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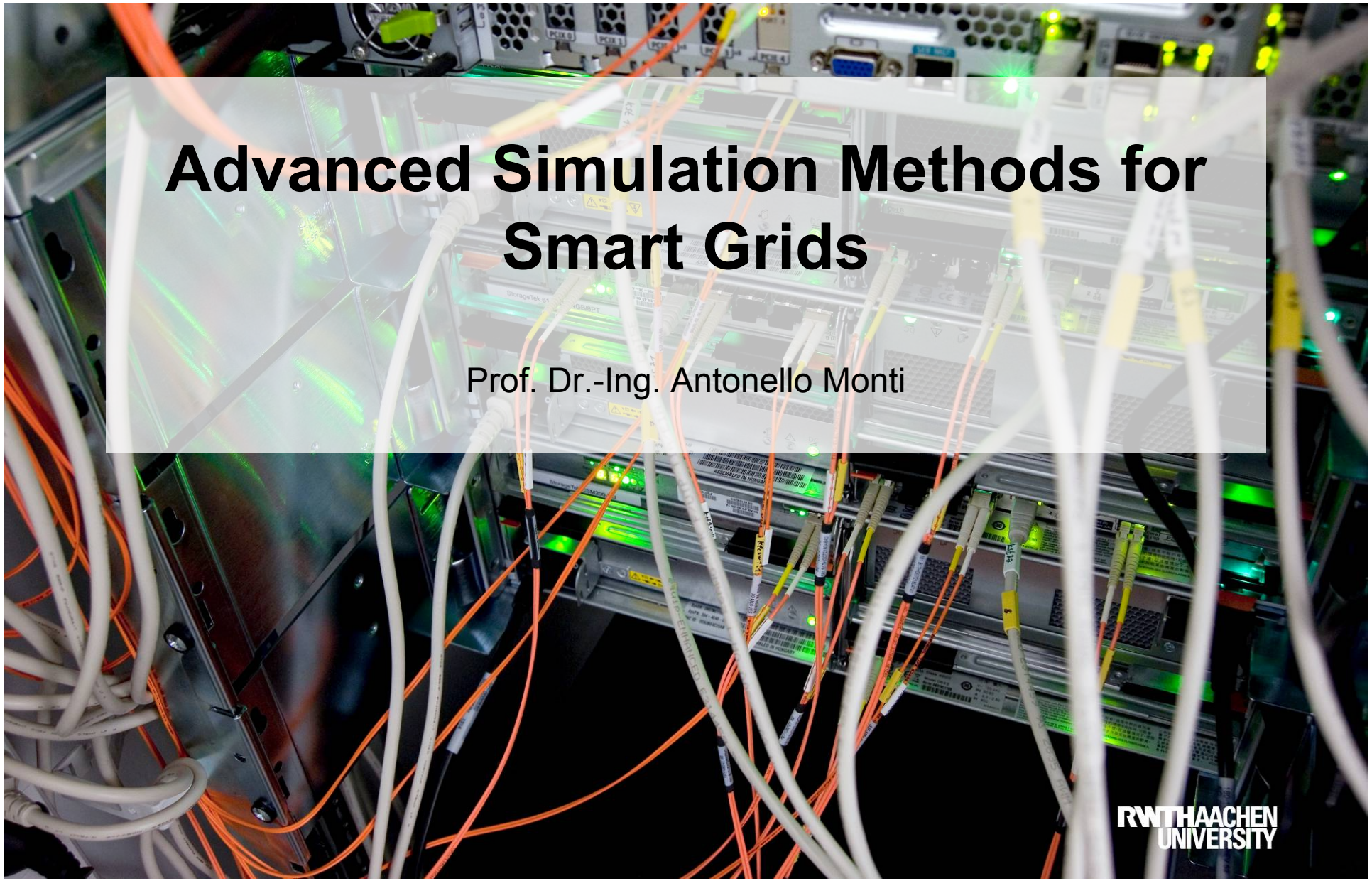


Advanced Simulation Methods for Smart Grids

Prof. Dr.-Ing. Antonello Monti

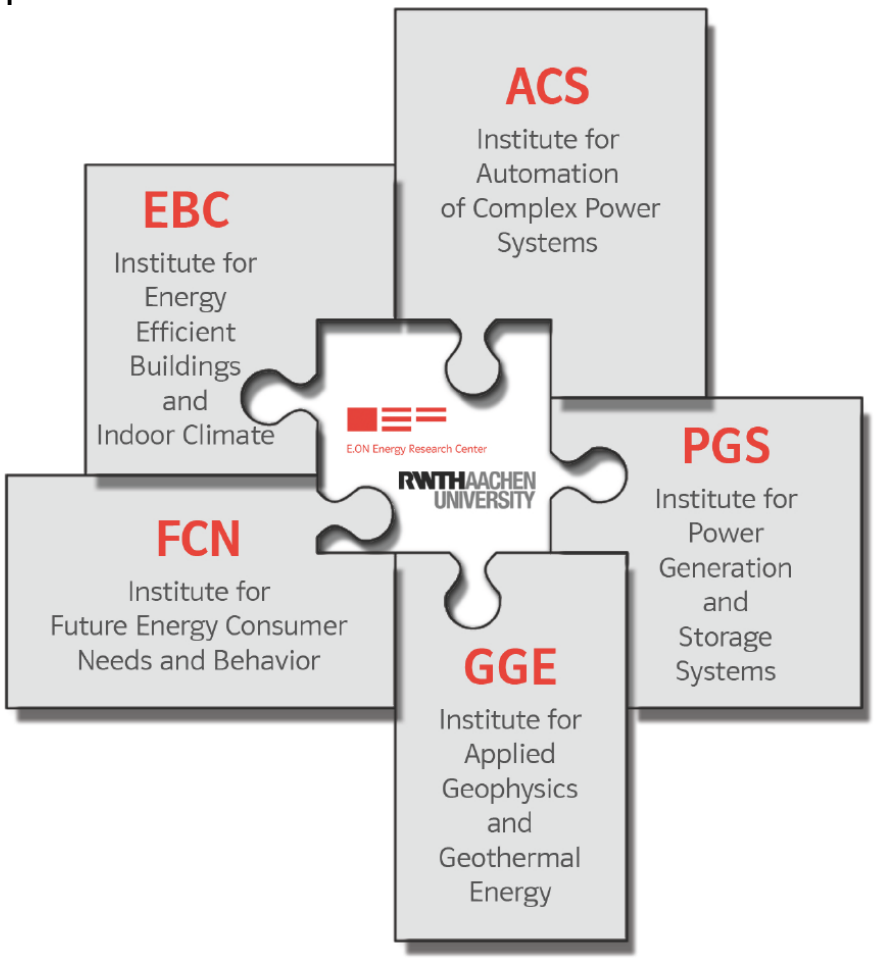
RWTH AACHEN UNIVERSITY

Cooperation between RWTH and E.ON

E.ON Energy Research Center

- June 2006: the largest research co-operation in Europe between a private company and a university was signed
- Five new professorships in the field of energy technology were defined across 4 faculties
- Research Area: Energy savings, efficiency and sustainable power sources

Groundbreaking E.ON ERC Main Building, April 2008



Smart Grid – stake holders and connections

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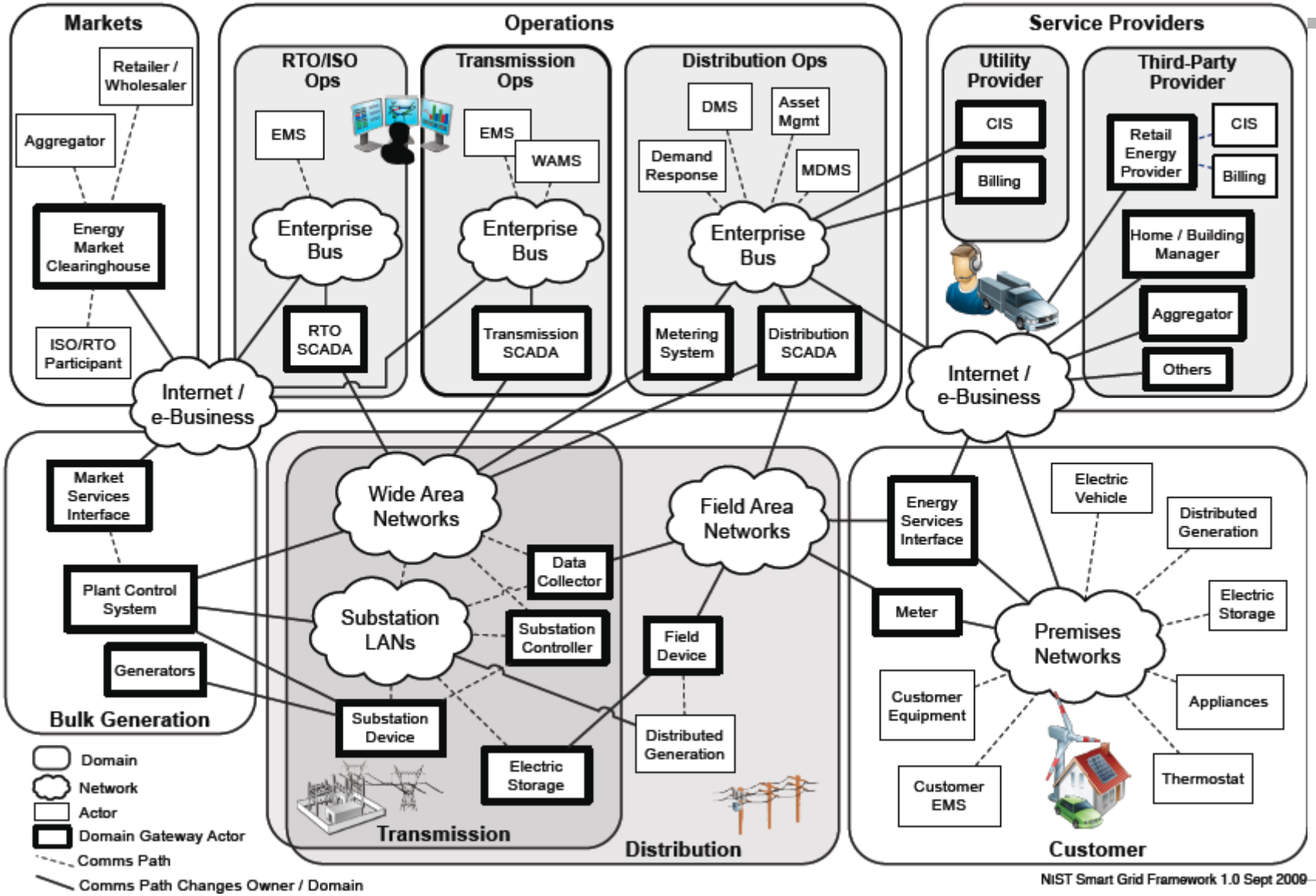

NIST Smart Grid Framework 1.0 Sept 2009

Smart Grid of grids

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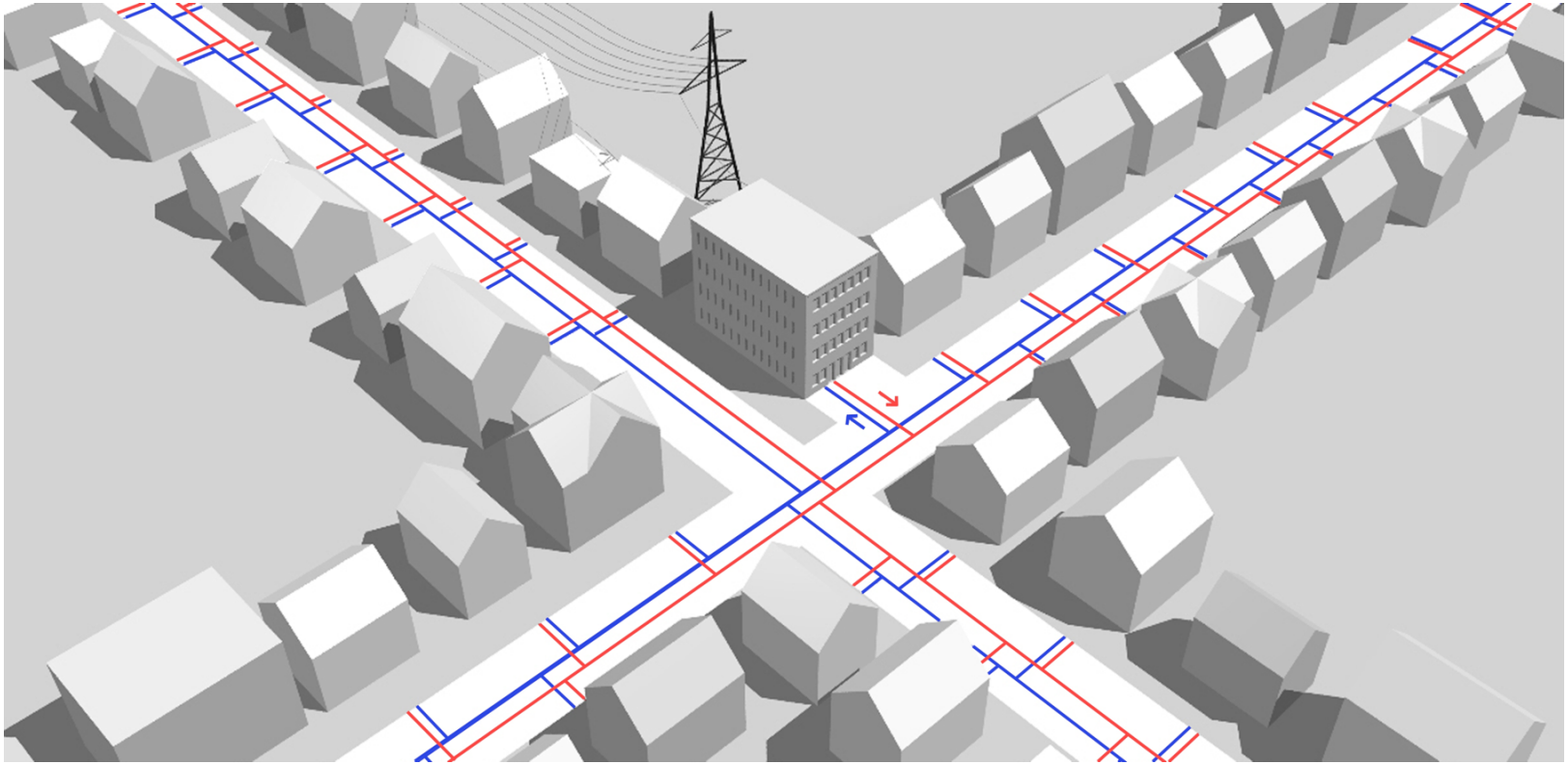
- Interdependent infrastructures: electrical, gas, heat, communication

  → interdisciplinary analysis and design

- Stochastic behavior of some renewable sources and loads



Simulation enablers of the smart grids

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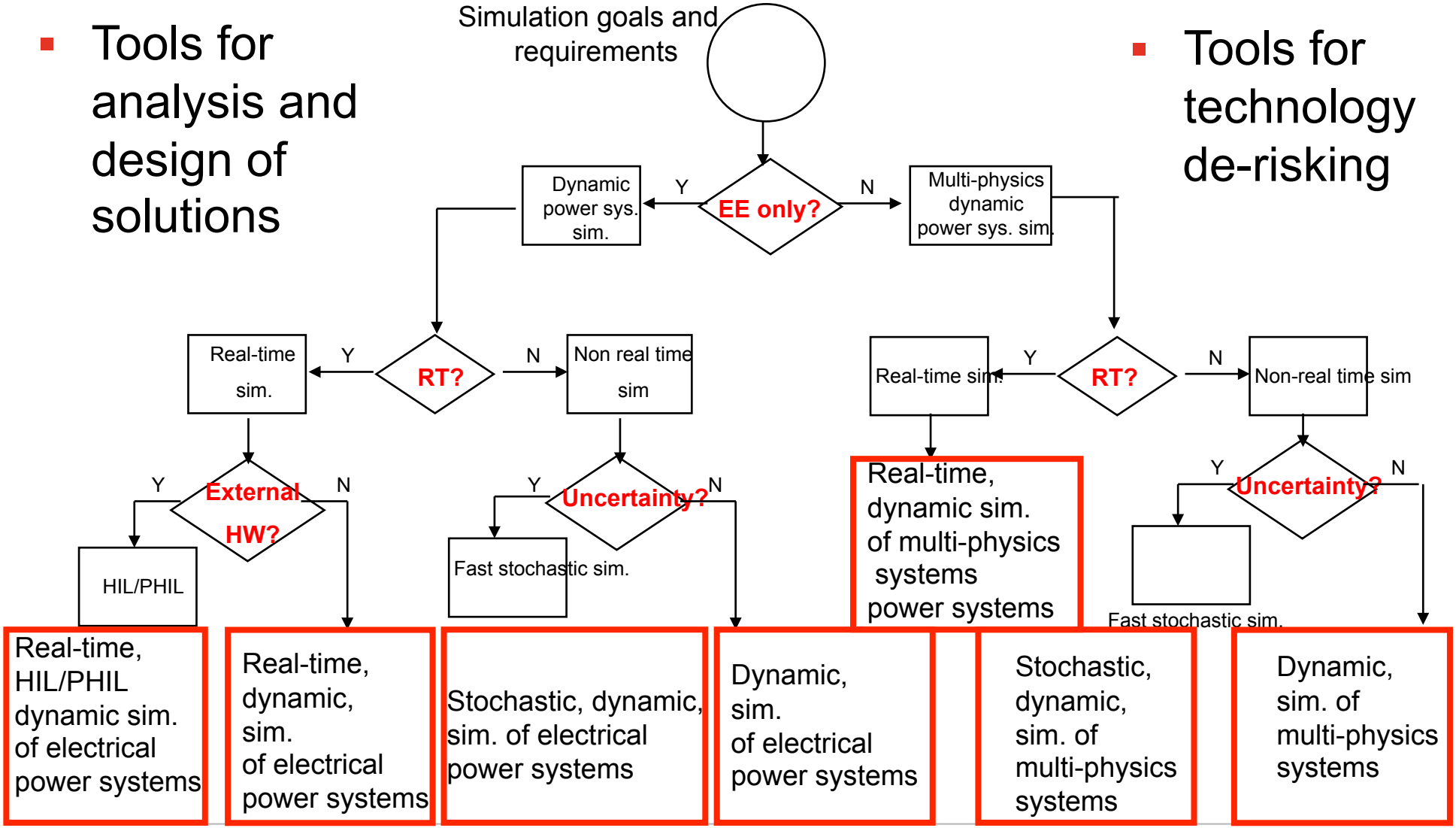
- Tools for analysis and design of solutions



- Tools for technology de-risking

Non real-time simulation

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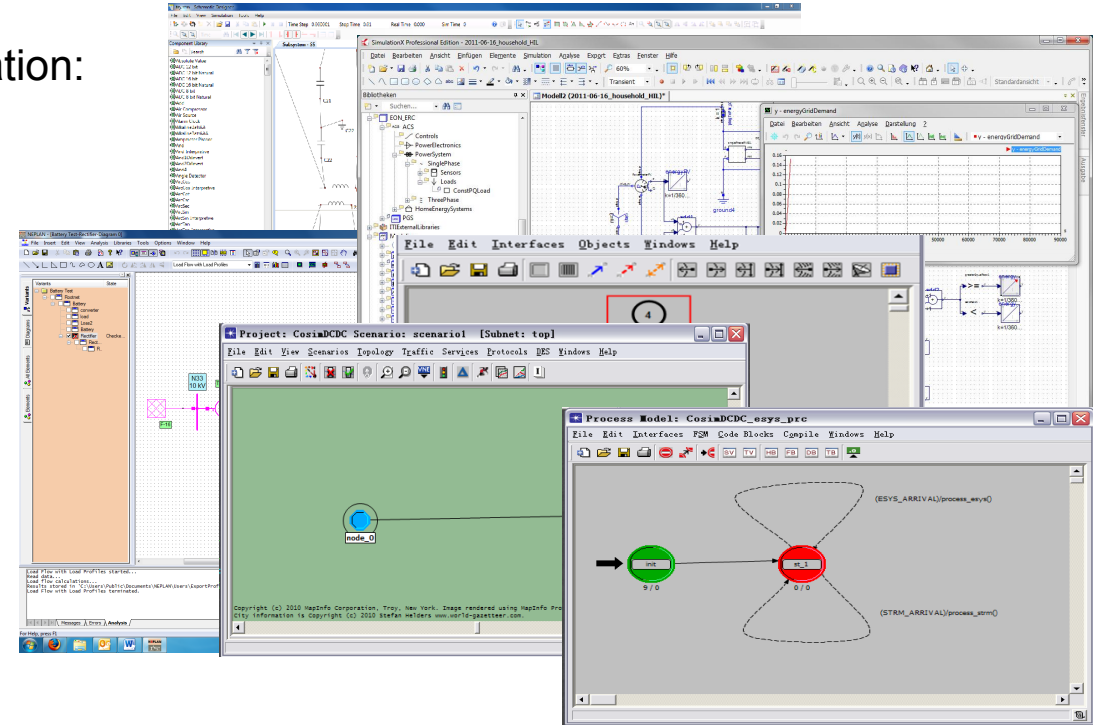
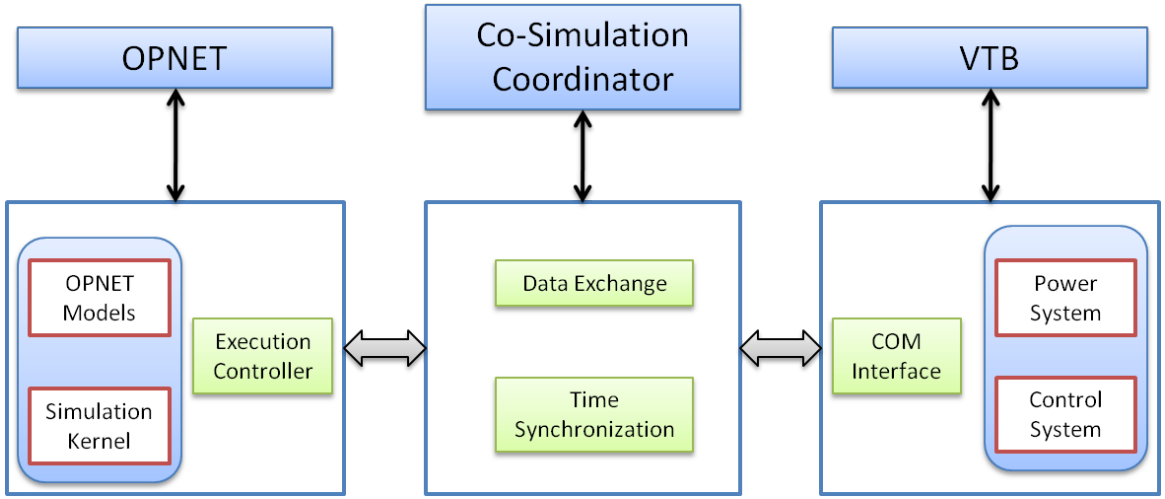
- Different tools depending on the application:
  - Physic-systems
    - Virtual Test Bed
    - Matlab-Simulink
    - Neplan
    - SimulationX(Modelica)
  - Communication
    - Opnet



Smart Grid requires a system approach, how to integrate different simulation tools ?

Co-simulation: OPNET-VTB



- VTB for dynamic, time domain simulation of the power system
- OPNET for simulating the communication system
- Co-Simulation coordinator:
  - Simulation time management
  - Data exchange

Co-simulation: An example

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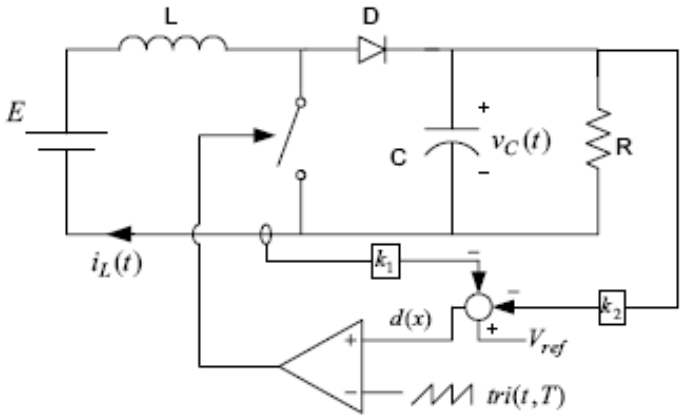
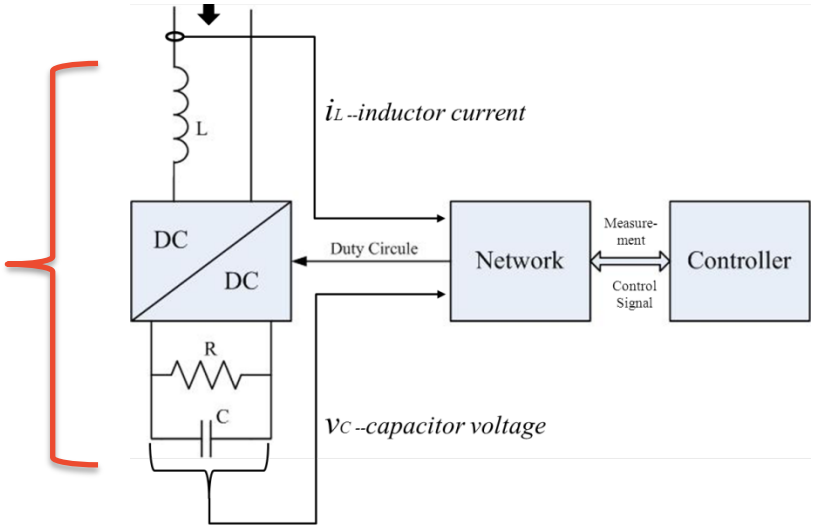
- Study of an information embedded power electronic system
- Example: power converter control over the network





E=4; L=5e-3; C=220e-6;
k1=0.1; k2=-0.05; R=10;

$$\dot{X}_1 = -\frac{X_2}{L}(1-u) + \frac{E}{L}$$

$$\dot{X}_2 = \frac{X_1}{C}(1-u) - \frac{X_2}{RC}$$

Co-simulation: An example

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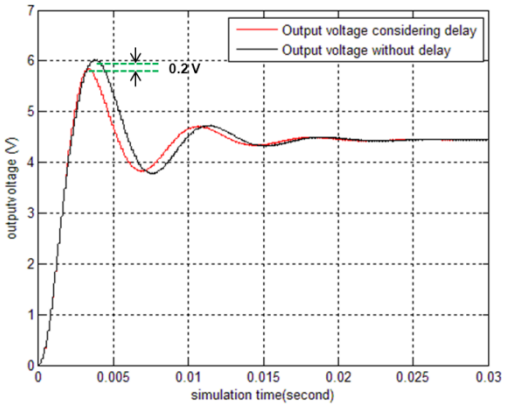
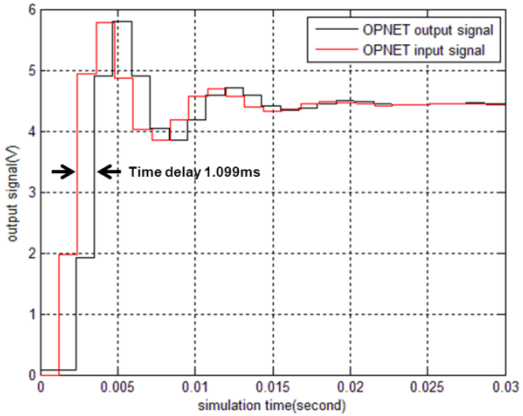
1Mbps data rate

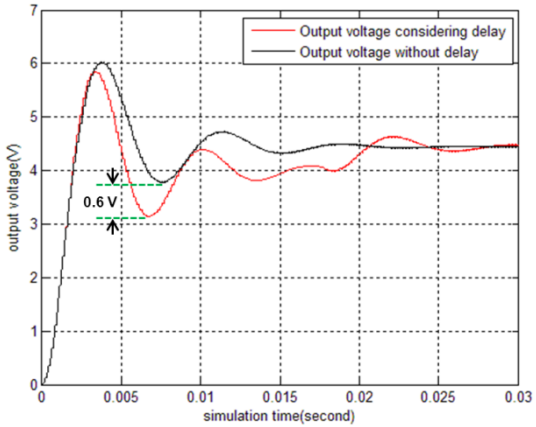


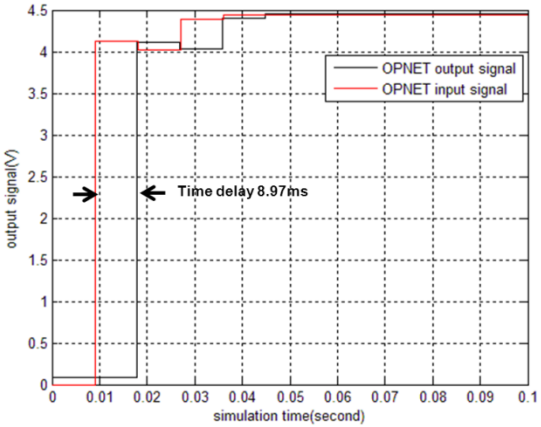
(a) Output voltage of the networked converter



(b) Measured values of the output voltage input and output OPNET

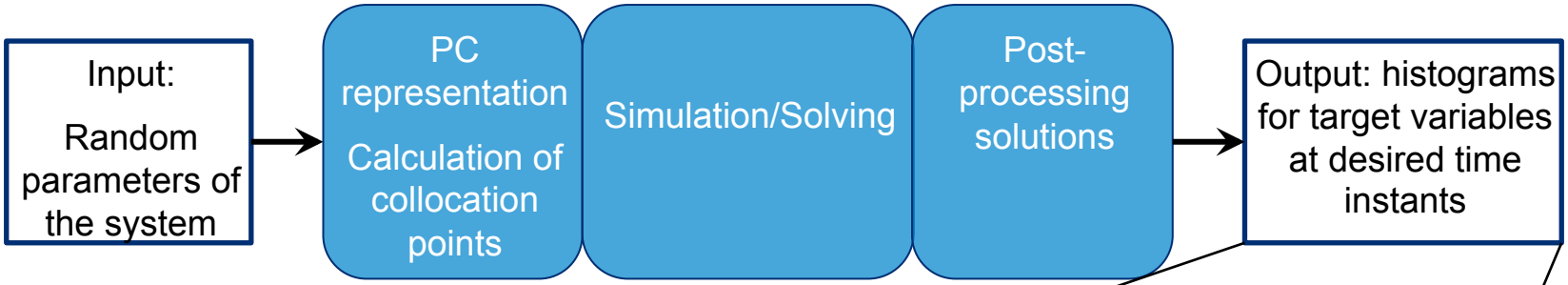
100kbps data rate





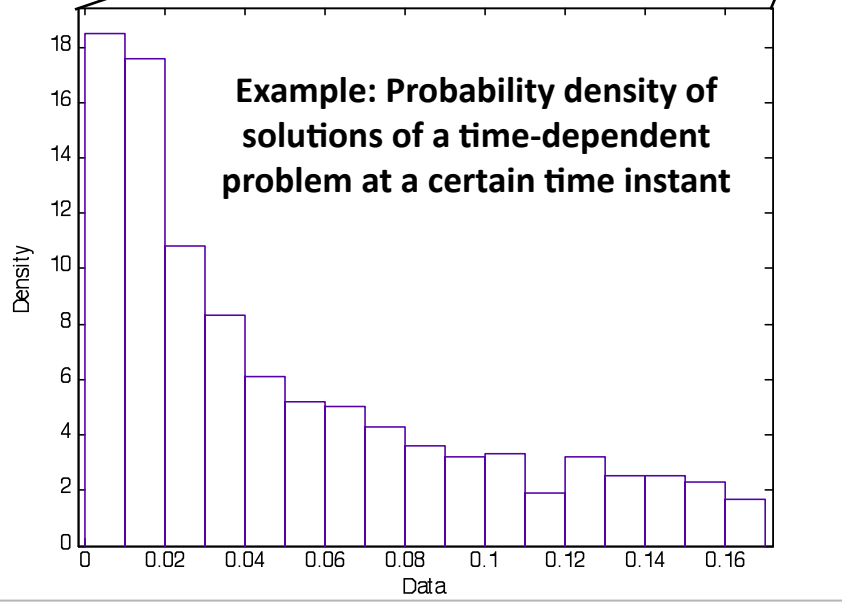
Fast stochastic simulation -Non-intrusive Polynomial Chaos

Main idea: Calculate PC coefficients of target variables via numerical integration



Four main steps:

- **Polynomial Chaos Representation** of parameters
- **Calculation of collocation points** and their combinations
- **Evaluation of the** system for each combination
- **Post-processing**



The Real-Time Simulation Lab

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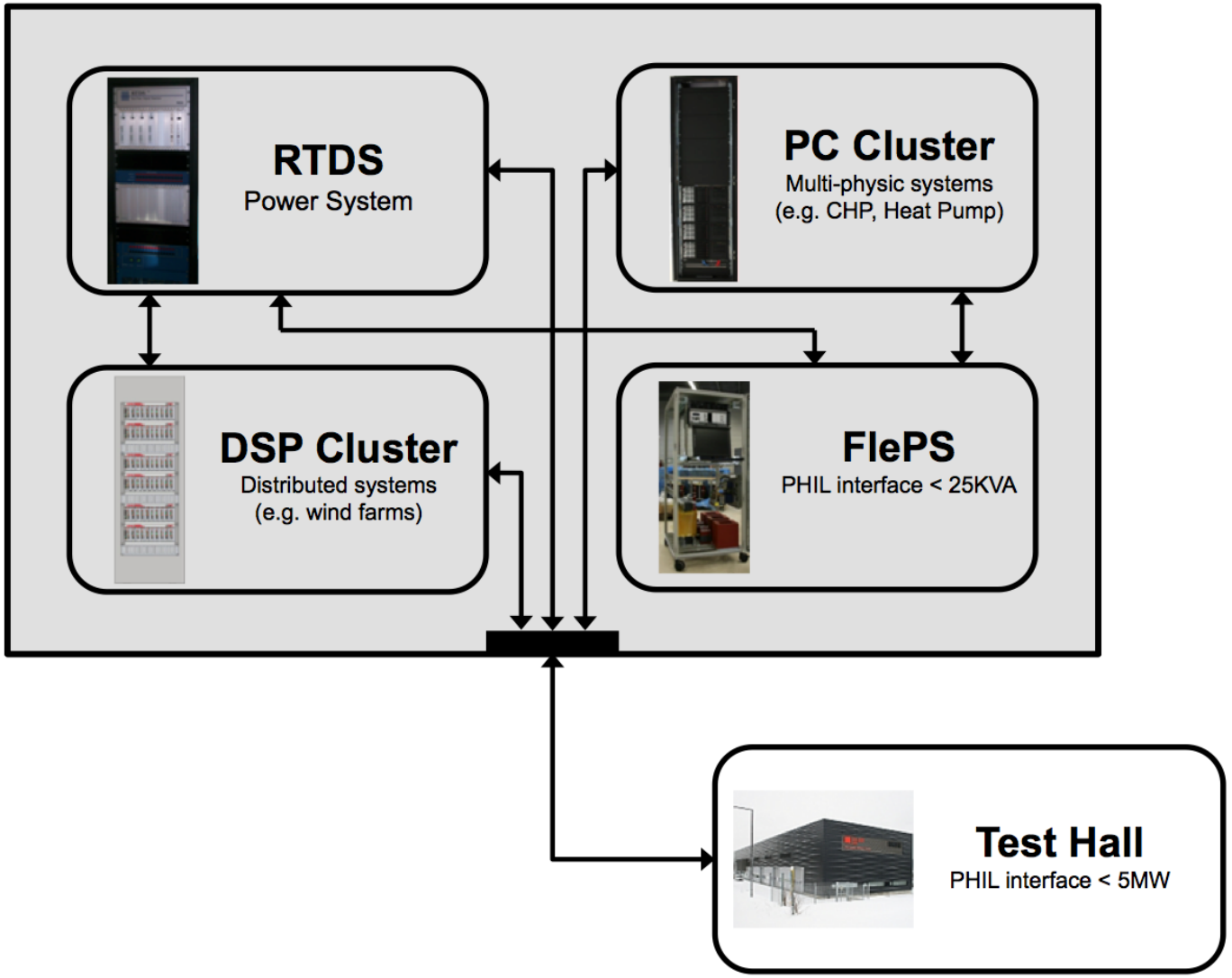

Real Time Digital Simulator (RTDS)

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Description: (one rack)

- 4 Giga Processor Cards
- 1 Workstation Interface Card
- 1 Network Communication Card
- Analog and digital I/O

Applications:

- State of the Art for power system real-time simulation
- Test of communication standard
- HIL test: through dedicated connections for relays and many analog and digital I/O
- PHIL test: through Grid Emulator
- Stochastic analysis

DSP Cluster

E.ON Energy Research Center

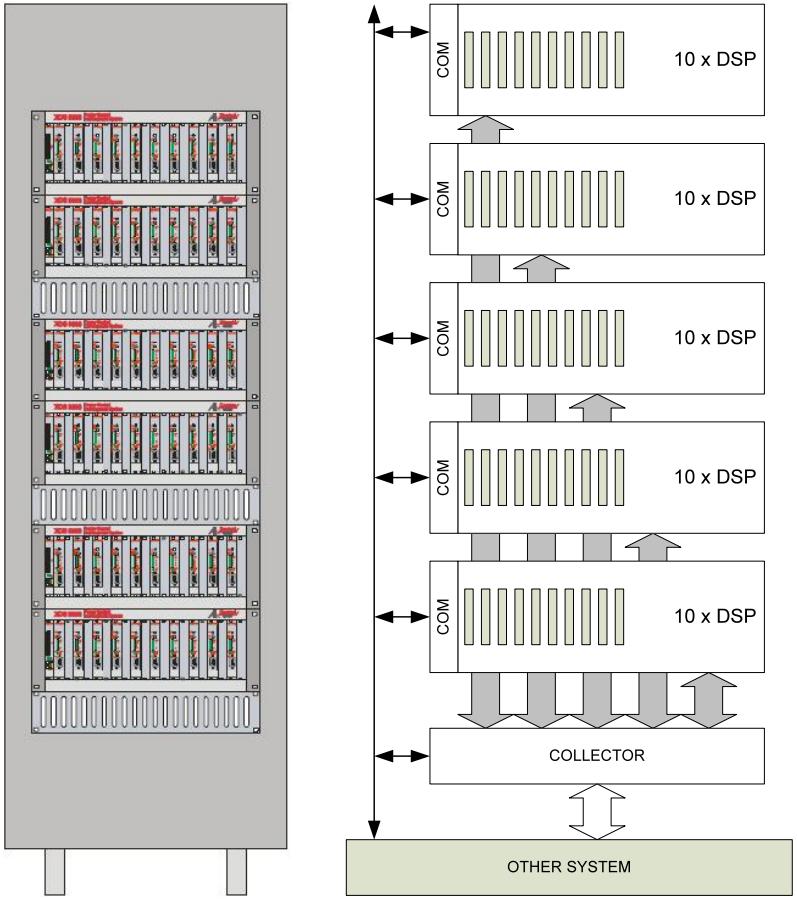
Description

- Multi DSP modular real time simulator

  Each board:
  - 1DSP, 1FPGA
  - Various I/O board

Applications:

- Simulation of distribuited system
  - Wind Farms
  - PV systems
- Hardware In the Loop, Power Hardware In the Loop



PC cluster

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- Description:
  - Each node:
    - 4 Processors, 32 cores
    - 128 GB RAM
    - 5 PCI connections
  - Four Node for a total of 128 cores and 512 Gb of RAM
  - InfiniBand and Ethernet connection
- Applications:
  - Real time and non real time simulation of multi-physic system
  - Modelica support
  - Stochastic analysis.
  - Support for standard scientific tools like Matlab.
  - Easy to replicate, expand and upgrade

Power Hardware In the Loop Interface: Flexible Power Simulator (FlePS)

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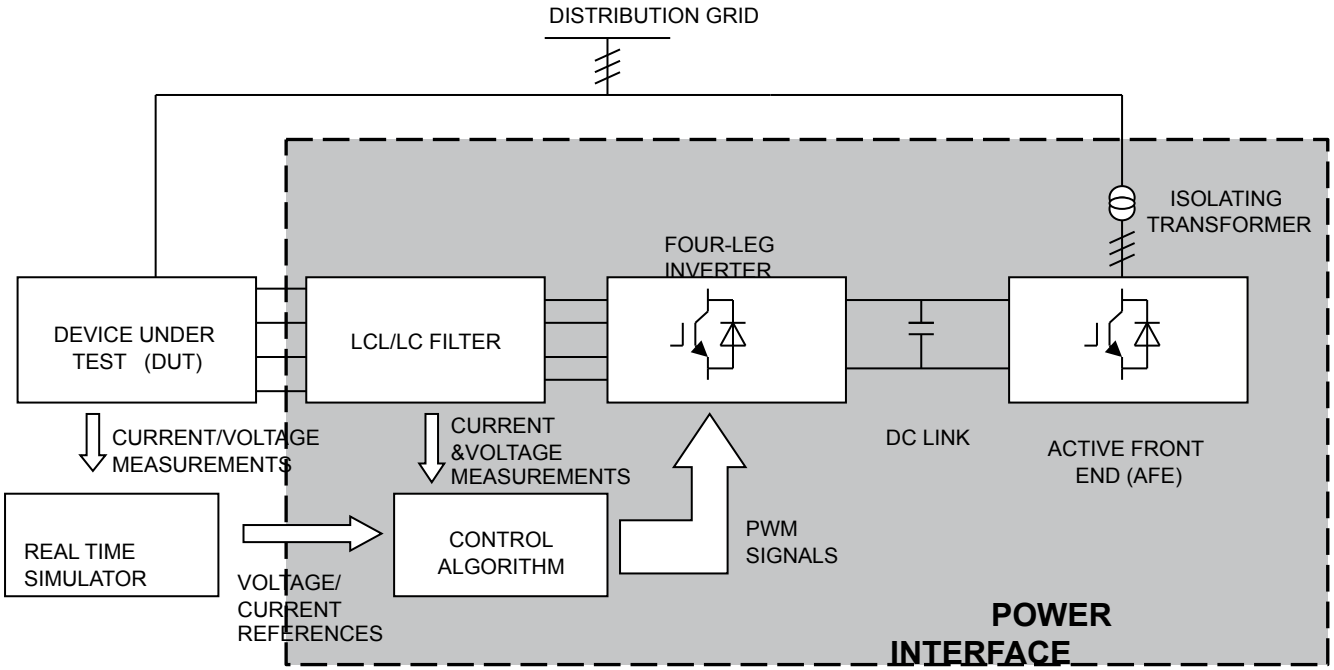
- Power rating: 25kVA
- Four phase output: 1 three phase system with control of the neutral point
  2 independent single phase AC systems
  2 independent DC systems
- Switching frequency: 40kHz



Laboratory Communication Infrastructure

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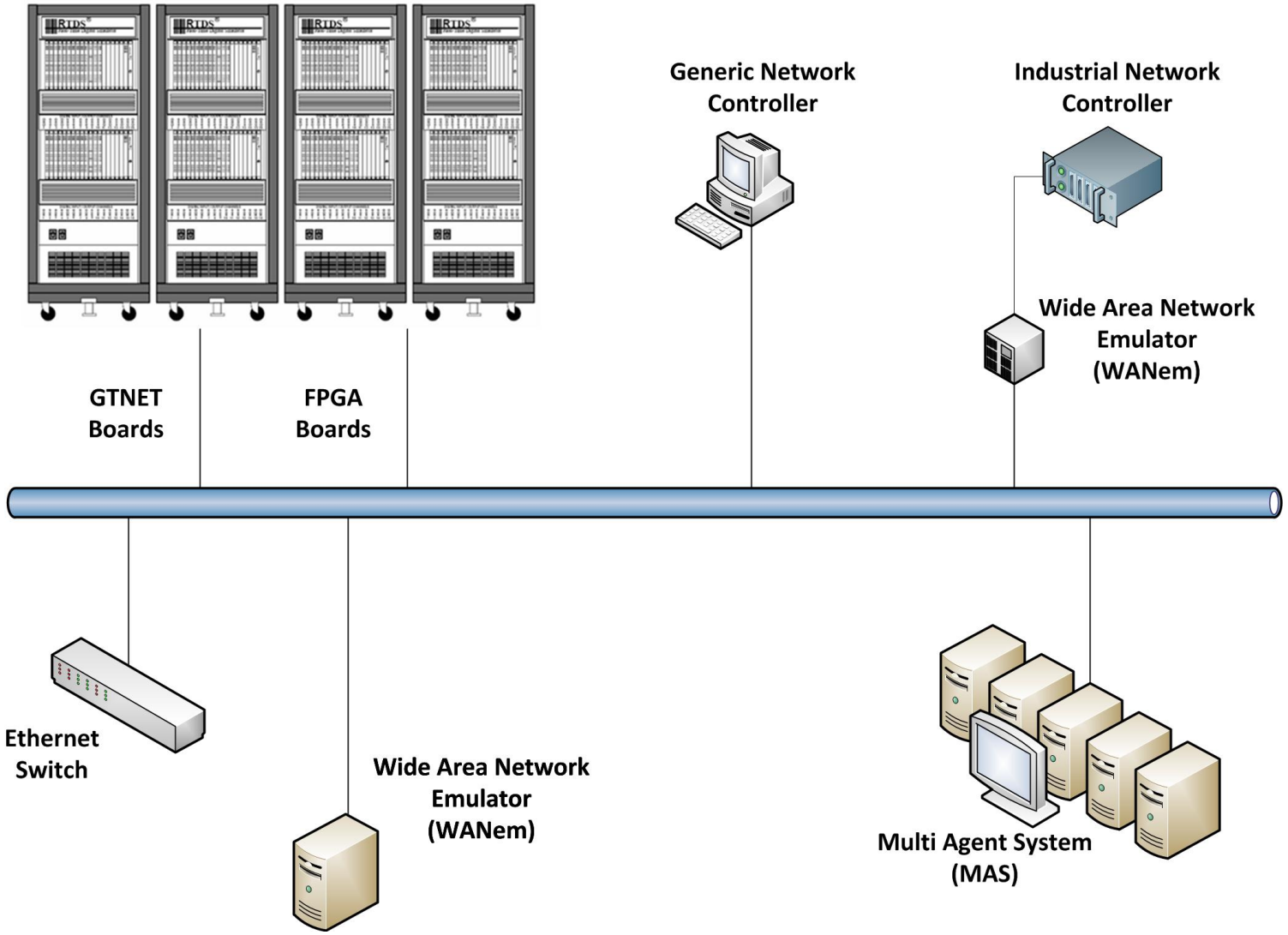

Communication Emulation

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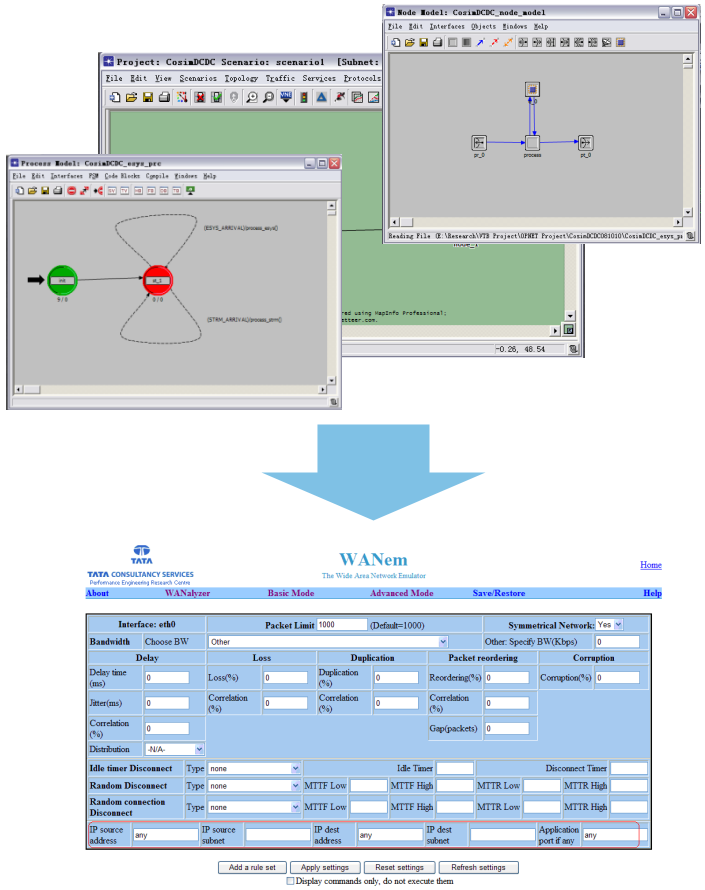
Goal: supporting the analysis of power systems with a reliable and accurate representation of communication networks

- Communication network simulated off-line using OPNET

  Parameter ↓ extraction

- Network emulated in Real Time using WANem (parameter can be defined in a stochastic way):
  - Time delay,
  - Packet loss,
  - Packet corruption,
  - Disconnections,
  - Packet re-ordering



Communication Emulation

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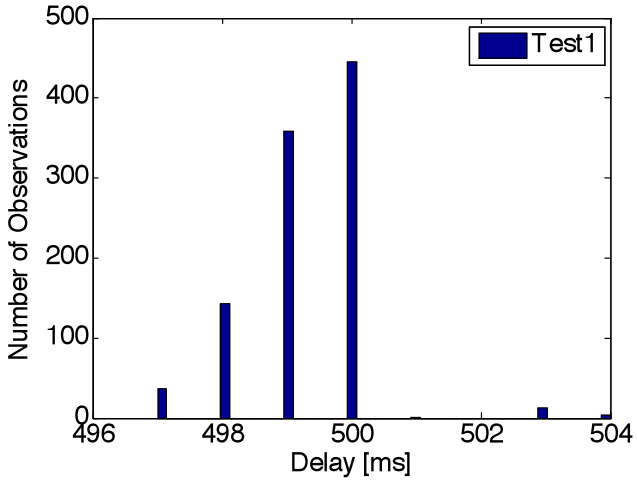

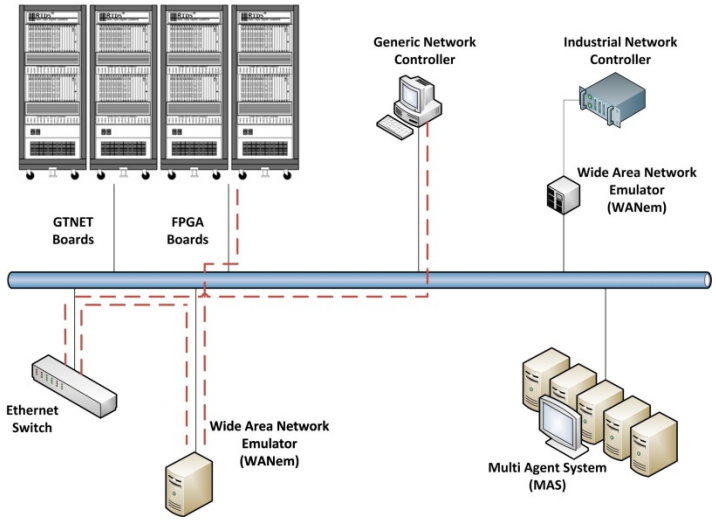

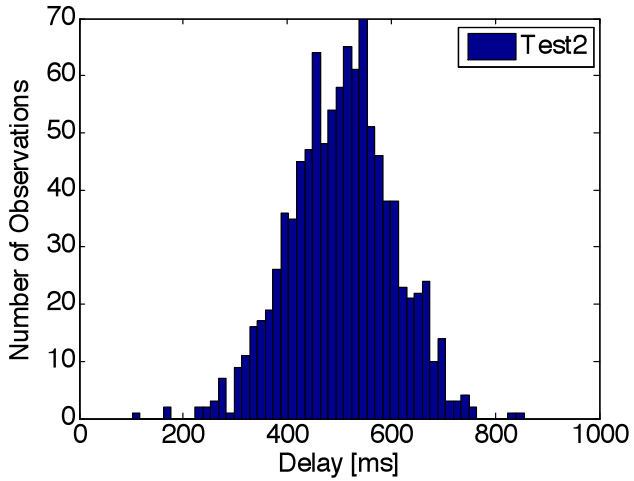

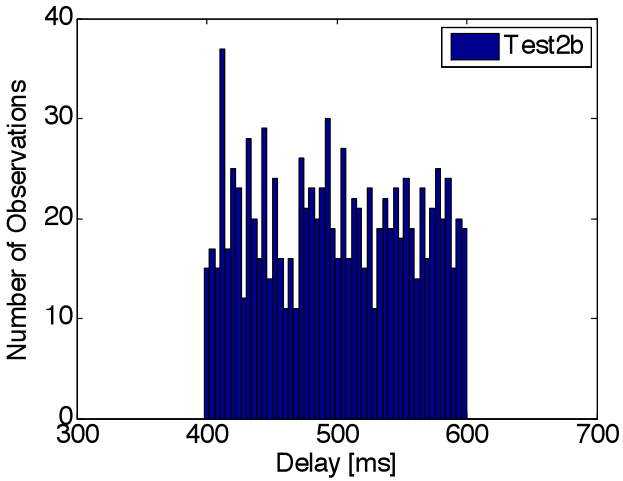

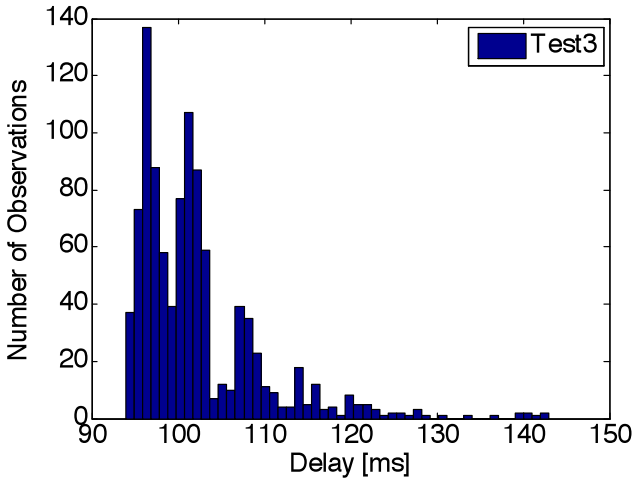

Sample project - RT for Large Wind Farm

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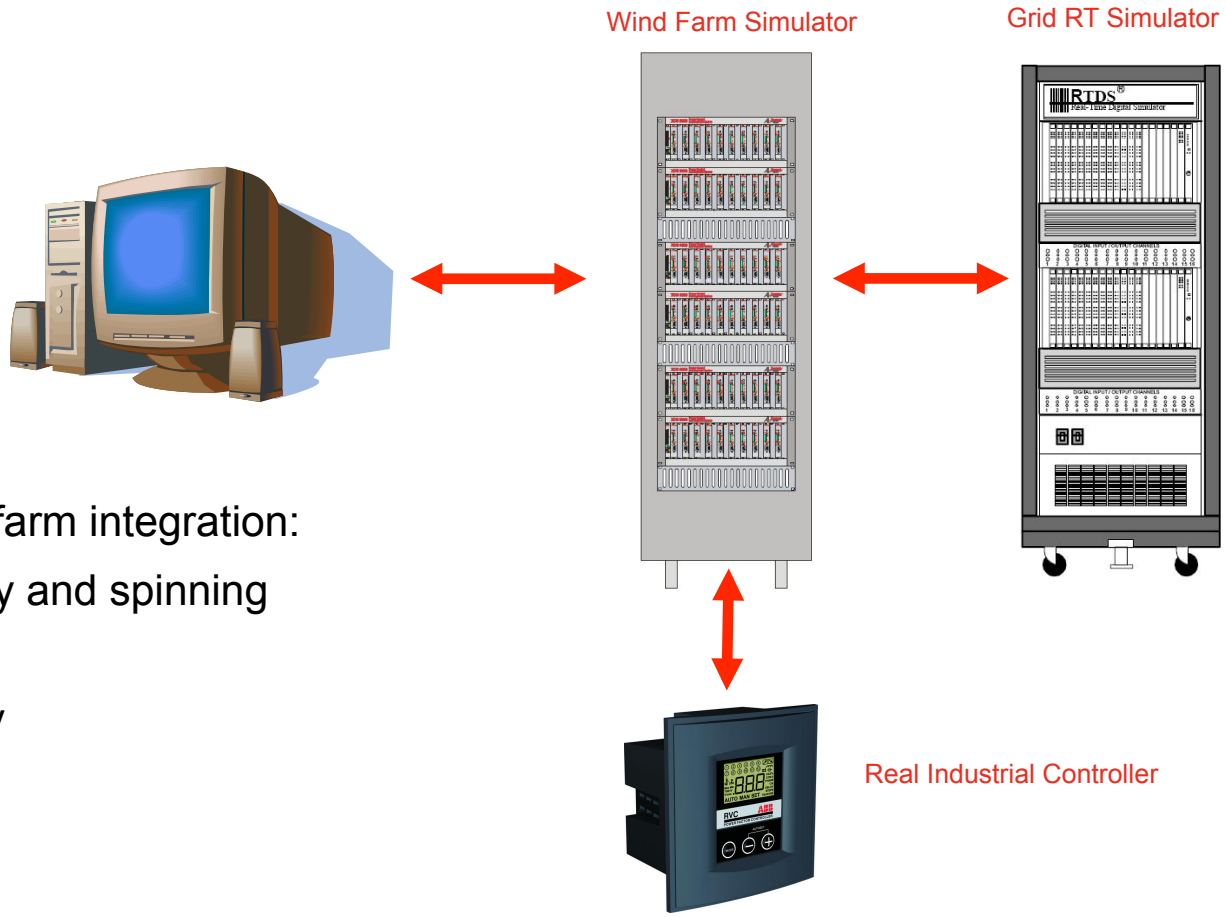

- Analysis of wind farm integration:
  - Intermittency and spinning reserve
  - Grid stability
  - Congestion
- Grid code testing

Sample project - RT for Wind Tower testing

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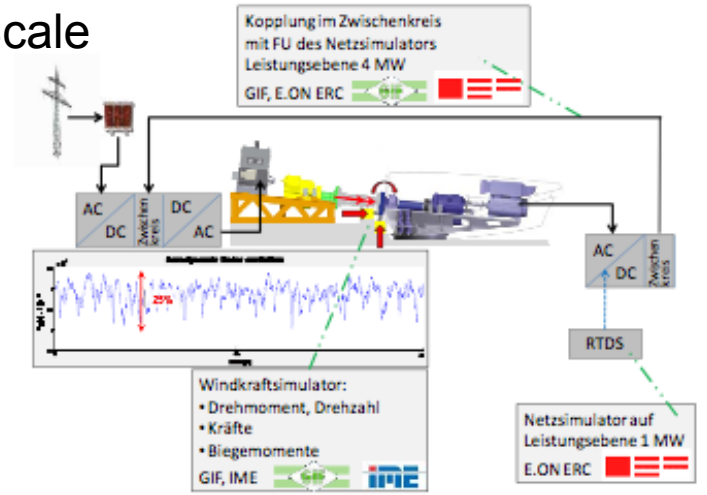
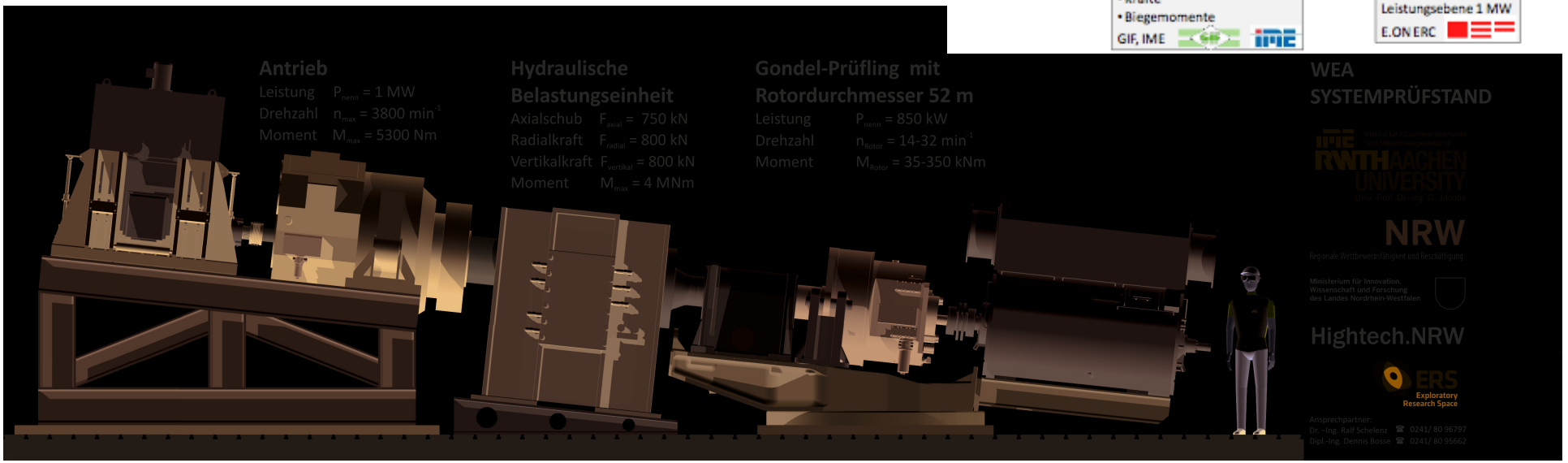
- Design of a test-bench for Wind Towers in a 1:1 Scale
- Two steps project: first 1 MW and then 4 MW
- RT simulation of the Interface to the main grid
- Collaboration of many Institutes of RWTH





Sample project - Home Energy Systems

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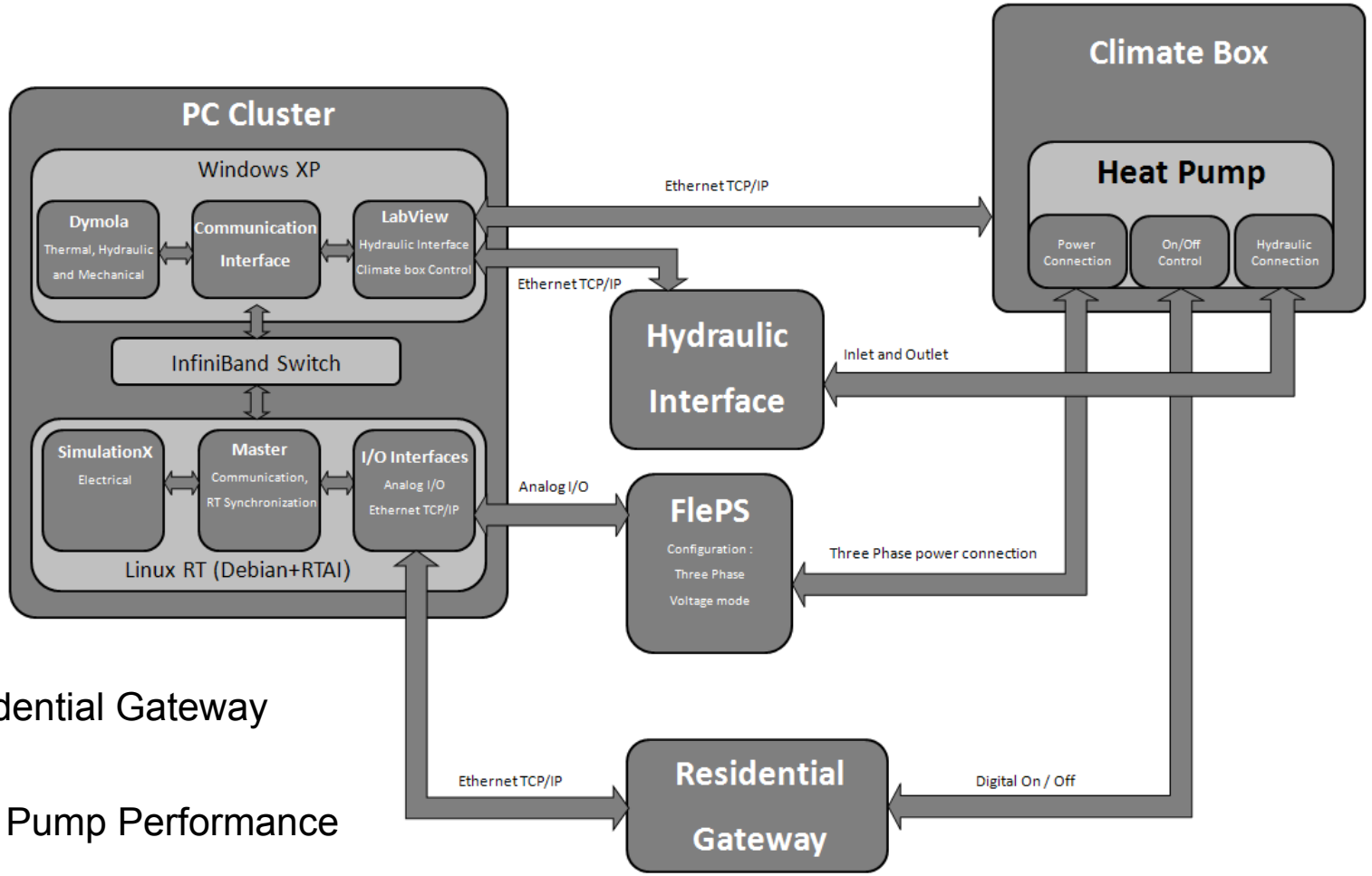

- Analysis of Residential Gateway strategies.
- Analysis of Heat Pump Performance

Sample project – HIL for Home Energy Systems

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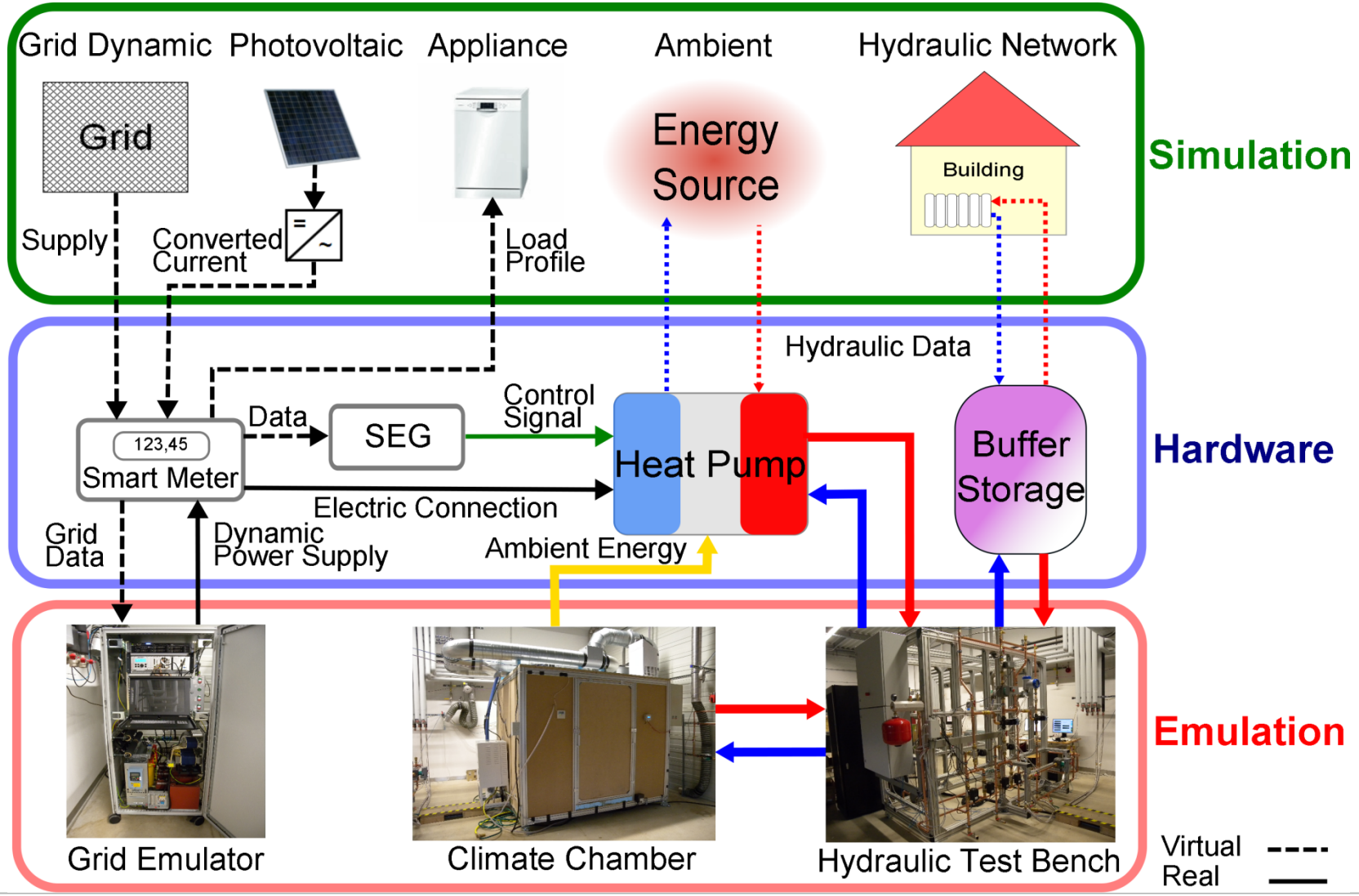

Sample project - Electrical and Hydraulic HIL Interfaces

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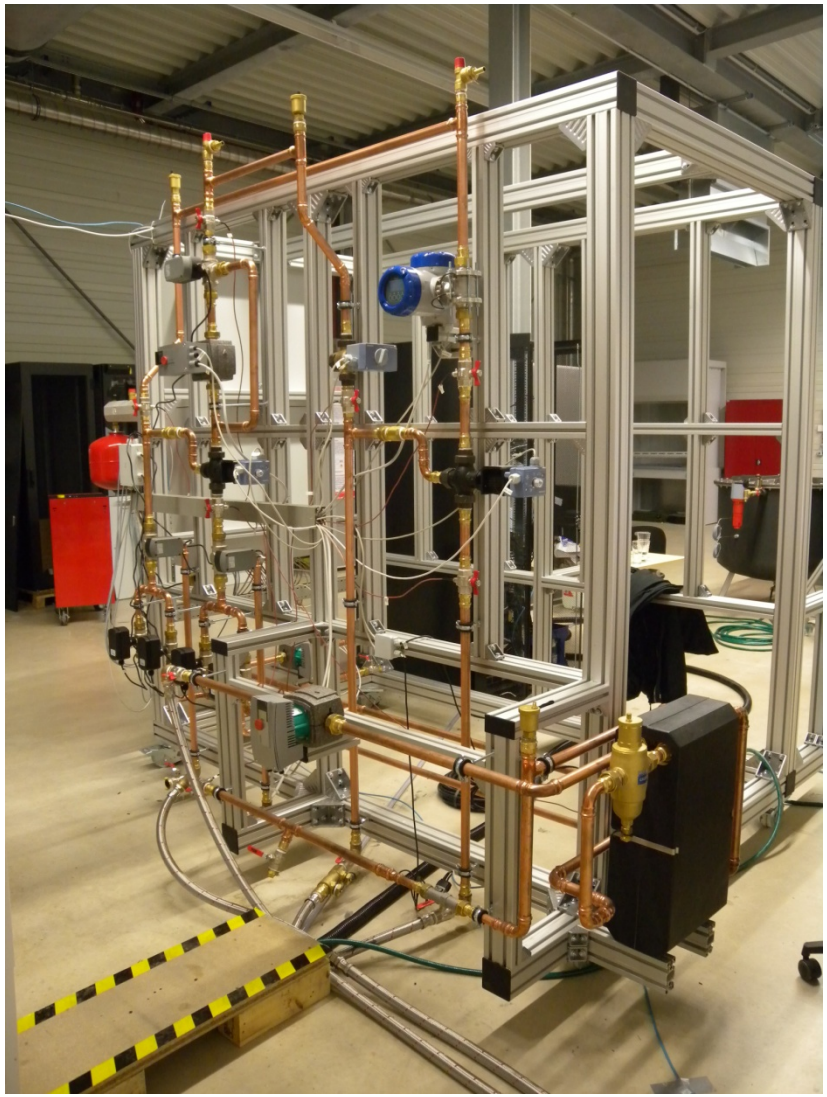

Sample project - climate chamber as HIL Interface

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Sample project - Distributed Monitoring with PMUs

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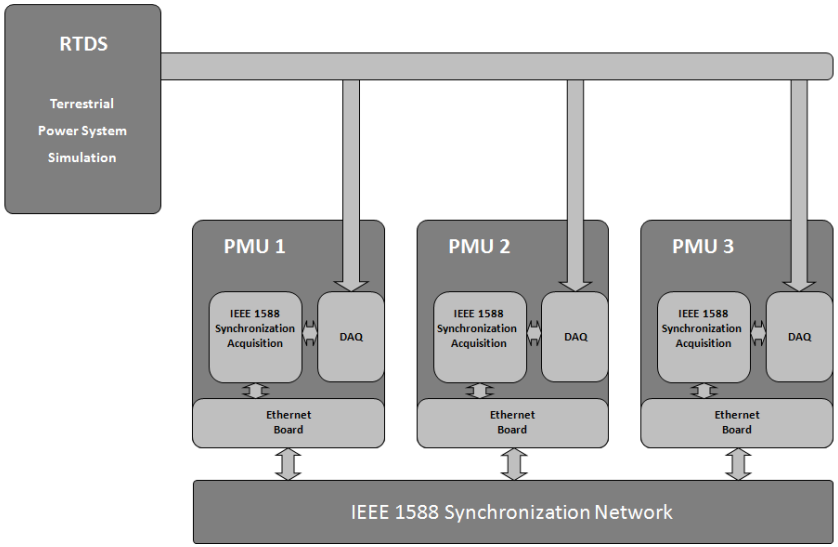
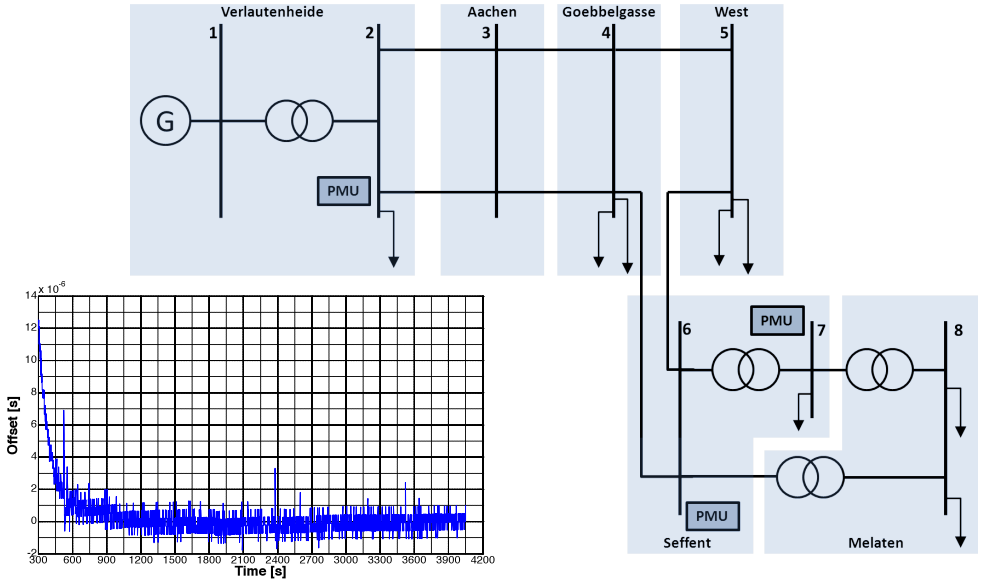
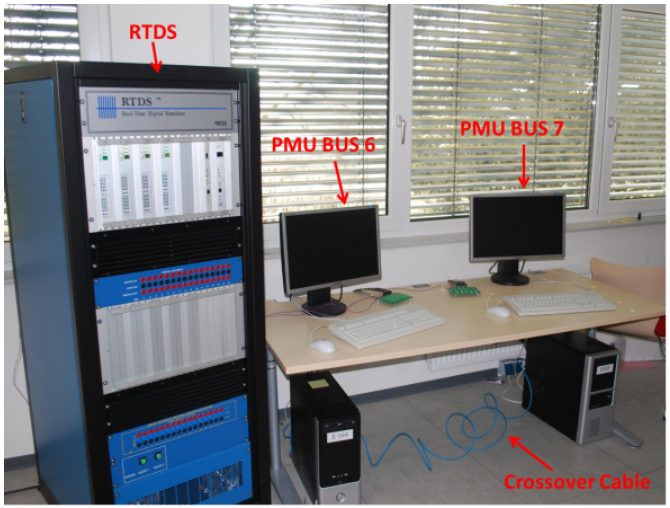
- Investigate the software-only PTP synchronization method for Phasor Measurement Units
- Evaluate the impact of synchronization on the State Estimation process.







Sample project – MAS for Distributed Monitoring and Control

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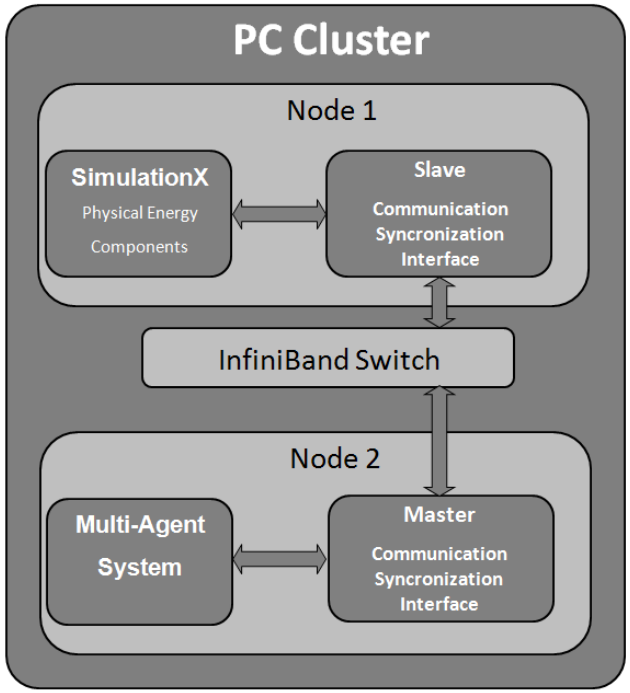
SmartPowerHamburg

Bundesministerium für Wirtschaft und Technologie

- Design of a Smart Grid System for the City of Hamburg
- Main focus on the Distributed Intelligence Infrastructure
- Final goal integration of different grids for a more flexible infrastructure (Electricity, District Heating, Storage, etc.)
- Development of an Agent Based simulation for validation of the concepts



Conclusions

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- The smart grid is a complex system of etheregeneous, interacting infrastructures
- Current analysis, design, operation, monitoring methods must be advanced to enable the smart grid
- Real-time and non real-time Numerical simulation is the method to:
  - Analyze new solutions in the full, interacting system
  - De-risk the introduction of new technologies and components with HIL/PHIL testing: Test in the system, not as a stand alone!
- Multi-disciplinary dynamic simulation, real-time and non real-time is the new cutting edge computational advancement
- Interfaces for multi-disciplinary, real-time PHIL testing are the new cutting edge in hardware testing advancement