HYBRID CO-SIMULATION OF FMUs USING DEV&DESS IN MECSYCO

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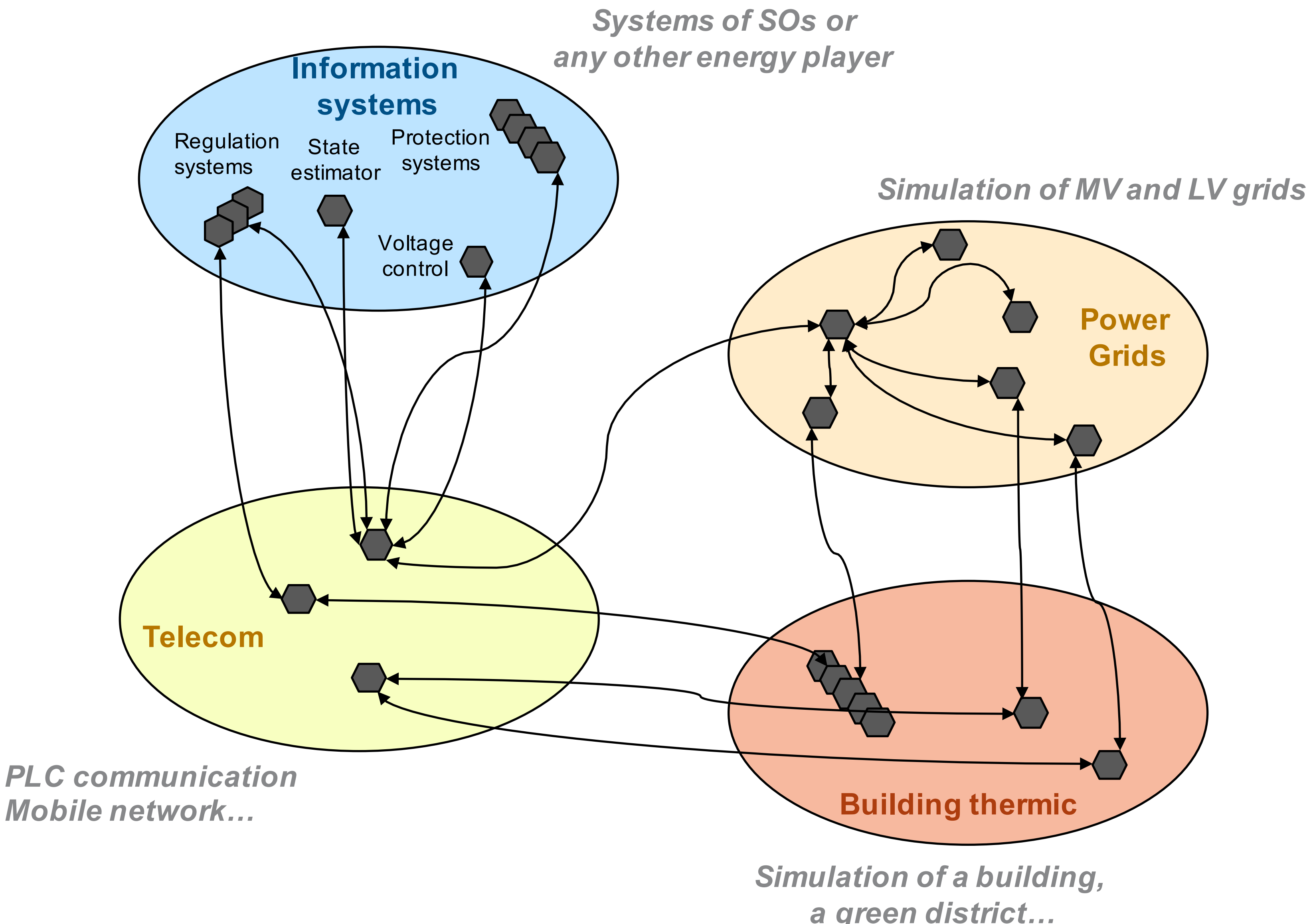
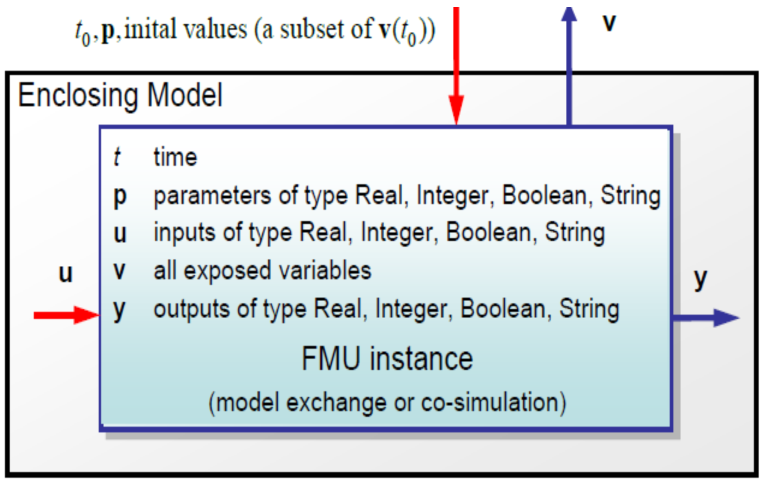
SIMULATION CHALLENGES OF SMART GRIDS



FMI 2.0 : PRESENTATION

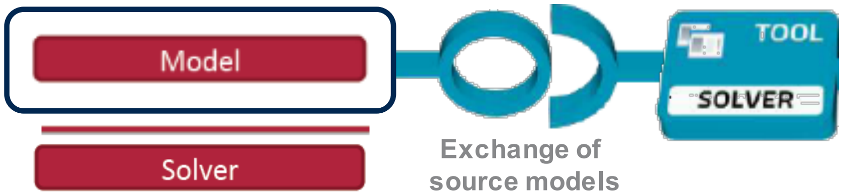
FMI, a standard for Model Exchange & Co-Simulation



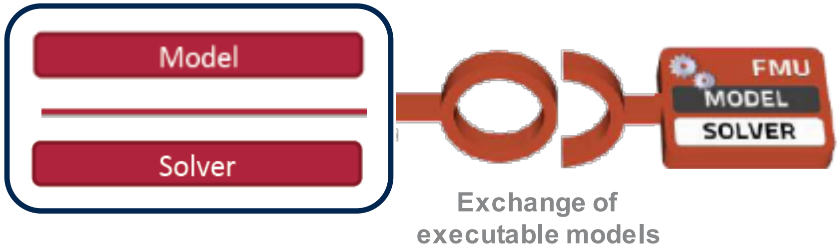
Models are managed by time-stepped solvers

Solution preferred by EDF

FMU for « Model Exchange »



FMU for « Co-Simulation »



FMI 2.0: FMI FOR “CO-SIMULATION” MAIN FEATURES

Based on a communication points execution strategy

Basic computation functions to:

- **perform an integration to a given time-step** (*fmi2DoStep*)
- **set inputs’ values** (*fmi2SetReal/Integer/Boolean/String)*
- **get outputs’ values** (*fmi2GetReal/Integer/Boolean/String*)

Optional functions **enabling to export/import the model state**

- *fmi2GetFMUState / fmi2SetFMUState*

➔**Essential to enable roll-back**, i.e. go a single integration step back

Many more functions available in the FMI API…

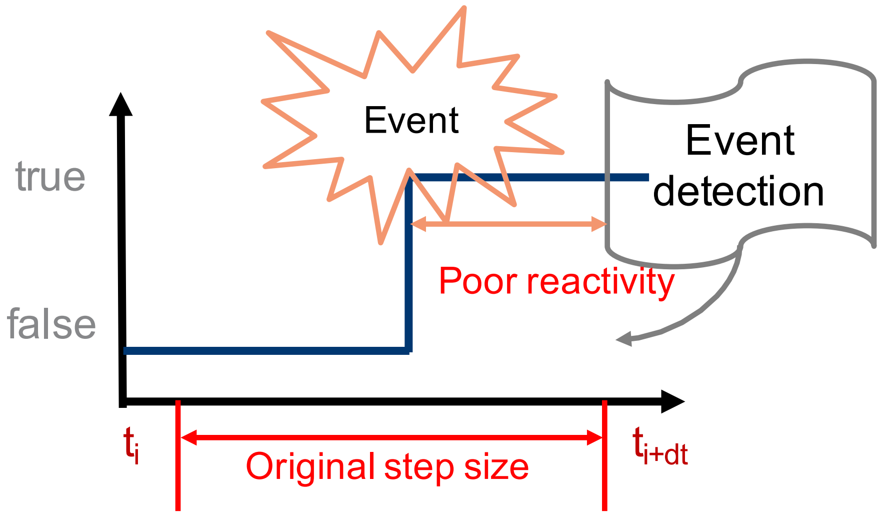
FMI 2.0: LIMITATIONS FOR STATE EVENTS

Hybrid co-simulation : FMU must interact with event-based model

- **We must integrate input events into an FMU,**
- **and manage the generation of state-event from an FMU**

Exact detection of occurrence times is difficult

- **<u>State-changes are not tagged</u> : No persistent variable to inform if (when) an event occurred during a simulation step**
- **Bias when event (states or input) occurs between two communication points**
  - state events are localized at the upper communication point
  - new inputs are integrated at the upper communication point



PROPOSITION: DEV&DESS WRAPPER FOR FMU 2.0

DEV&DESS :

- **offers a sound framework for formalizing how an equation based component interacts with the discrete-world.**
- **embedded by Zeigler in DEVS which is a universal formalism for describing discrete-event models**

➔ If it is wrapped into DEV&DESS, an FMU can interact with discrete-event models.

Issues :

- **the original DEVS version of DEV&DESS relies on a quantized integrator approach**
- **Not compliant with the time-stepped framework of FMI for co-simulation**

➔ We need to adapt the original DEVS version of DEV&DESS

DEV&DESS WRAPPER ARCHITECTURE

Continuous component = the FMU to integrate

Discrete-event component = the discrete behavior of the FMU – i.e. :

- **How the FMU state changes when events occurs?**
- **What are the output event produced by the model?**

Event-detection component – i.e. :

- **Is there a state-event according to the FMU state?**

GETTING THE TIME OF THE NEXT INTERNAL EVENT

The Time of the Next Internal Event is the minimum between:

- **the date of the next internal event scheduled in the discrete event component**
- **the date of the next communication point of the FMU** } **Trivial**
- **the date of the next state-event** } **Not known a priori**

getNextInternalEventTime() **must not change the state of the model**

Thus, we :

- **Perform a time exploration with the FMU** to see if a state-event occurs before its next communication point
- **Use its rollback capability to restore the state of the FMU** before the exploration, if required

STATE EVENT LOCALIZATION STRATEGY

Bisectional search for state-event localization

INPUT: $\Delta T \in \mathbb{R}_0^+, m \in \mathbb{N}_0^+$

$\delta t \leftarrow 0$

$\Delta t \leftarrow \Delta T$

for 1 **to** m **do**

$\quad solver.rollBack()$

$\quad \Delta t \leftarrow \Delta t/2$

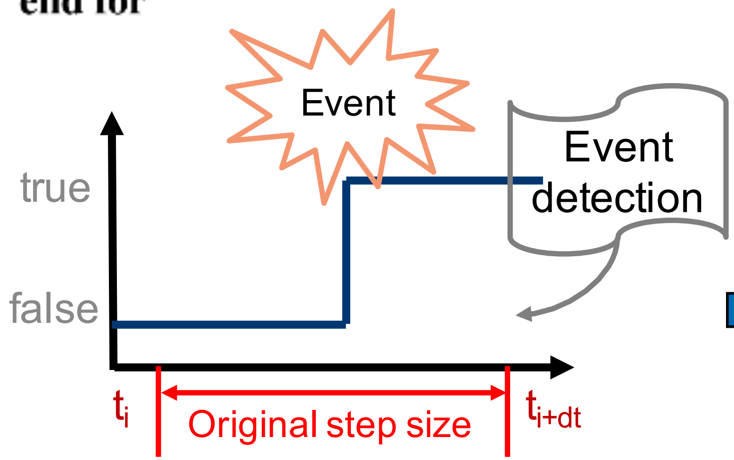
$\quad solver.doStep(\delta t + \Delta t)$

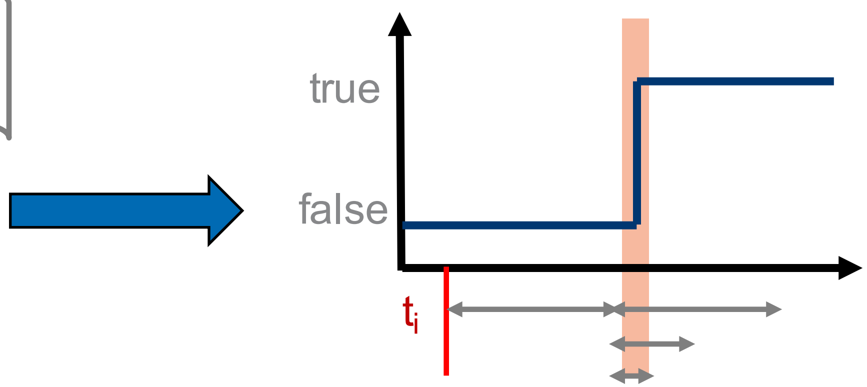
$\quad$ **if** $\neg detFunction.stateEventOccurence()$ **then**

$\quad\quad \delta t \leftarrow \delta t + \Delta t$

$\quad$ **end if**

end for





PROCESSING EVENTS

processExternalEvent reports the occurrence of an external input event at *t*

1. The FMU is rolled back to its previous state
2. A new simulation step to *t* is computed to reach the point where the event occurs (no new event will occur in the meanwhile)

processInternalEvent works similarly

- But, the FMU state after the exploration is reused if the internal event time is the same
- This limits the computational burden of the exploration method

MECSYCO

Co-simulation middleware

Using a DEVS wrapping strategy

- **1 wrapper = 1 model/simulator**

Based on Agent & Artifact (A&A) concepts :

- **Autonomous agents**
- **Passive artifacts proposing services to Agents**

Advantages for co-simulation :

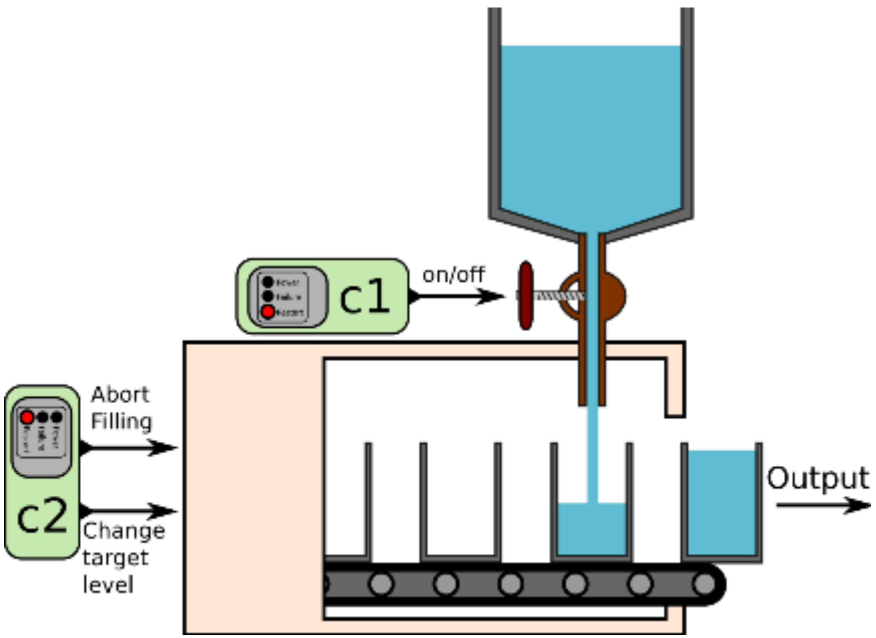
- **Multi-representation integration** (e.g. multi-level modeling)
- **Multi-formalism integration** (thanks to DEVS)
- **Simulators interoperability** (e.g. NS-3, OMNeT++, NetLogo, ad-hoc)
- **Modular view**
- **Parallel & decentralized execution**
- **Distributable architecture**

} **thanks to the multi-agent paradigm** (applies to Modular view, Parallel & decentralized execution, Distributable architecture)

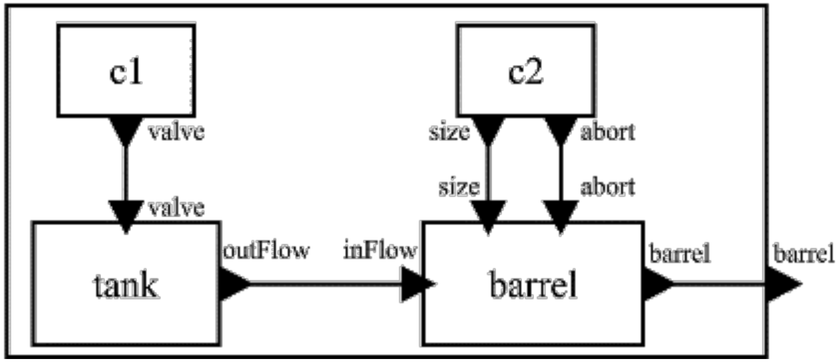
STUDIED USE CASE: A BARREL FACTORY

A simple use case to illustrate the generic aspect of our methodology:

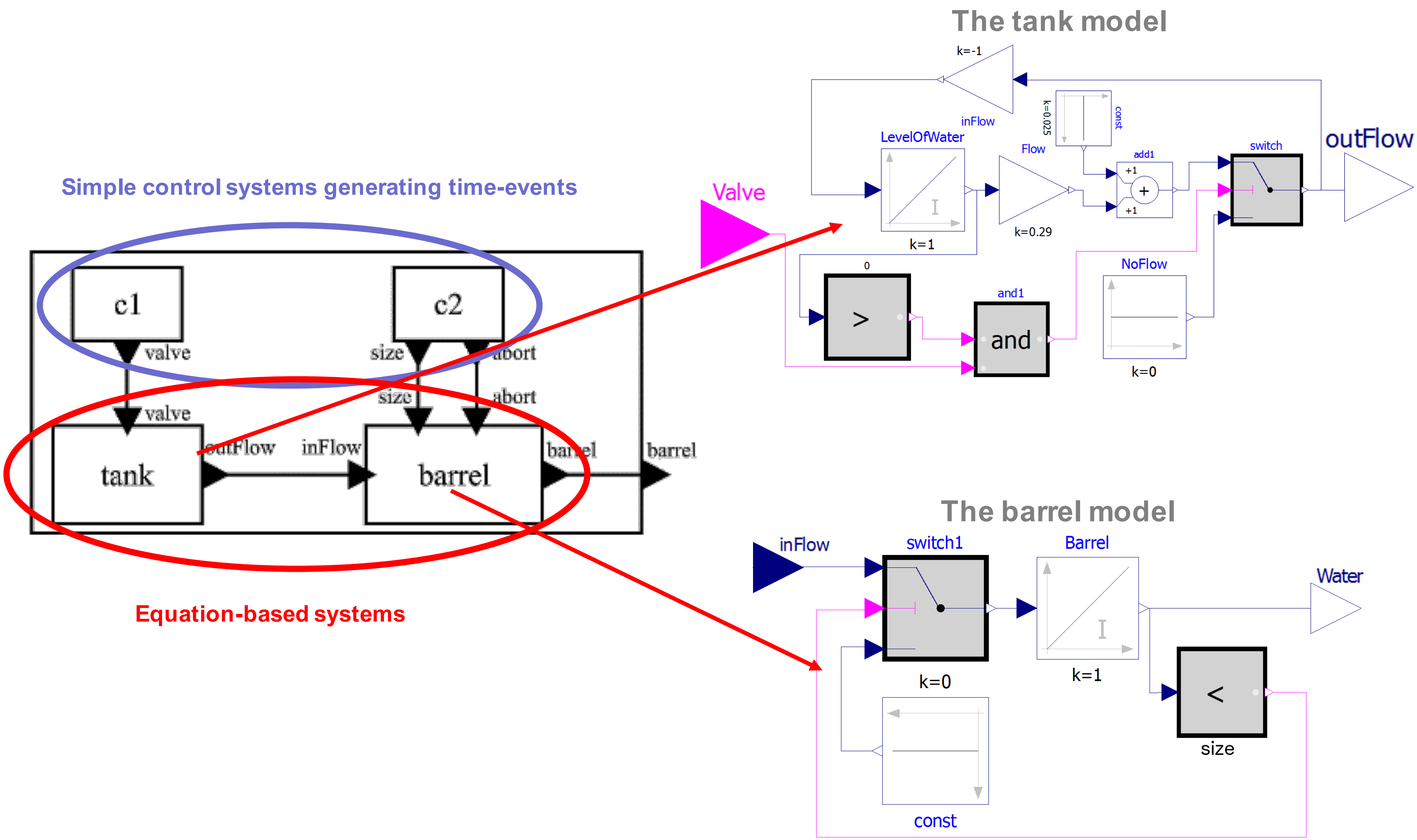
- applicable outside from the context of Smart Grids



A fully implemented and functional wrapper for integrating FMU 2.0 components into a hybrid co-simulation was developed

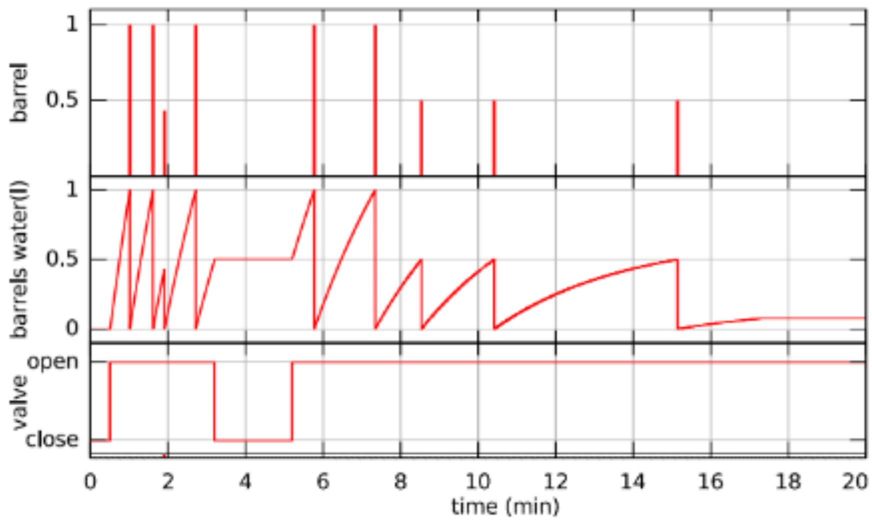


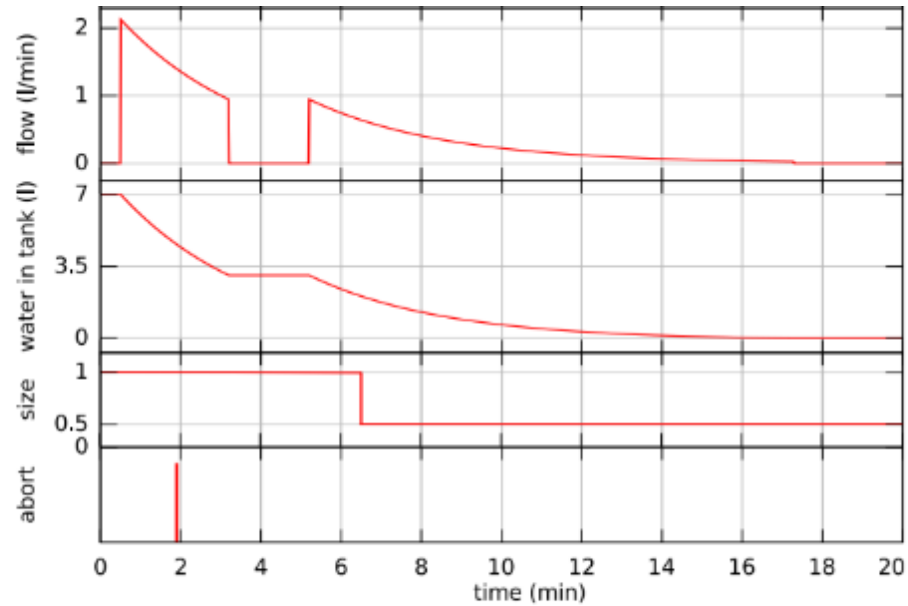
STUDIED USE CASE: MODELING



RESULTS

Outputs of the continuous and discrete components





Taking simultaneously account of continuous and discrete dynamics within the FMU components.

RESULTS

Accuracy of the state event detection

	step size	$t_{barrel1}$	$t_{barrel2}$	$t_{barrel3}$	$t_{barrel4}$	$t_{barrel5}$	$t_{barrel6}$	$t_{barrel7}$	$t_{barrel8}$	$t_{barrel9}$
Series1	**0.001**	1.016	1.613	1.910	2.715	5.773	7.342	8.535	10.412	15.139
	0.01	1.016	1.613	1.910	2.715	5.773	7.342	8.535	10.412	15.139
	0.1	1.016	1.613	1.910	2.715	5.773	7.342	8.535	10.412	15.139
Series2	**0.001**	1.017	1.615	1.910	2.716	5.774	7.344	8.538	10.419	15.167
	0.01	1.020	1.620	1.900	2.710	5.770	7.340	8.540	10.430	15.230
	0.1	1.100	1.800	1.800	2.600	5.700	7.300	8.500	10.400	15.300

Series 1 : proposed implementation of the DEV&DESS model artifact
Series 2 : classic FMU co-simulation strategy with constant time step

Bisectional search = same accuracy, independently of the step size

CONCLUSIONS AND PERSPECTIVES

A fully functional and generic wrapper for integrating FMU 2.0 components into a hybrid co-simulation

- Respects the DEV&DESS semantics and the FMI 2.0 operational constraints
- Rigorous interactions of FMU and event-based models within DEVS framework

Further improvements of the event location strategy:

- Illinois algorithm or a combination of other existing algorithms are considered.

A solution applied to large Smart Grids and Smart Spaces

- Large use cases involving several domains are being considered, among which: electric systems, telecom systems, thermal systems and information systems

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