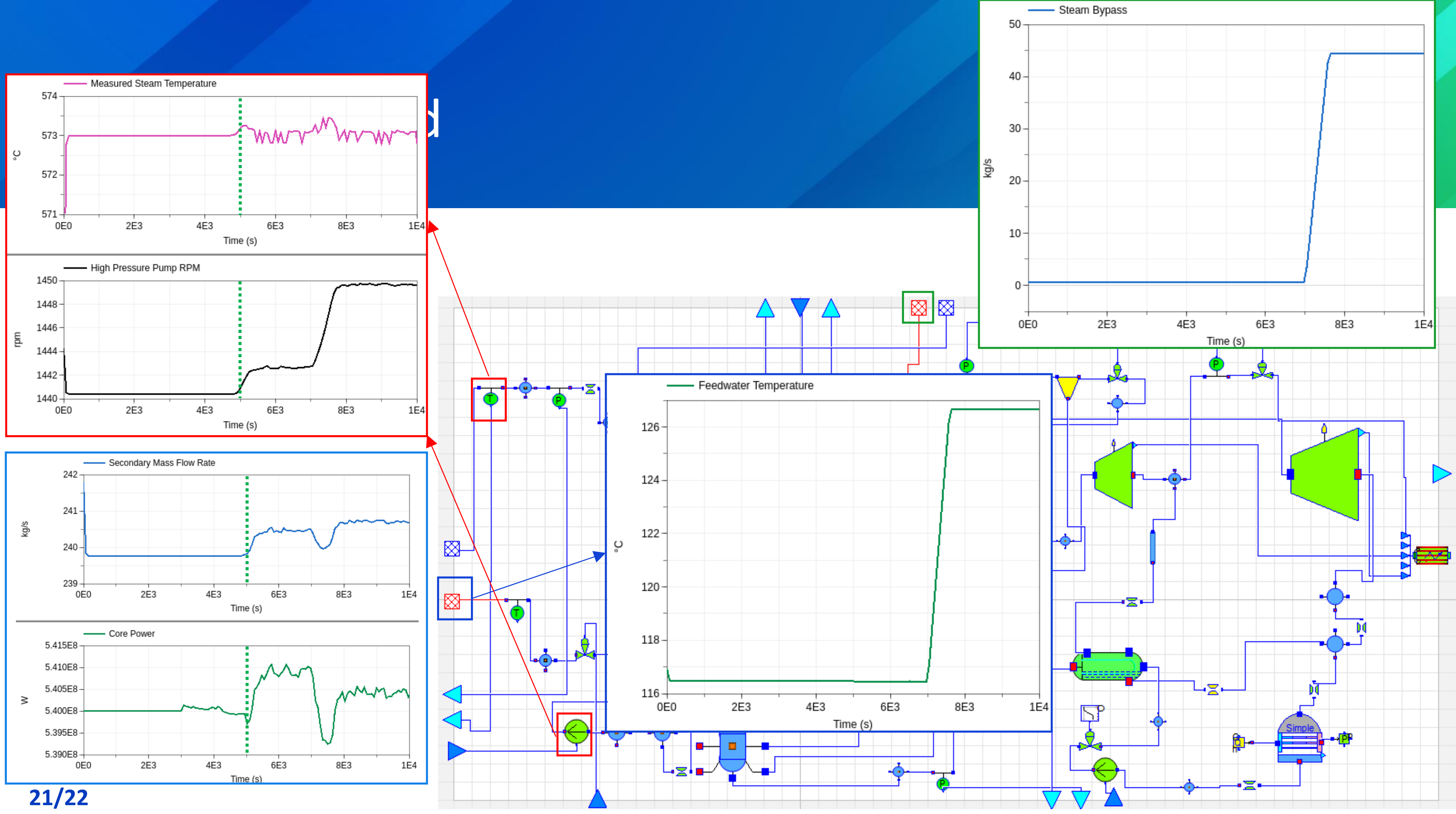
Measured Steam Temperature
°C
574
573
572
571
0E0
2E3
4E3
6E3
8E3
1E4
Time (s)
High Pressure Pump RPM
rpm
1450
1448
1446
1444
1442
1440
Secondary Mass Flow Rate
kg/s
242
241
240
239
Core Power
W
5.415E8
5.410E8
5.405E8
5.400E8
5.395E8
5.390E8
Feedwater Temperature
126
124
122
120
118
116
Steam Bypass
50
40
30
20
10
0
Simple

Conclusions

The following conclusions can be drawn:

1) The coupling works (good news!)

2) The co-simulation was able to handle transient scenarios

3) Impact of cogeneration transient on the primary side was found to be mild

4) Results provide interesting hints and highlight the potentialities of the code coupling

Nevertheless, there are points that must be reminded:

1) BOP model is quasi-static: introduction of dynamics may give different results

2) Controllers designed for a quasi-static BOP, in reality they may be different with different outcomes

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Other Useful References

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Publications on Works and Updates about FMI: https://fmi-standard.org/literature/

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