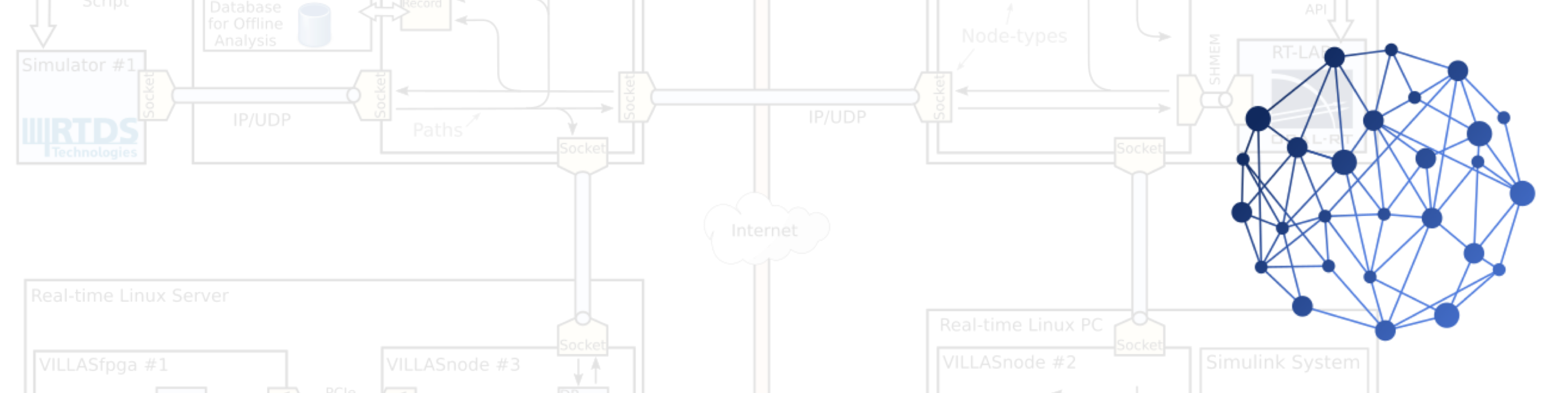

Applications of VILLASframework

Geographically Distributed and Local Power System co-simulation

Technical Workshop of the ERIGrid Project

13.09.2018
Oldenburg, Germany

Prof. Antonello Monti

ACS | Automation of Complex Power Systems
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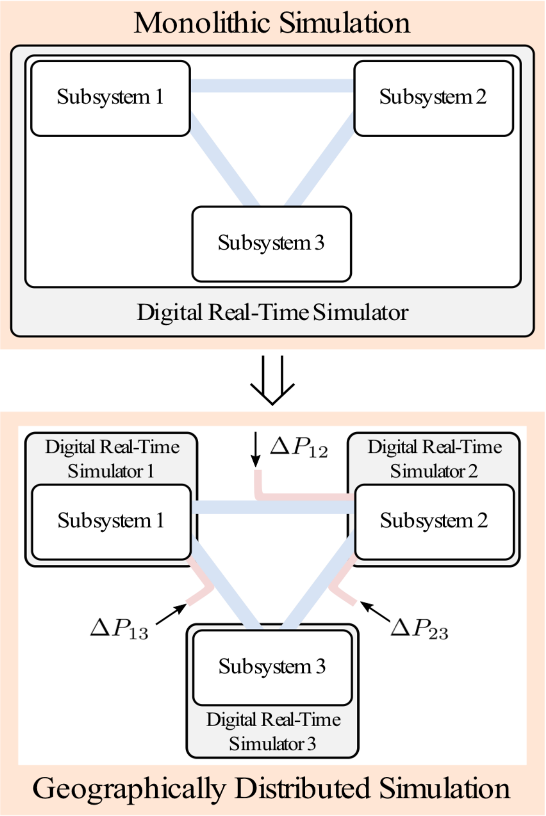
Co-Simulation Interface Algorithm (IA)

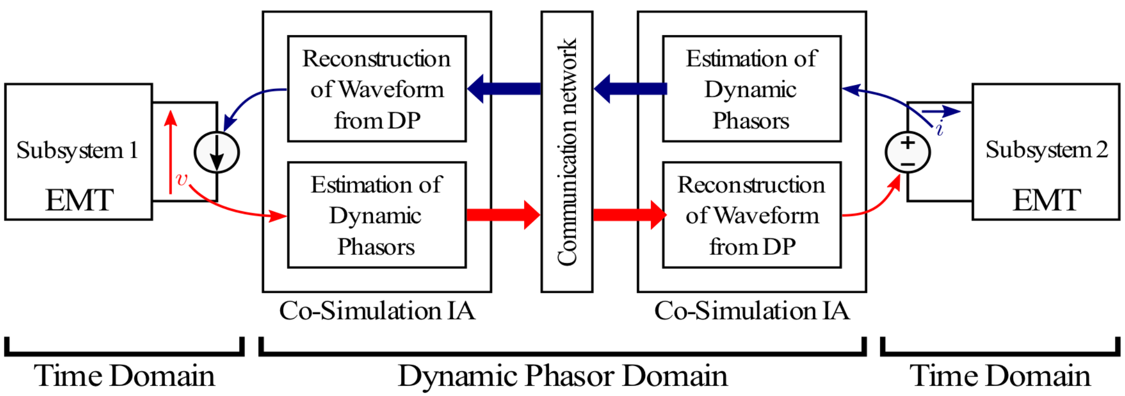
- Co-Simulation Interface Algorithm (IA) for geographically distributed real-time simulation (GD-RTS)
  - Objectives: conservation of energy at the interface and interface transparency
  - Violation of energy conservation at the interface is inherent problem in (geographically) distributed co-simulation due to the following
    - system decoupling (subsystems are solved separately)
    - communication medium (delay, delay variation, packet loss, limited data sampling…
  - Co-simulation IA should preserve stability of the simulation and ensure simulation fidelity



Violation of energy conservation in GD-RTS

Co-simulation IA based on Dynamic Phasors

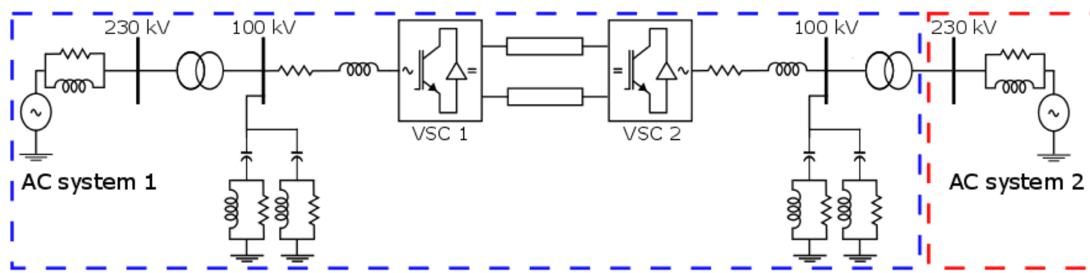
- Co-Simulation IA for geographically distributed real-time simulation
  - based on one of the most commonly employed IA for PHIL interfaces: ideal transformer model (ITM)
    - controlled current and voltage sources that impose in the local subsystem the behavior of the remote subsystem
  - current and voltage interface quantities are exchanged between the simulators in the form of time-varying Fourier coefficients, known as dynamic phasors
  - time clocks of the two simulators are synchronized to the global time
  - dynamic phasor concept includes absolute time that enables time delay compensation based on the phase shift



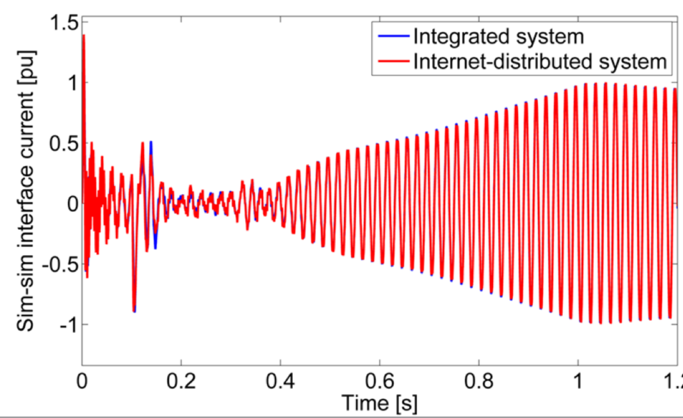
Example of Application of Co-Simulation Interface Algorithm based on Dynamic Phasors

- ACS-SINTEF Distributed Real-Time Simulation Platform
  - Real-time simulation of multi-terminal HVDC grids interconnected with AC grids and wind farms
    - Studies of potential interactions of the control concepts implemented in the AC grid generators and control strategies of converters

- VSC-HVDC point to point link that connects two AC systems
  - a case study to demonstrate applicability of the Internet-distributed simulation platform for simulation of HVDC grids



- Simulation start
  - System response after simulation start indicates high fidelity of geographically distributed simulation in steady state and during slow transients



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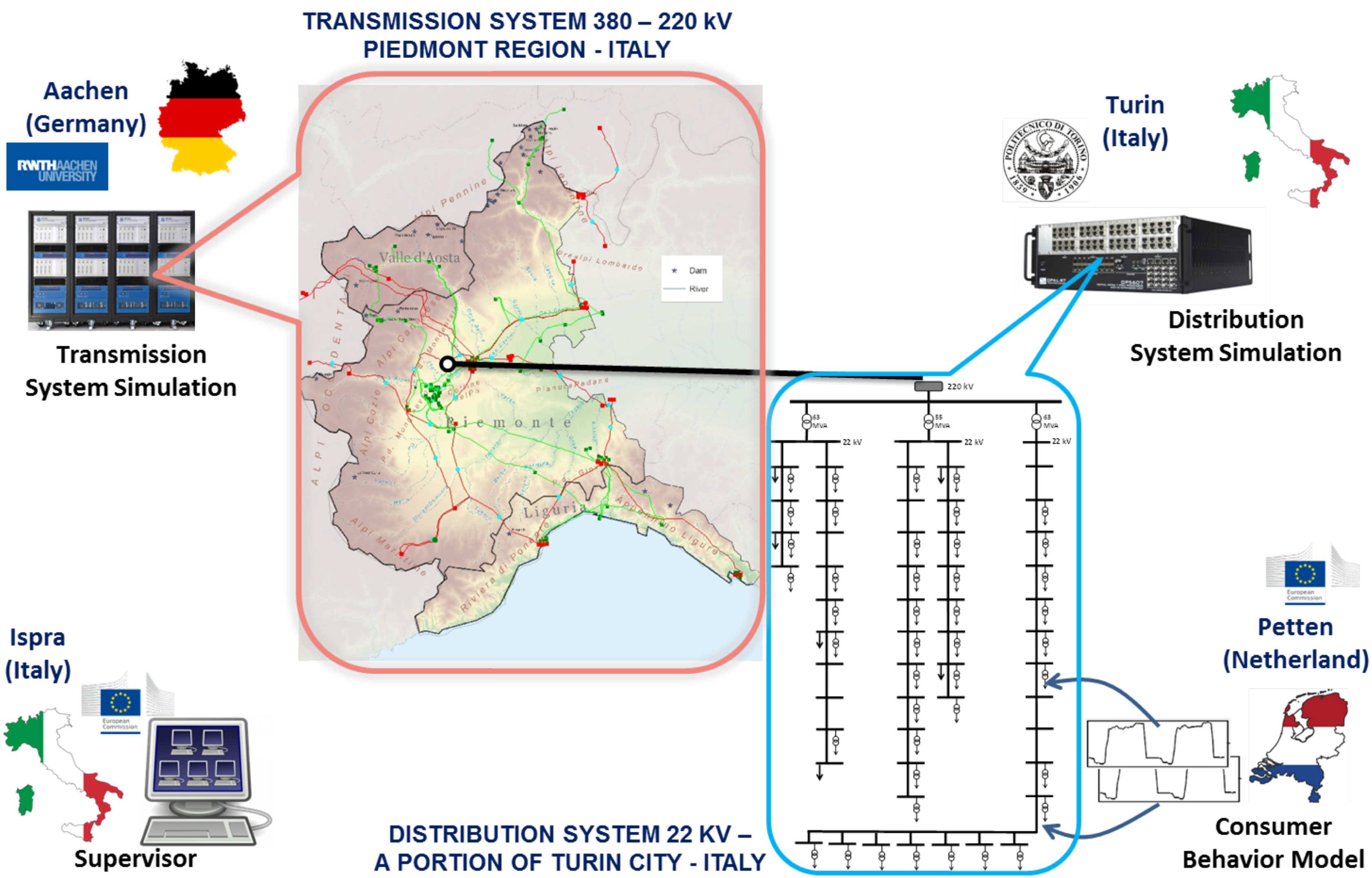
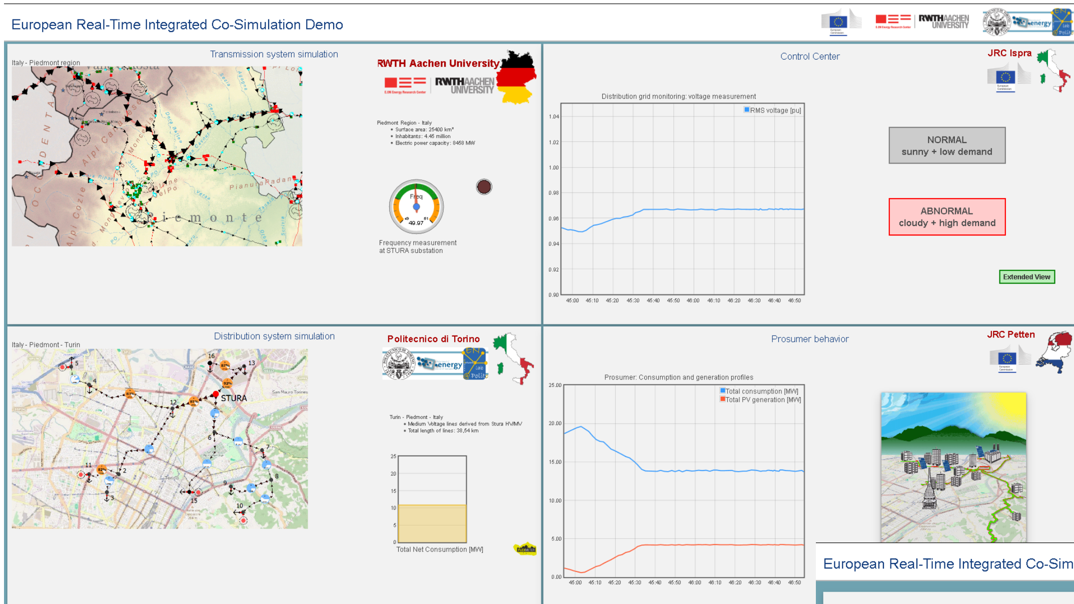
ERIC Lab Demonstration

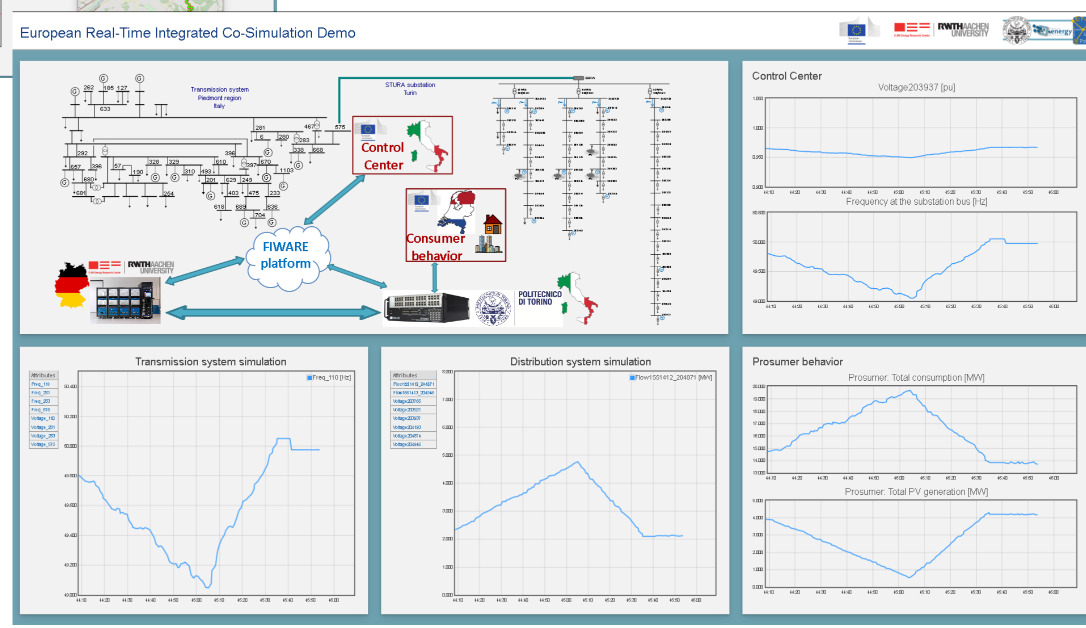
- Objectives of simulation scenario
  - Real-time co-simulation of the interconnected transmission and distribution systems
  - Studies of how different levels of distributed generation, EV penetration in the distribution system affect the system operation at both transmission and distribution levels
  - Collaboration based on a virtual integration is particularly beneficial for this scenario
    - There is a need for large-scale power system simulation consisting of detailed simulation models of both transmission and distribution systems
    - Competences of different areas are required (transmission and distribution systems, consumer behavior patterns)
    - Confidentiality aspects of sharing data and models among operators is not an issue as only interface quantities at the decoupling point are exchanged
- Overview of roles of laboratories
  - Transmission system is simulated on RTDS system at RWTH, Germany
  - Distribution system is simulated on OPAL-RT system at POLITO, Italy
  - Prosumer behavior patterns are provided by JRC-Pettan, Netherland
  - Monitoring based on a web-client in JRC-Ispra, Italy

ERIC Lab Demonstration Overview



ERIC Lab Demonstration
Web Interface



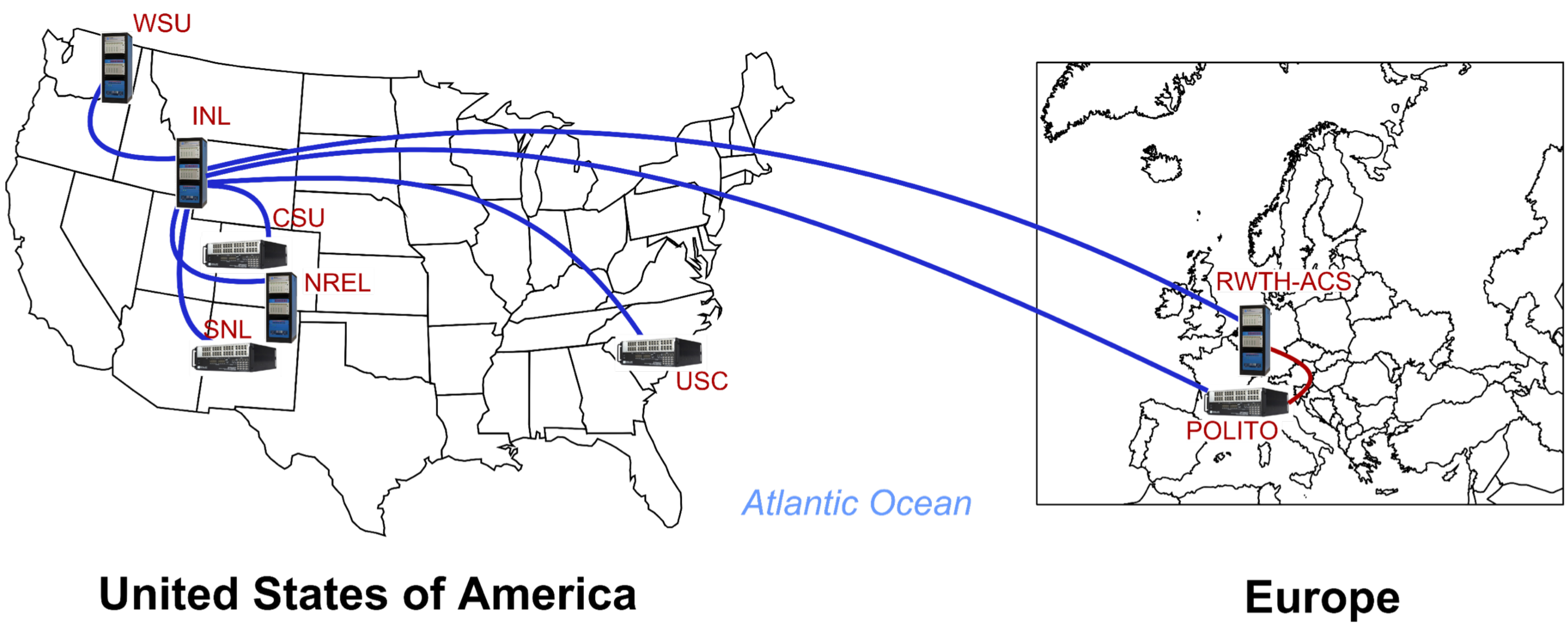


- Web interface for consolidated monitoring of simulation
  - Conceptual layout (to the left)
  - Technical layout (below)

RT-Super Lab
Transatlantic Distributed Test Bed

Objectives

- Establish a vendor-neutral distributed platform based on interconnections Digital Real-Time Simulators (DRTS), Power-Hardware-In-the-Loop (PHIL) and Controller-Hardware-In-the-Loop (CHIL) assets hosted at geographically dispersed facilities
- Demonstration of multi-lab real-time simulation and distributed PHIL and CHIL setup for simulation and analysis of next generation global power grids



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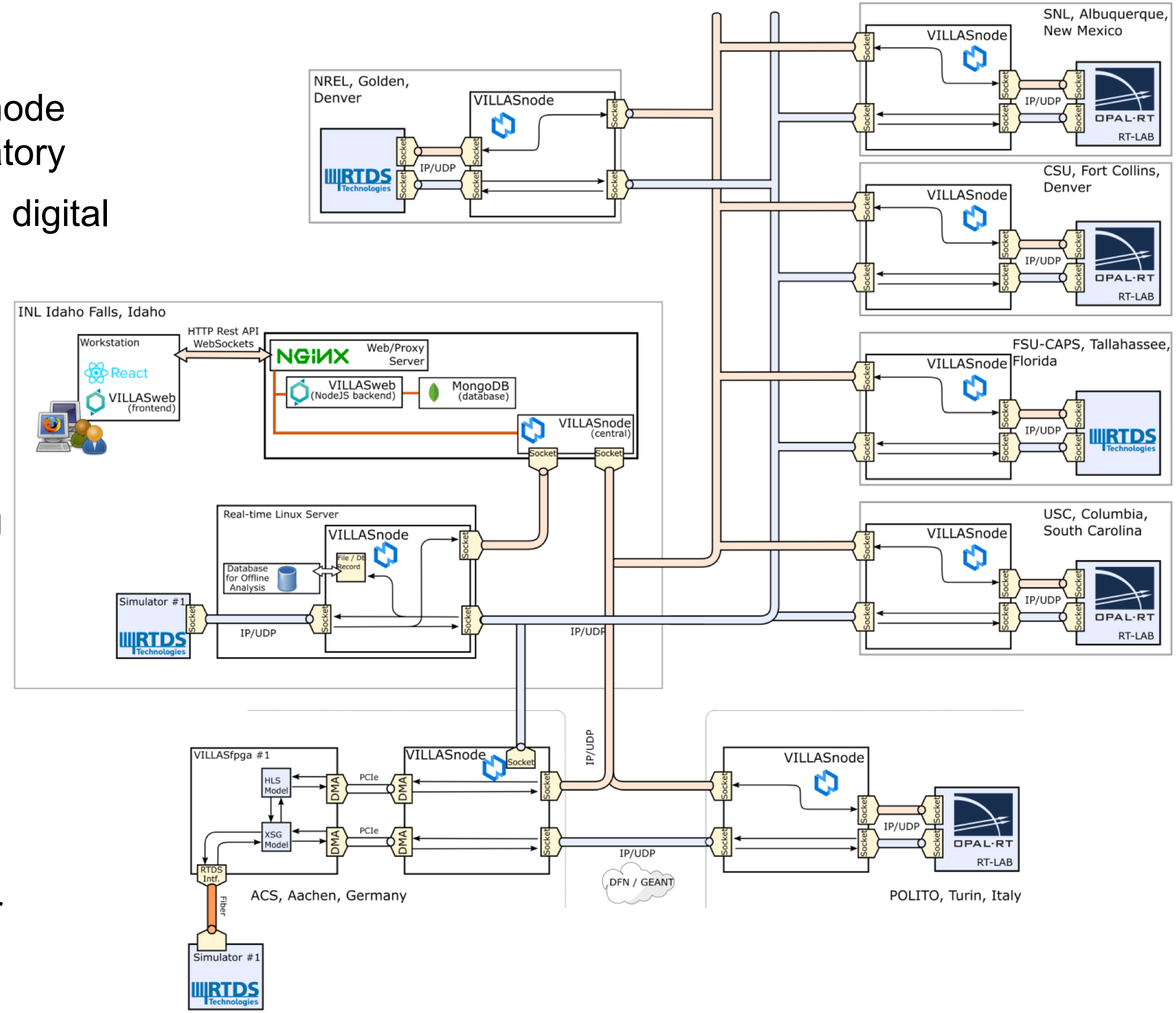
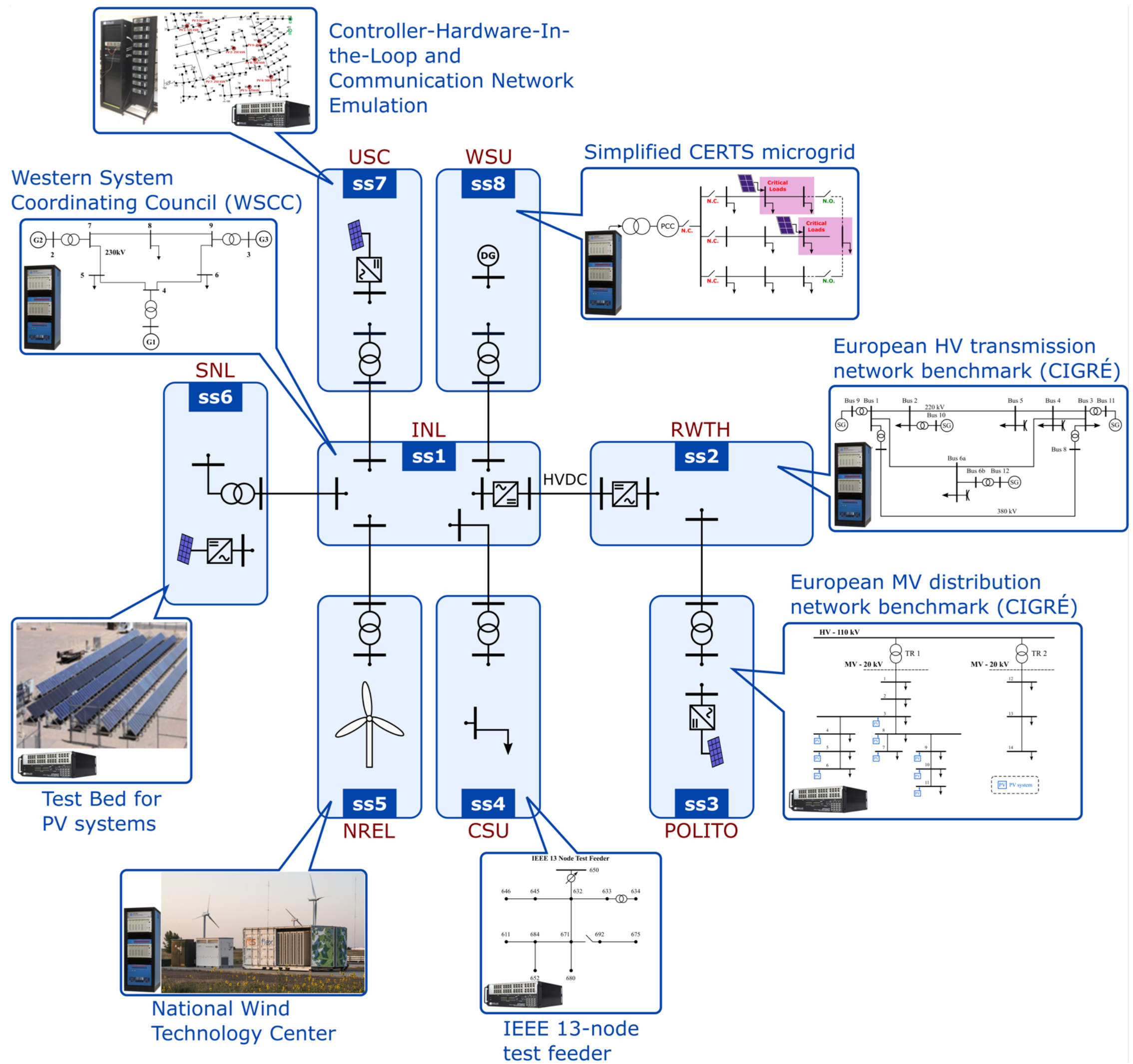
VILLASframework for RT-Super Lab

- VILLASnode
  - An instance of VILLASnode installed at every laboratory
  - Gateway for connecting digital real-time simulators
  - Interface to VILLASweb
- VILLASweb
  - Web interface for consolidated monitoring of the distributed simulation
  - Web Server, Backend and Database hosted at INL for RT-Super Lab Demo
  - Web interface is available within VPN for all participants



RT-Super Lab Demonstration

- Leverage unique hardware assets located at different laboratories and academic institutions for simulation and testing of next generation interconnected grids
  - 8 Labs
    - 5 OPAL-RT, 4 RTDS, 1 Typhoon
  - 1 CHIL at USC
  - Communication network emulation based on Apposite N-91
  - 2 PHIL
    - NWTC Controllable Grid Interface (CGI) interfaced to the GE 1.5 MW wind turbine
    - Test Bed for PV inverters
  - Simplified transatlantic HVDC interconnection of transmission systems in the U.S. and Europe

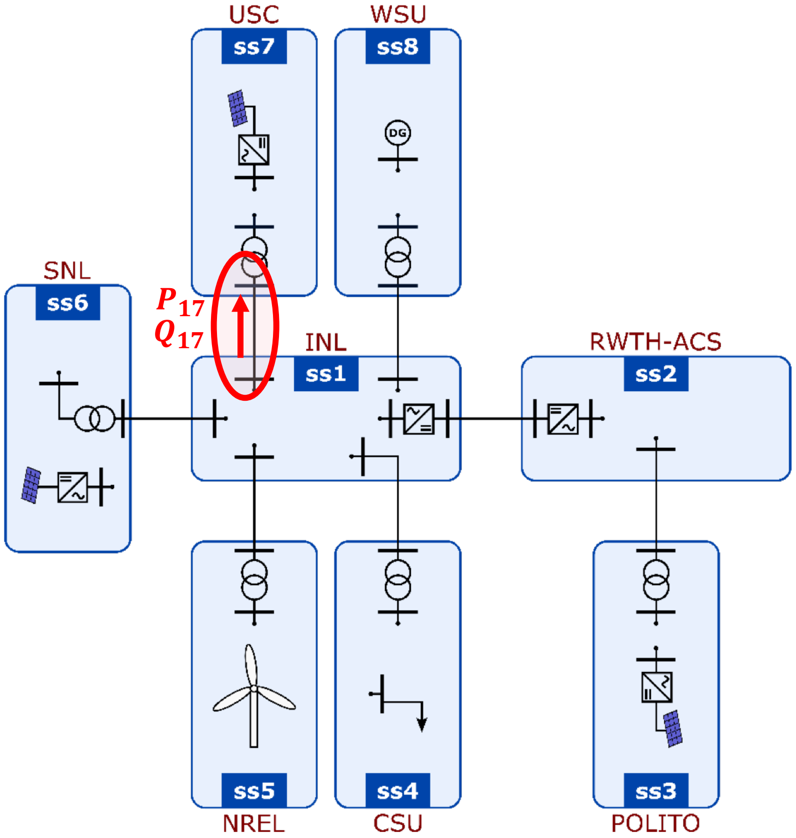


RT-Super Lab Participants

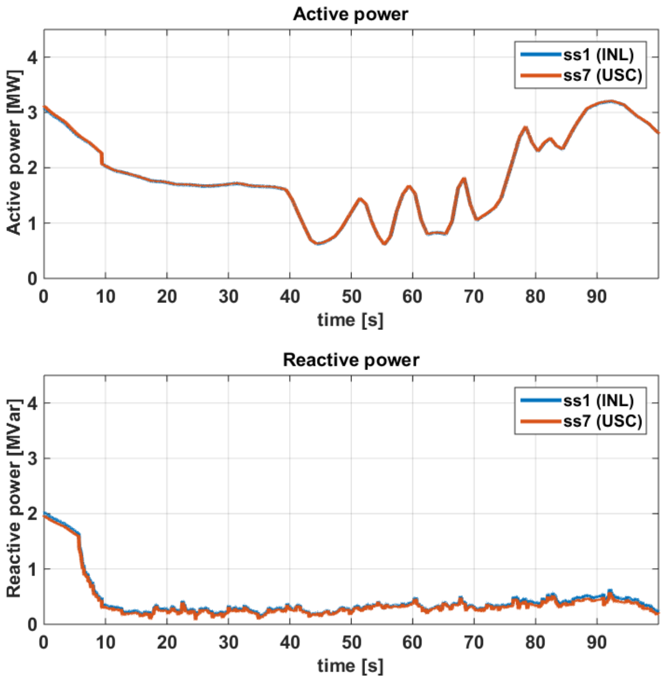
	Laboratory		Simulation model / HIL setup	Subsystem ID
	Full Name	Acronym		
National Labs	Idaho National Laboratory	**INL**	Western Systems Coordinating Council (WSCC); HVDC converter station	**ss1**
National Labs	National Renewable Energy Laboratory	**NREL**	PHIL for wind turbines	**ss5**
National Labs	Sandia National Laboratories	**SNL**	PHIL for PV inverters	**ss6**
US universities	Colorado State University	**CSU**	IEEE 13-bus distribution test feeder	**ss4**
US universities	University of South Carolina	**USC**	Modified IEEE 123-bus distribution system, CHIL, communication emulation	**ss7**
US universities	Washington State University	**WSU**	Simplified CERTS microgrid	**ss8**
EU universities	RWTH Aachen University	**RWTH**	European transmission network benchmark model (CIGRÉ); HVDC converter station	**ss2**
EU universities	Politecnico di Torino	**POLITO**	European distribution network benchmark model (CIGRÉ);	**ss3**

RT-Super Lab
Simulation results #1

- Activation of CHIL at USC
  - PV inverters controlled to minimize reactive power at the substation of IEEE 123-bus system
- Simulation results at ss1-ss7 co-simulation interface (INL-USC)
  - Decrease in reactive power at co-simulation (substation) bus

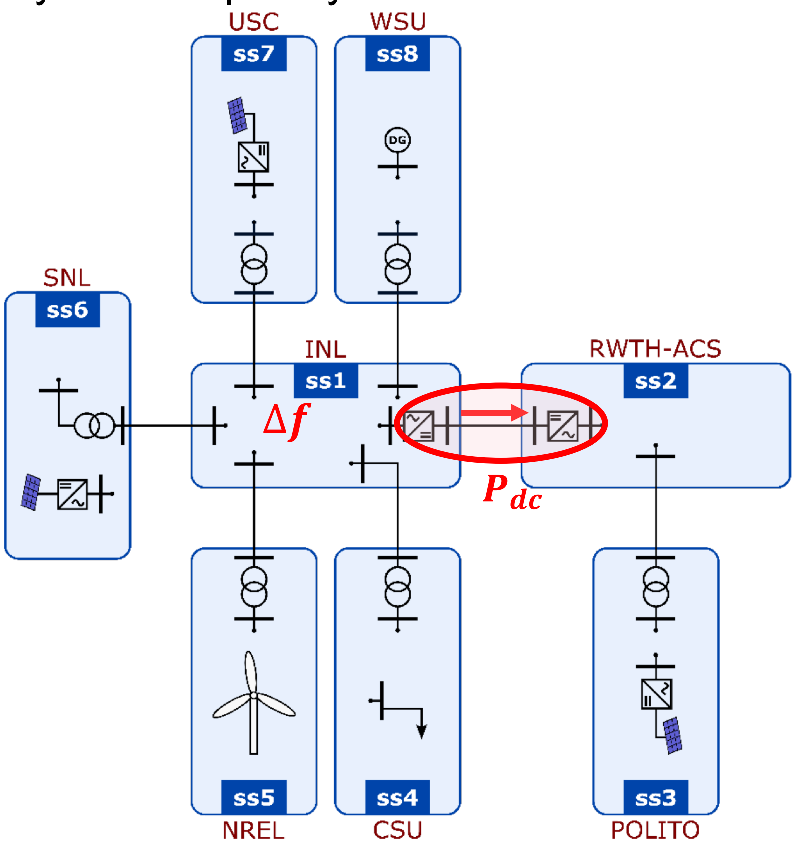


Simulation results at ss1-ss7
co-simulation interface (INL-USC)

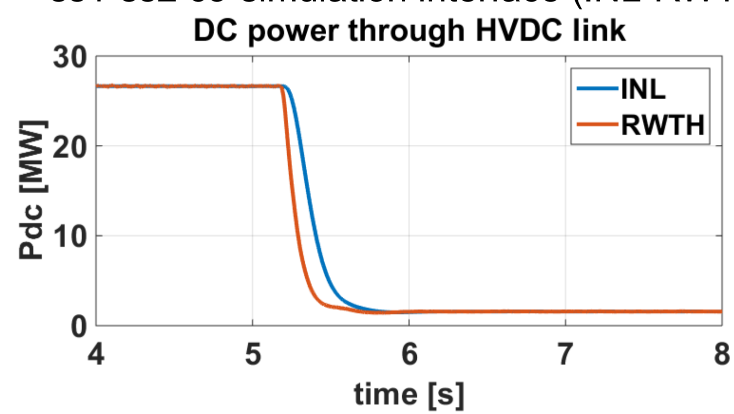


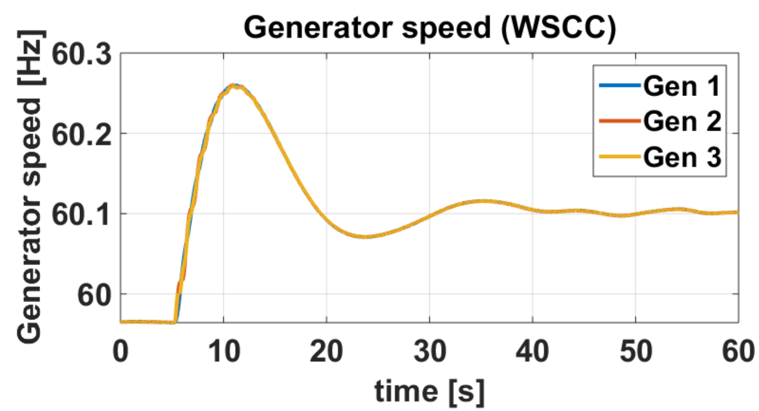
Simulation results #2

- Flow of power from INL to RWTH via HVDC
- Power in the HVDC link is decreased by 25 MW
  - Generators at WSCC (INL) respond
  - System frequency at INL increases



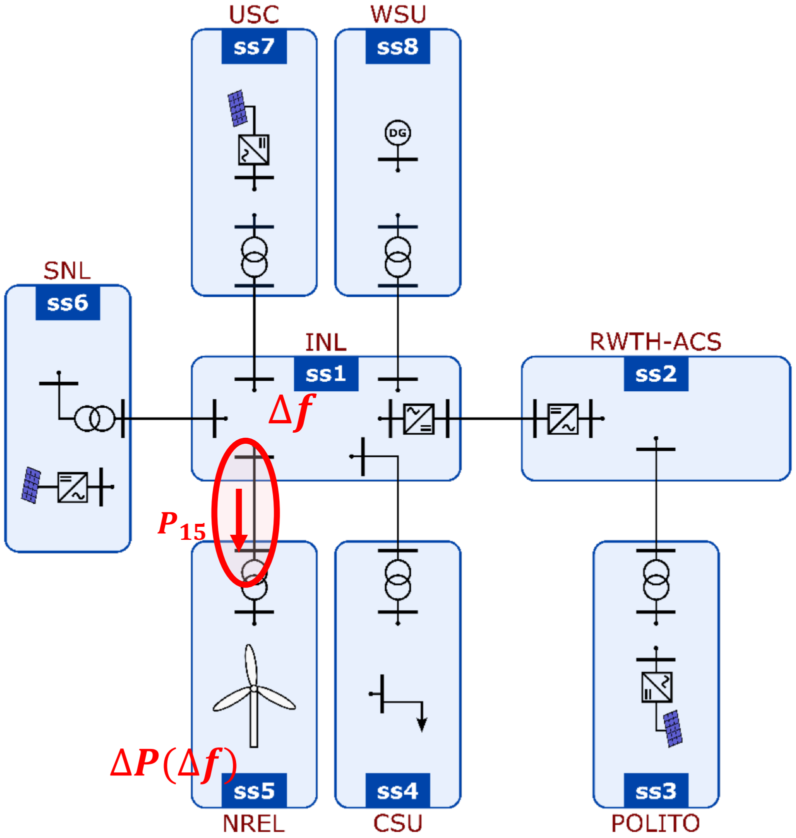
ss1-ss2 co-simulation interface (INL-RWTH)



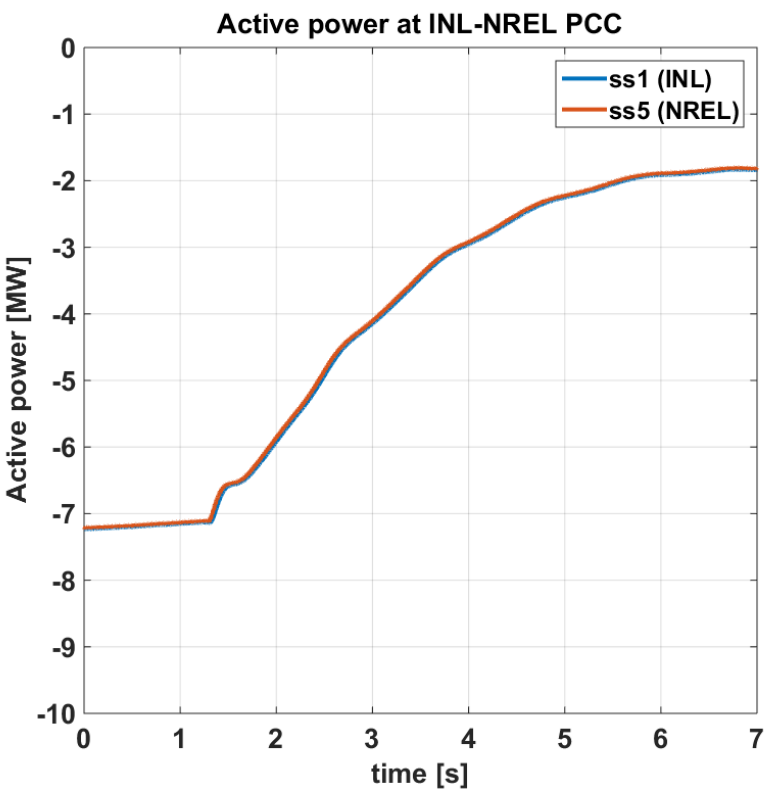


RT-Super Lab
Simulation results #3

- Frequency support from a wind turbine
  - Over frequency event on account of over-generation
- Wind turbines respond based on droop settings
  - Negative sign indicates import to INL from NREL

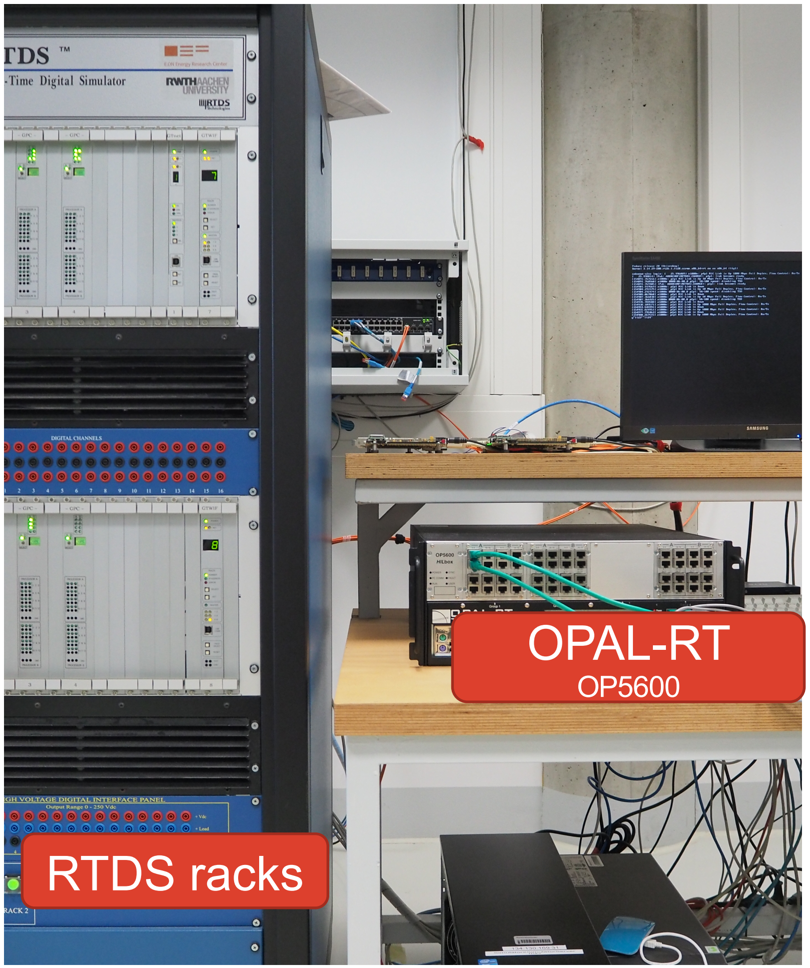


Simulation results at ss1-ss5



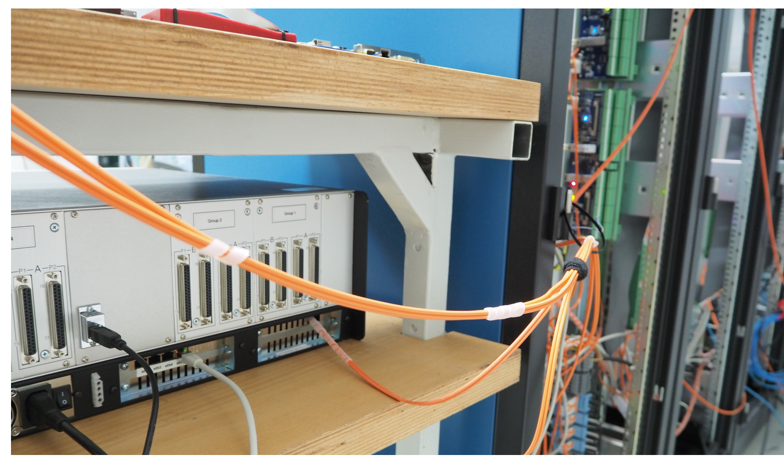
Local Power System co-simulation
Interconnection of RTDS and OPAL-RT at ACS lab

- Hard real-time communication
- Synchronized execution of simulation time steps



RTDS Rack next to OPAL-RT OP5600

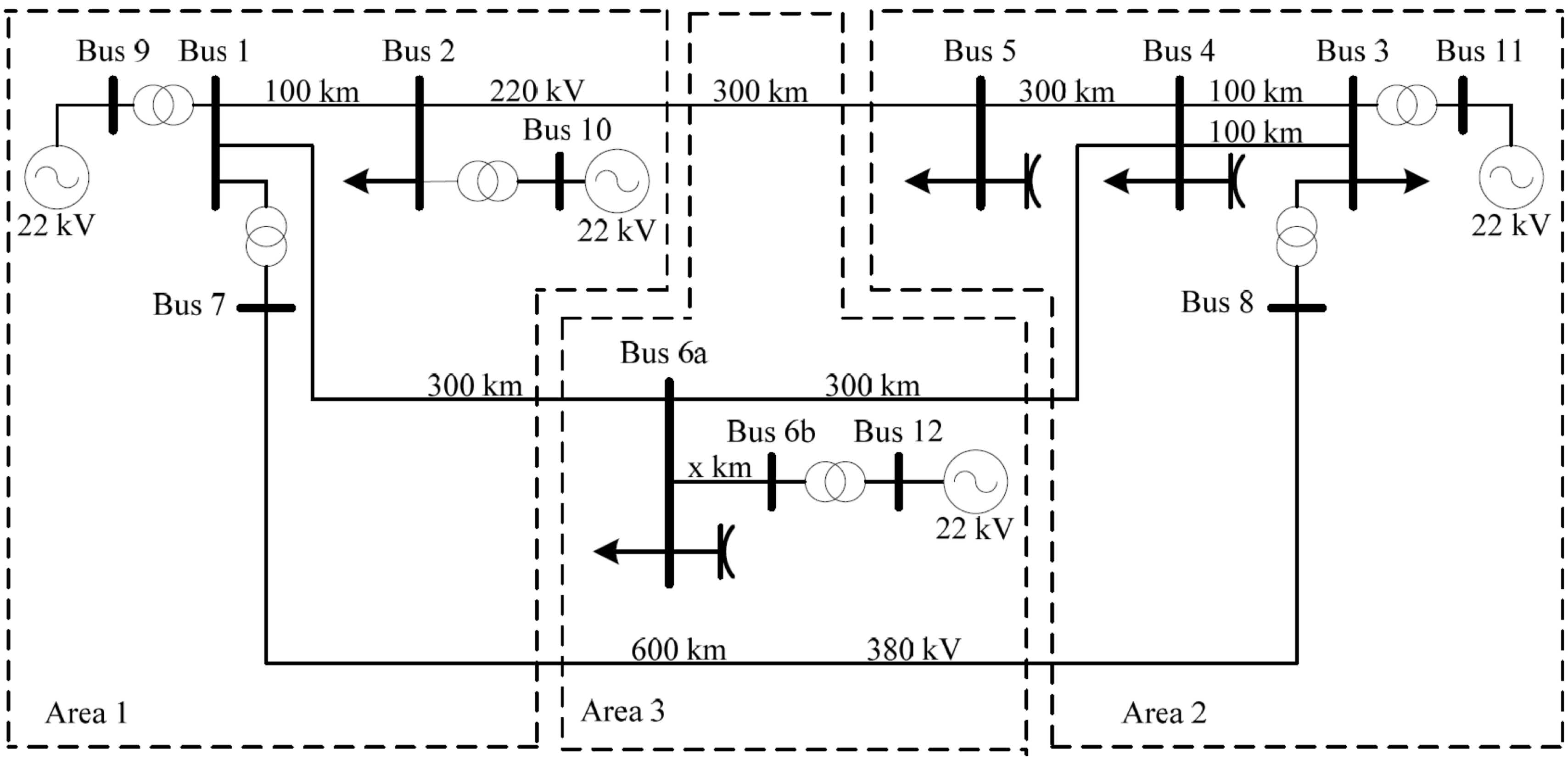
RTDS rear panel: GPC cards



OP5600 rear panel: internal fiber connection to ML605 SFP port

Transmission: Benchmark Network for DERs testing (by CIGRé)

- High Voltage Transmission Network Benchmark – European Configuration
  - 13 buses, 4 generators
  - 220 and 380 kV, 50 Hz
  - Simulated on RTDS



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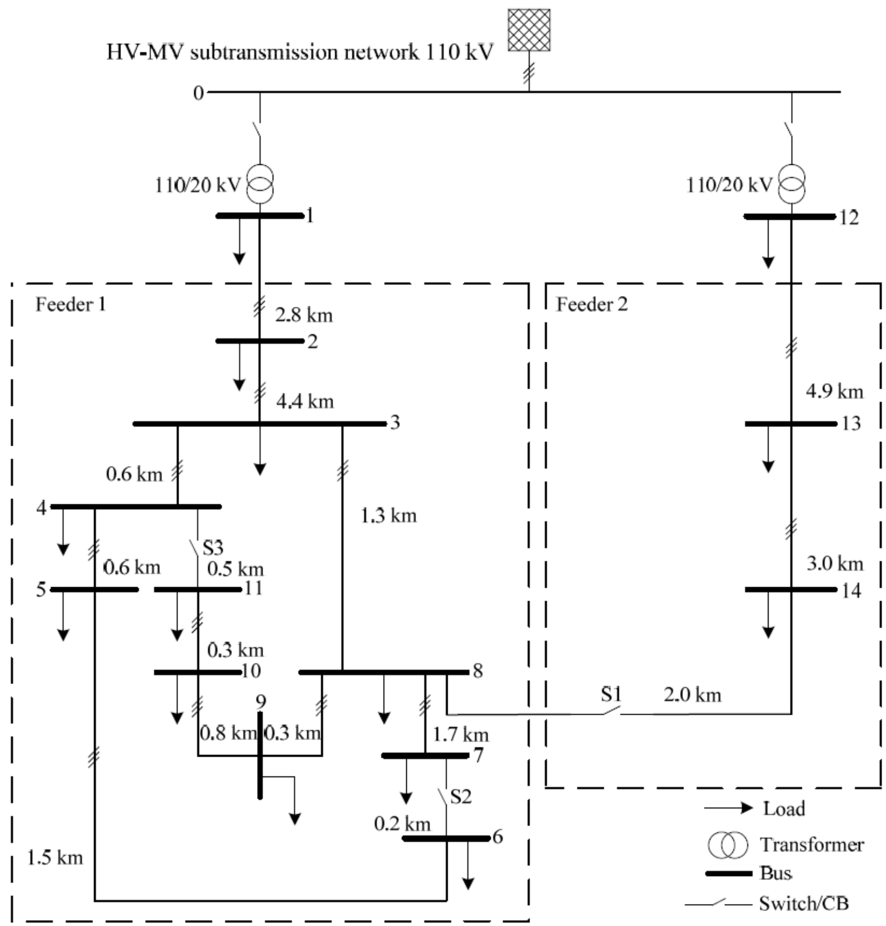
Models
Distribution: Benchmark Network for DERs testing (by CIGRé)

- Simulated on OPAL-RT
- Medium Voltage Distribution Network Benchmark – European Configuration
  - 14 buses
  - 2 feeders
  - 2 transformers
  - 46 MVA contractual load
  - Different PV penetration levels:
    - 6 %
    - 20 %



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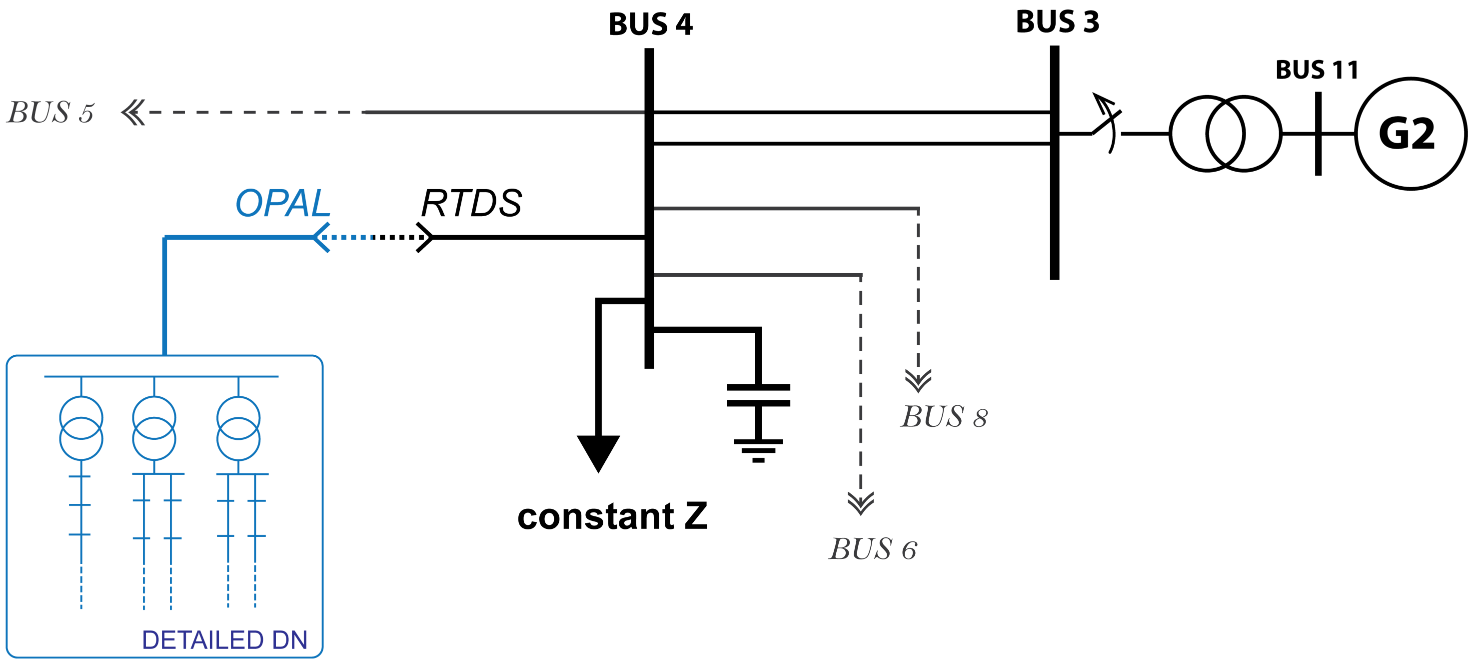
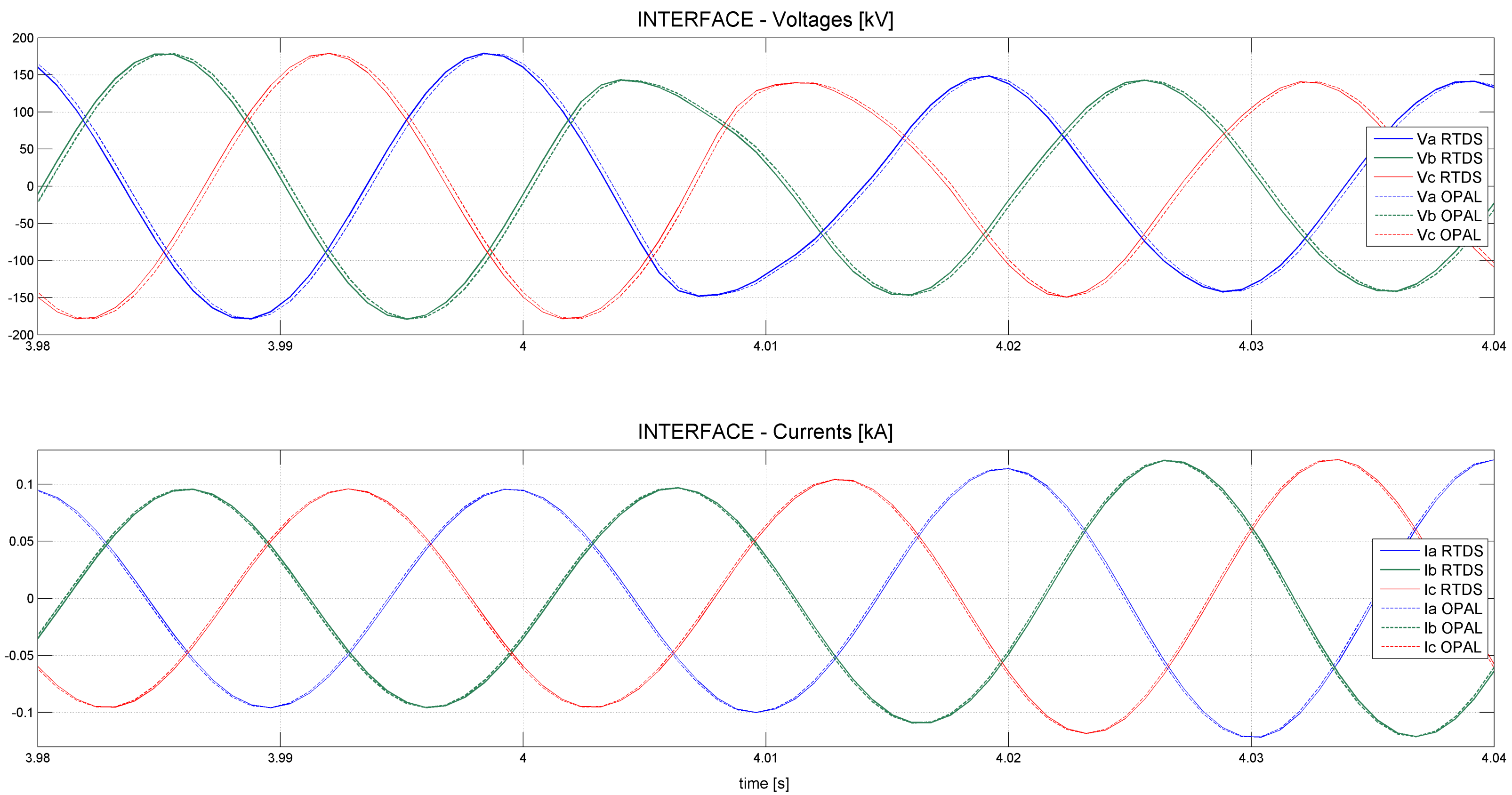
Simple Demonstration: Scenario

- The loss of generator 2 at bus 3 of TN causes a voltage drop in neighbouring buses and, consequently, the disconnection of PVs in DN (details represented) connected to bus 4.



TN & DN interactions
Simple Demonstration: Interface values



- Currents and voltages measured at the interface point on the two simulators.
  - Instantaneous voltages decrease after G2 disconnection
  - Interface accuracy is guaranteed also during transients

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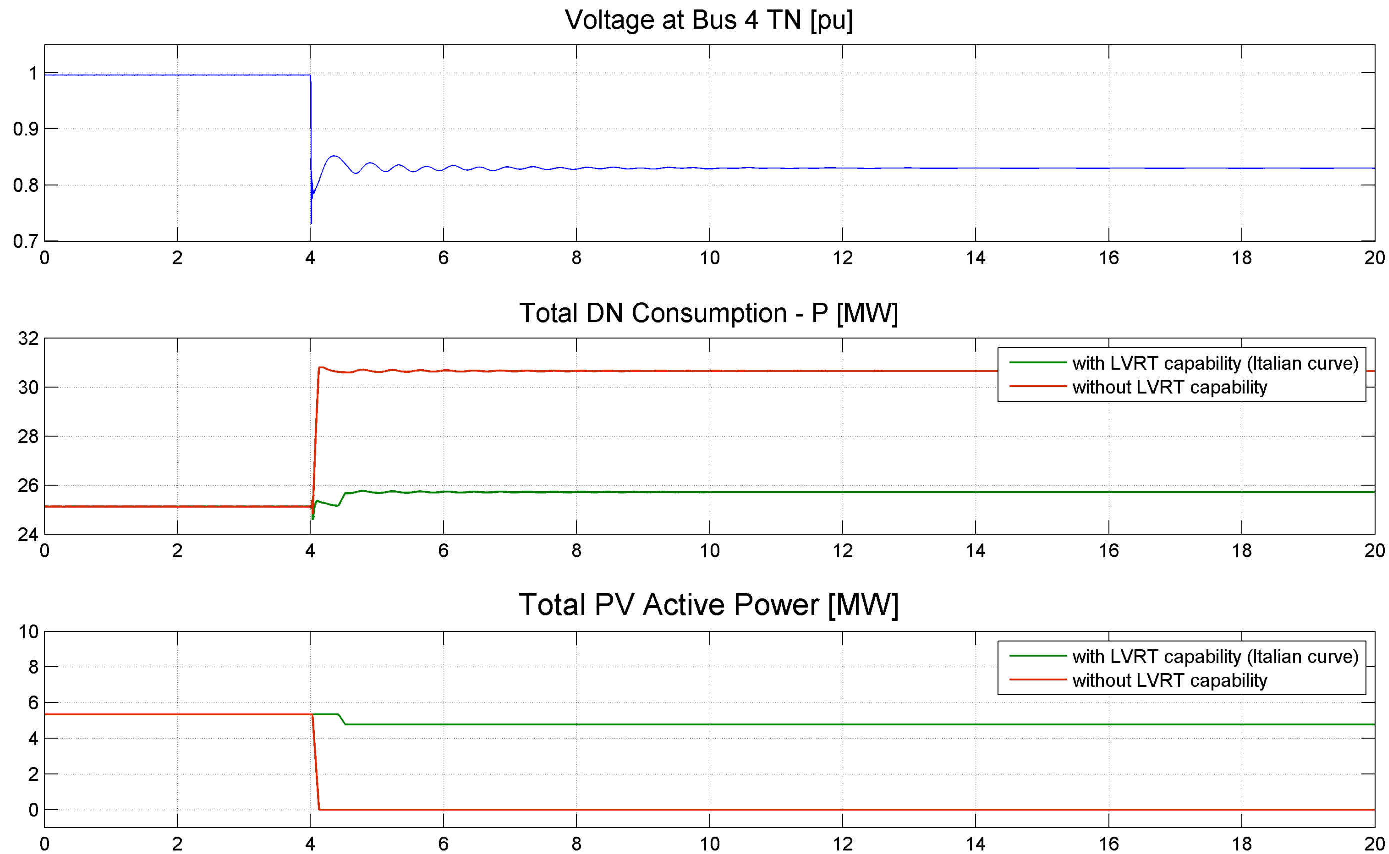
TN & DN interactions
Simple Demonstration: Results



- In this scenario, the Italian LVRT capability allows most of the PVs to stay connected in the detailed DN:
  - Using co-simulation, new LVRT curves and different placement for PV plants can be analysed with regard to the voltage security after an event in the transmission network.

Contact

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