AARHUS UNIVERSITY
DEPARTMENT OF ENGINEERING

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Hardware-in-the-Loop Co-simulation of Distribution Grid for Demand Response

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Outline

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Motivation

- High penetration of renewables (42% of the consumption in Denmark in 2015 from wind turbines)
- Flexibility required for generation-consumption balancing
- Demand response as a solution
  - Help renewables integration
  - Create market opportunities at distribution level
- Need tools for comprehensive assessment of new demand response opportunities

Source: *Energinet.dk (2015)*

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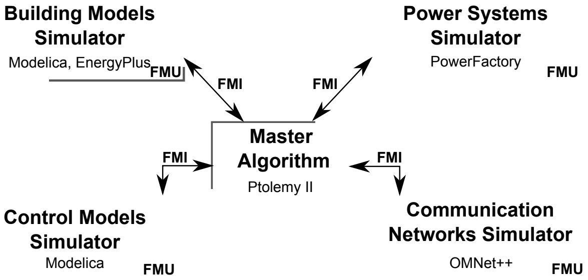
Co-simulation Environment

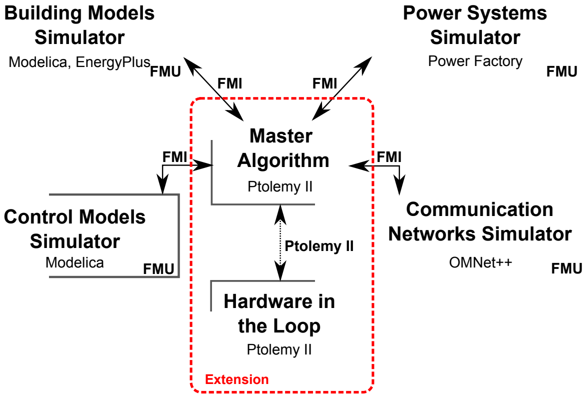
Virtual Grid Integration Laboratory (VirGIL)



FMI standard: Functional Mockup Interface
Ptolemy II (actor-oriented simulation software)

Source: *Chatzivasileiadis et al. (2016)*

Contribution



*Coupling of **co-simulation** environment (VirGIL) with a **Hardware-in-the-Loop (HiL)** infrastructure, ventilation system of large building, for **demand response assessment***

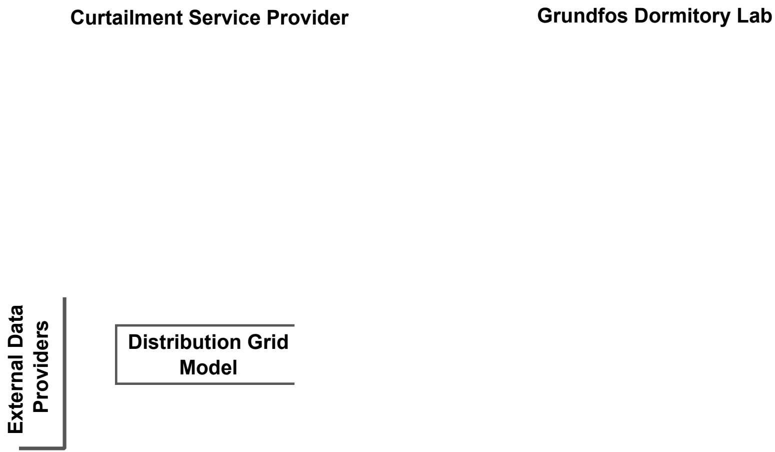
Test Bed: Grundfos Dormitory Lab

- Student residence in Aarhus (Denmark)
- 12 floors, 159 apartments, 200 students
- 3,400 sensors (5 s resolution)
  - indoor climate conditions
  - electricity consumption
  - domestic water
  - district heating
  - others

Source: *www.vpp4sgr.dk*

Outline

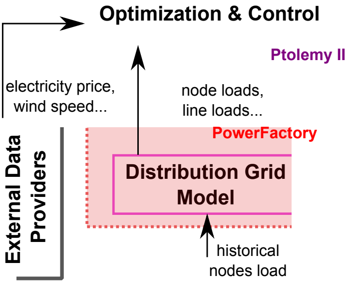
Co-Simulation with HiL - Case Study



Co-Simulation with HiL - Case Study

Curtailment Service Provider

Grundfos Dormitory Lab



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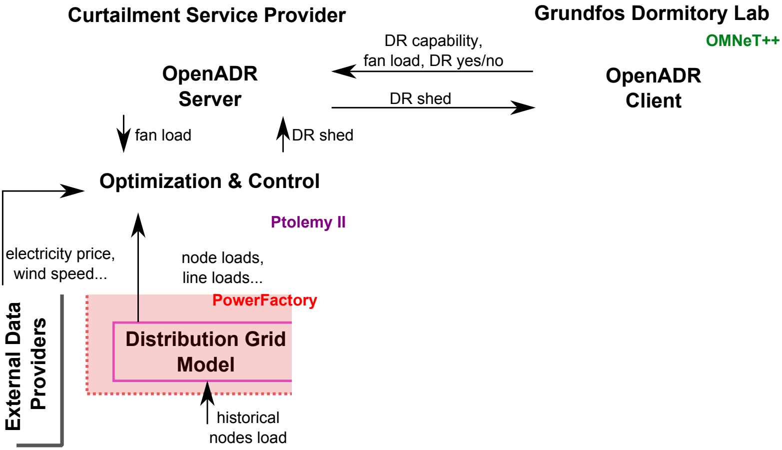

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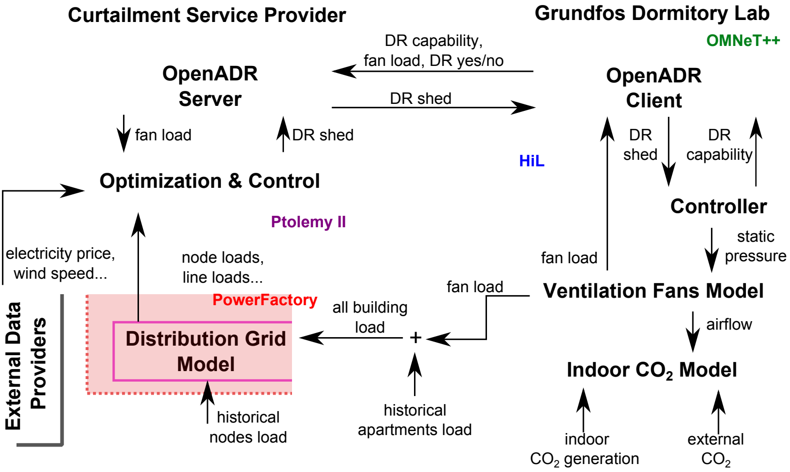
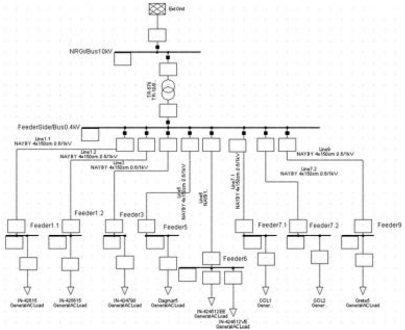


Distribution Grid Modelling

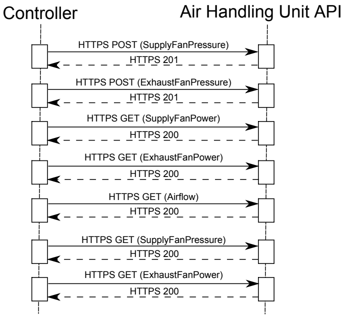
- PowerFactory (integrated in VirGIL via FMI standard)
- Grid data provided by DSO
- Test bed electricity consumption from sensors
- Assumptions:
  - 3 times more dense area
  - all buildings similar power consumption



Hardware-in-the-Loop Component

- Ventilation fans interaction

Secured API (HTTP-Modbus)



- CO_2 sensor data: MongoDB query in Ptolemy II

Source: *Rotger-Griful et al. (2016)*

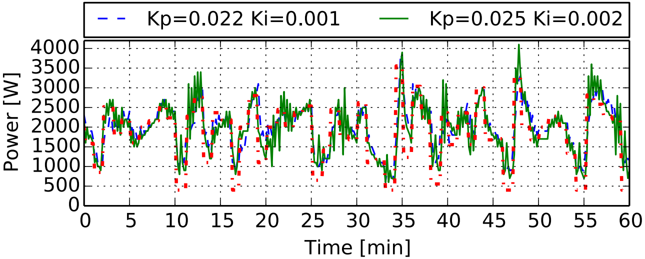
Other Components

- Communications Networks
  - OMNet++
  - Demand response protocol: OpenADR
- Demand response controller:
  - Ptolemy II
  - Multiple control strategies
- Master algorithm
  - Ptolemy II
- Prior execution time analysis
  - *simulation time* $<$ *real time*

Outline

Load Following for On-site RES Integration

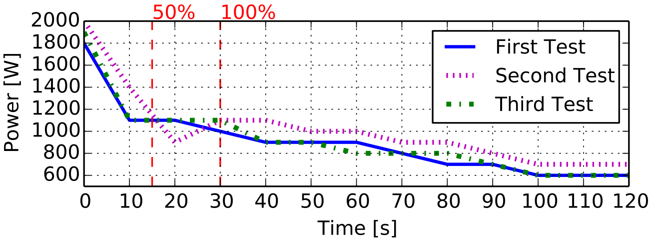
- **Strategy:** 1-minute load reference based on measured on-site wind speed



- **Observations:**
  - Building CO_2 level OK
  - Capable of following signal

Ancillary Services - Primary Reserves

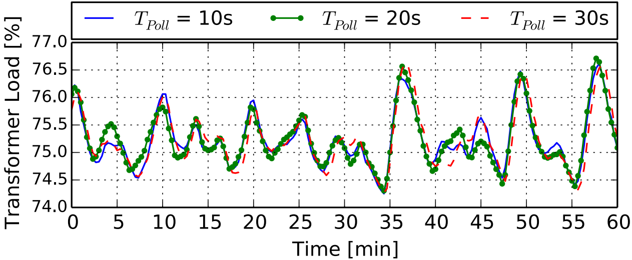
- **Strategy:** Primary reserves for up-regulation → reduce consumption



- **Observations:**
  - Inner fan controller limits response time
  - Aggregation required for market participation (≥ 300 systems)

Load Aggregation with Load Following

- **Strategy:** 15 ventilation systems following 1-minute varying reference (white noise added)



- **Observations:**
  - 2% transformer load change in few seconds
  - Communication protocol effect (tuning time between polling events)

Outline

Conclusions

- Propose co-simulation with Hardware-in-the-Loop (HiL) to support demand response development
- Extend the VirGIL co-simulation platform with HiL of ventilation system
- Proposed HiL approach can be deployed to other systems
- Case studies:
  - Ventilation system can respond to fast demand response requests
  - Ancillary services regulations should reduce participation barriers for demand response resources
  - Communication protocol parameters can affect the loading of power components