Real-time Cyber-Physical Co-simulation of Power Grids

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Overview

- About OPAL-RT Technologies
- Real-time simulation (RTS) concepts
- OPAL-RT's RTS tools v.s. applications
- Some user stories:
  - ADMS testbed
  - Frequency-based load control
  - 108,000 T&D nodes
  - Cyber-physical co-simulation

About OPAL-RT Technologies

- Established in **1997**
- Headquarter is located in **Montréal, Canada**
- OPAL-RT offices in Michigan, Paris, Bangalore, Beijing and Sydney…
- Over **220 employees** worldwide
- More than **500 customers** worldwide

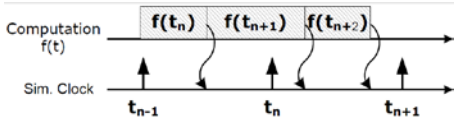
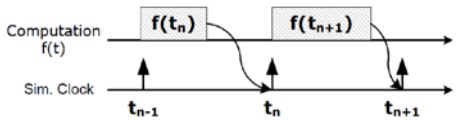
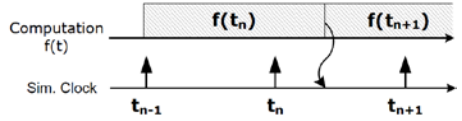
Real-time simulation and HIL/RCP for:

- ✓ **Power systems**
- ✓ **Power electronics**
- ✓ **Automotive**
- ✓ **Aerospace & Defense**

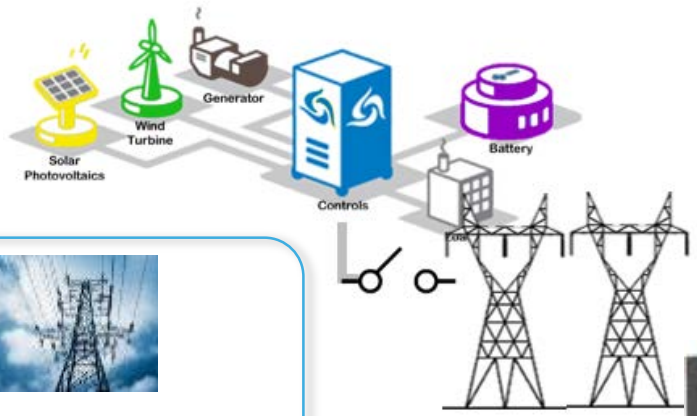
OPAL-RT TECHNOLOGIES

Main applications of OPAL-RT real-time simulators

Some definitions for real-time simulation technology

(*A*) Faster-than-Real-Time	(*B*) Real-Time	(*C*) Slower-than-Real-Time
		
Can be achieved with ***desktop/offline simulations*** (simpler models only)	Strictly requires an ***RTS***. Studies with or without HIL can be performed.	Usually the case of ***desktop/offline simulations***
Can be achieved with an ***RTS*** (***Accelerated*** mode, where model allows for clock acceleration)	Hardware-in-the-Loop (***HIL***) is the general term for test applications of an ***RTS***	Best achieved with an ***RTS*** with complex models (***Accelerated*** mode, where model is too complex for running in RT, but the RTS allows for faster simulation than desktop simulation)
	Controller HIL (***CHIL***)	
	Rapid Control Prototyping (***RCP***)	
	Power HIL (***PHIL***)	
← Software-in-the-Loop (***SIL***) →		

RTS for test & study of power grid's layers



RT simulation of equipment

Actuation

Physical Interactions

Power System

Sensors (CT/PT)

RT simulation of virtual protection and control

Trip & Control Commands

Protection & Control

Fast/local Interactions

Monitoring (MU, PMU, etc.)

Protocol data manipulation emulation of devices, WAMPACS, etc.

Data Transit

Comm. Network

Data Concentration

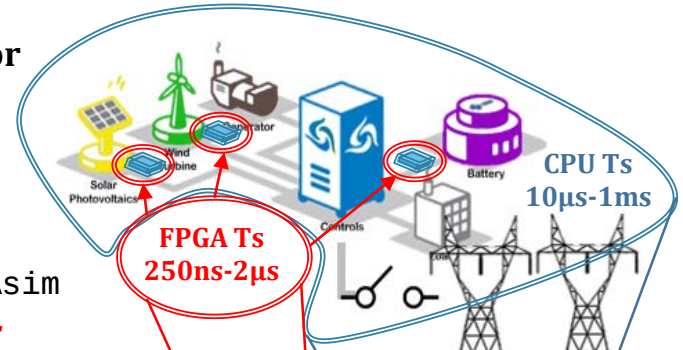
Comm. devices
WAMPACS
Control Center
Operator Training

HIL
AN and DI values

Comm. Protocols
- IEC61850 SV
- IEC61850 GOOSE
- DNP3
- MODBUS
- OPC-UA
- ...

OPAL-RT's real-time simulator architecture

Power Grid running on OPAL-RT simulator



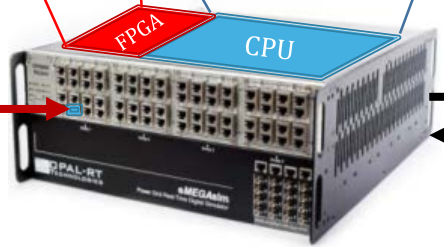
ePHASORsim
HYPERSIM
eMEGAsim

Phasor, Electromagnetic Transient (EMT) or Hybrid Phasor-EMT

eFPGAsim

Fast power electronics and electric machines

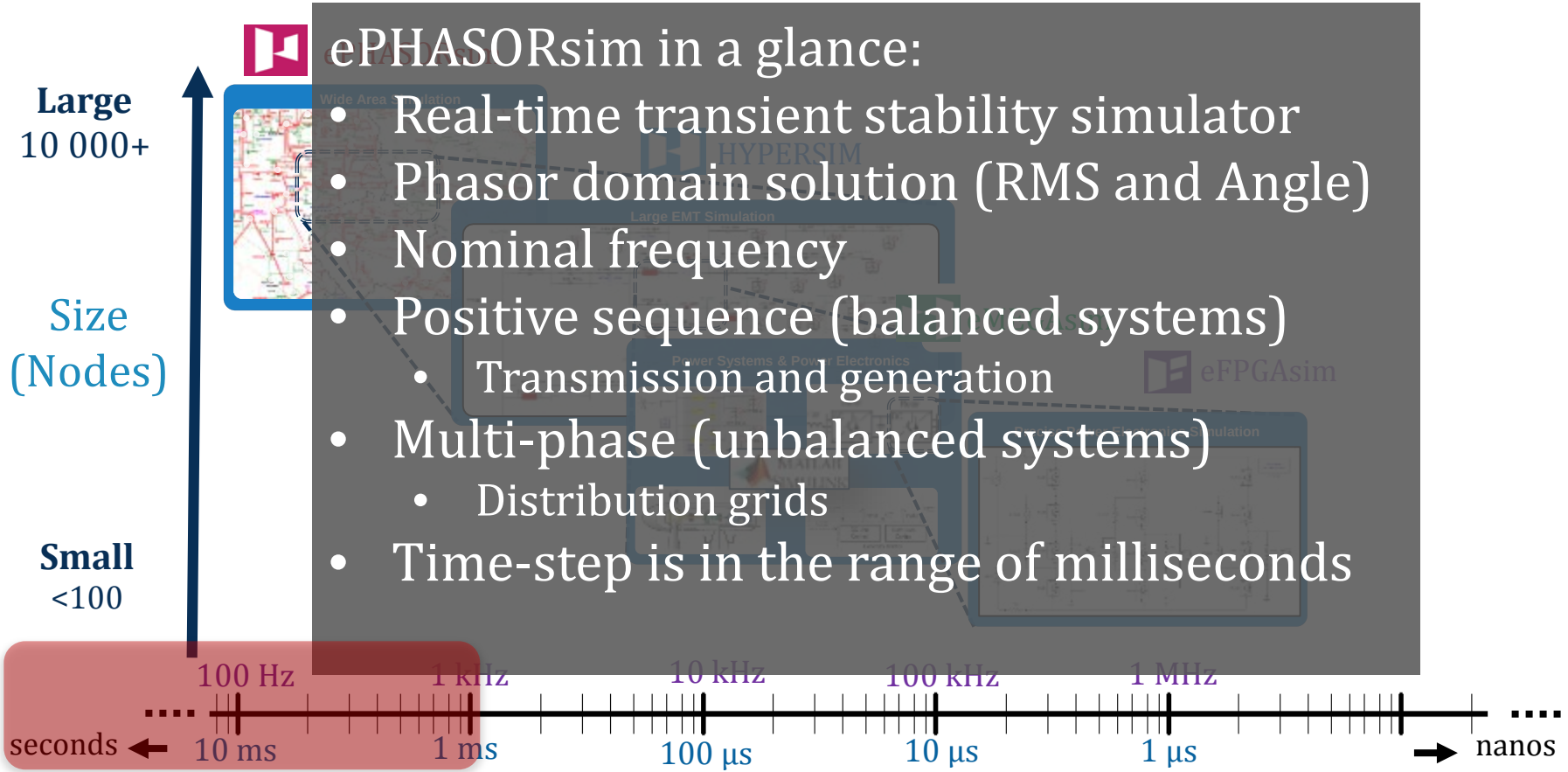
Power Electronics Controller



OPAL-RT RTS

Control and Protection Systems

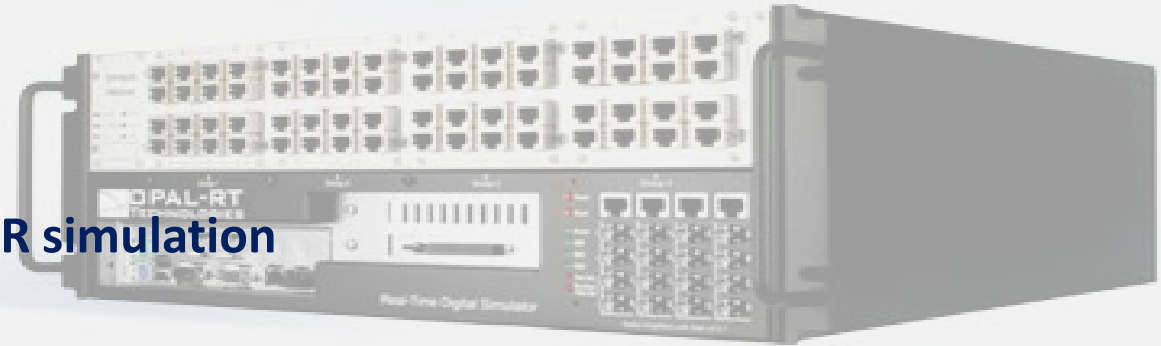
OPAL-RT's real-time simulation tools



- ✓ **Over 10k nodes on single core CPU**
- ✓ **[new] Over 108k T&D nodes on 9 cores**
- ✓ **Import data from other tools**
  - PSS/e (raw, dyr)
  - CYME (sxst)
  - [new] PowerFactory (dgs)
- ✓ **Integrate with various protocols**
  - C37, DNP, MODBUS, etc.

- ✓ **Python API package for test automation**
- ✓ **User defined models**
  - Simulink, Modelica
- ✓ **Multi-threaded solver**
- ✓ **Feasibility of EMT-PHASOR simulation**

…



Trending topics in the domain

Grid Models for Future

- Developing power grids to anticipate future scenarios
- Model future power systems in country or even continent size
- Large grids of the future at several resolution levels for evaluation of new technologies

High Performance Analysis and Large Data

- Synthesizing large-scale data to examine the efficiency of computations
- Improving the performance of power system analysis
- Open source data and repositories for different types of analysis

Demands for Advanced Simulation

- Hybrid transmission and distribution simulation
- PMU-based applications and tools
- Design and test tools for wide area monitoring, control and protection
- ...

Some Ongoing User Stories…

Project Title: ADMS Testbed

Project Lead: NREL

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

- **Project Objective:**
  - Establish a national, vendor-neutral Advanced Distribution Management System (ADMS) testbed to accelerate industry development and adoption of ADMS capabilities for the next decade and beyond

- **Simulation Challenges:**
  - Simulation of large scale distribution systems for evaluating ADMS applications
  - Integrating distribution system hardware in NREL ESIF for power hardware-in-the-loop (PHIL) experimentation

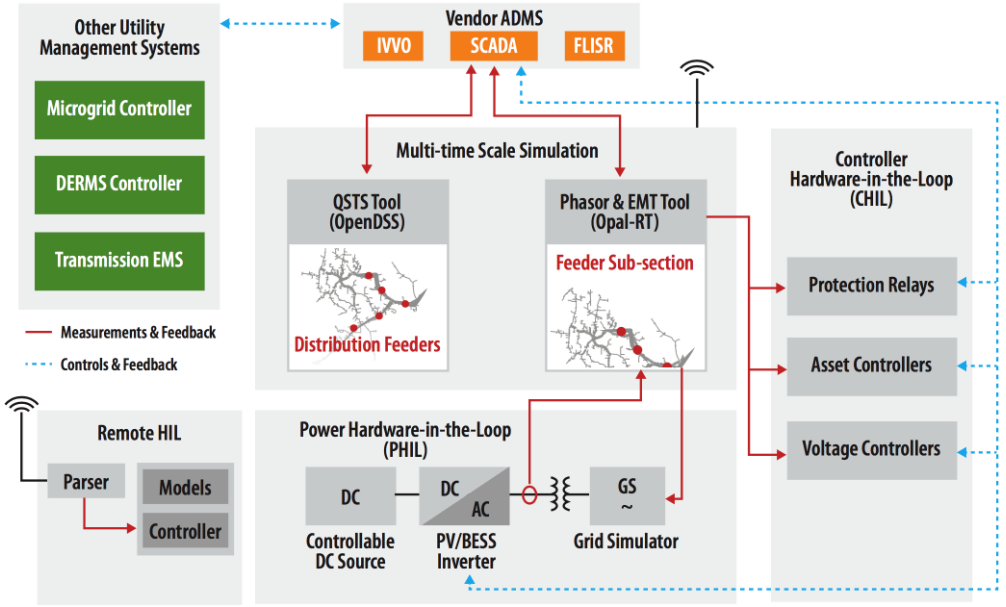


Figure source: NREL (from 2018 ISGT presentation)

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Project Title: A Novel Hierarchical Frequency-Based Load Control Architecture

Project Lead: Northwestern University

Northwestern University

- **Project Objective:**
  - To develop and validate a new, hierarchically coordinated, frequency-based load control architecture that provides a reliable complement to generator inertia and governor response so as to enable a high penetration of renewable generation

- **Simulation Challenges:**
  - Real-time simulation of large-scale transmission, distribution and controllable loads in phasor-domain
  - Different data formats for T and D grids (PSS/e and CYME)
  - HIL validation of new control algorithms using real-time models connected to a large number of controllable devices

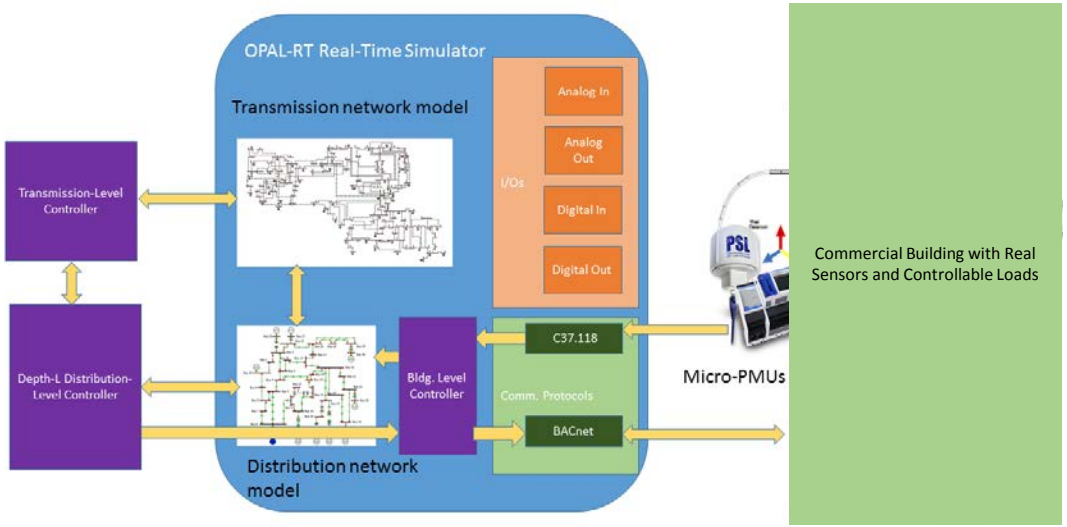

Figure source: Northwestern University (from 2018 ARPA-E NODES Annual Review presentation)

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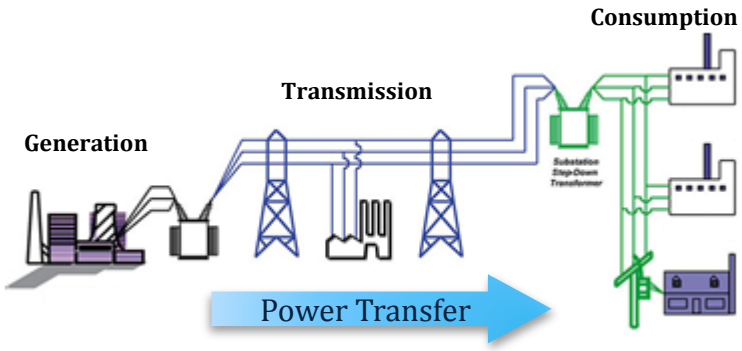
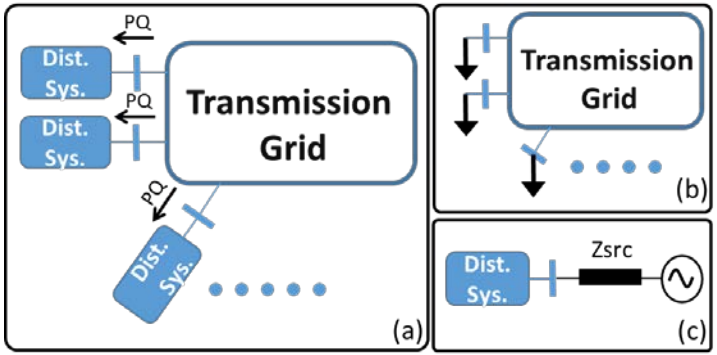
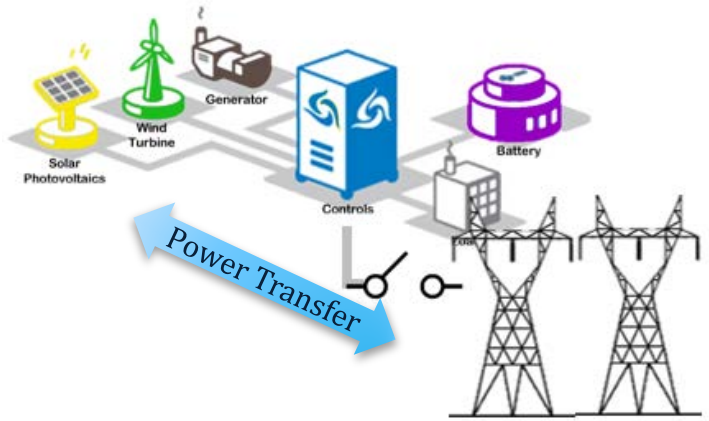
Real-time simulation of over 108k T&D nodes

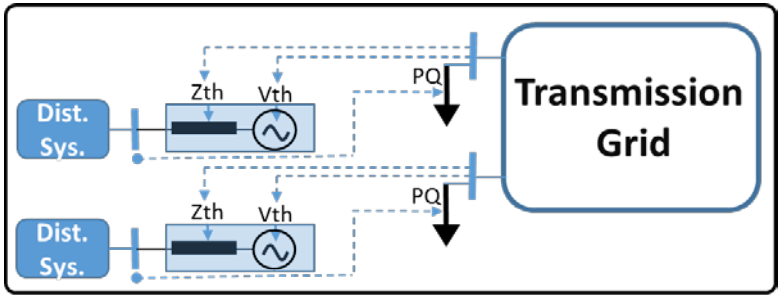
Conventional T&D Grids



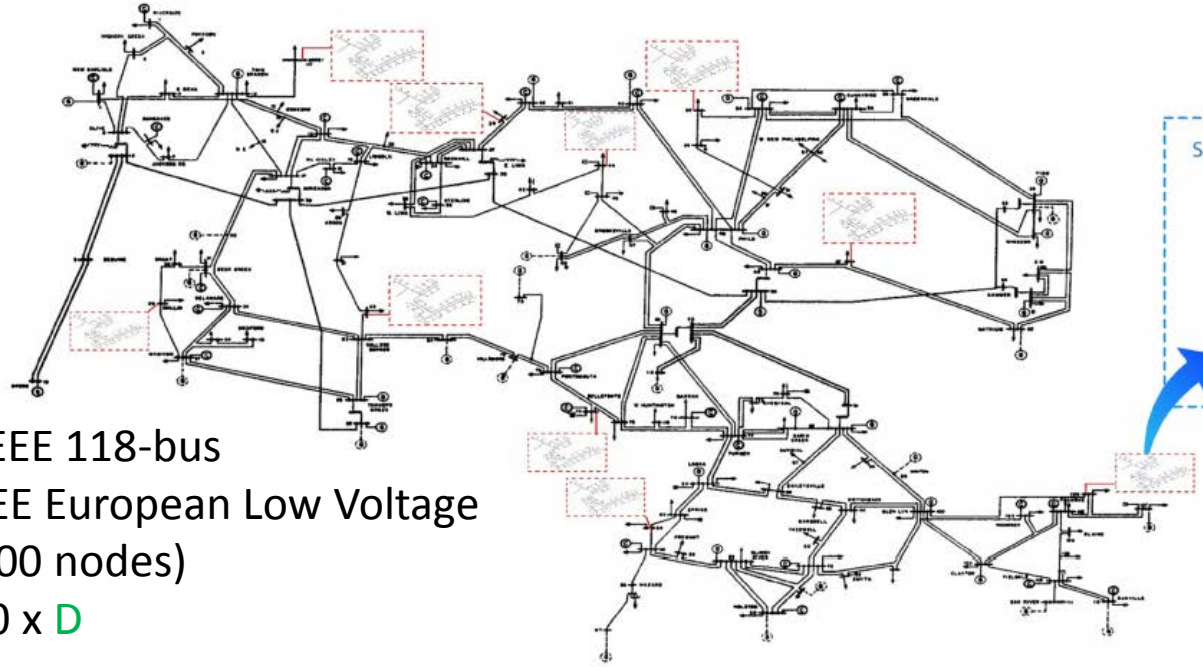


Modern T&D Grids



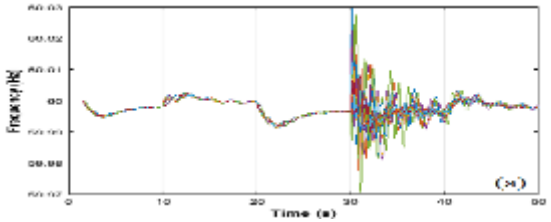


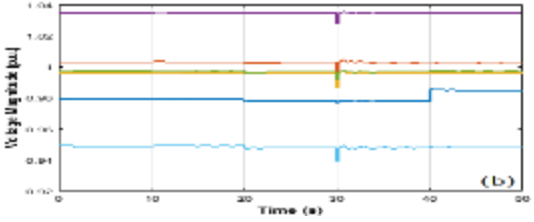
Real-time simulation of over 108k T&D nodes

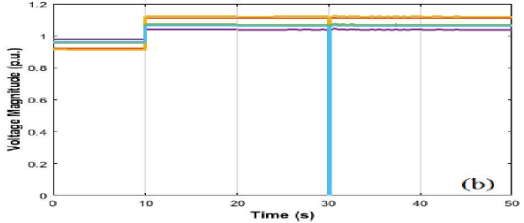


Synthesized Grid:

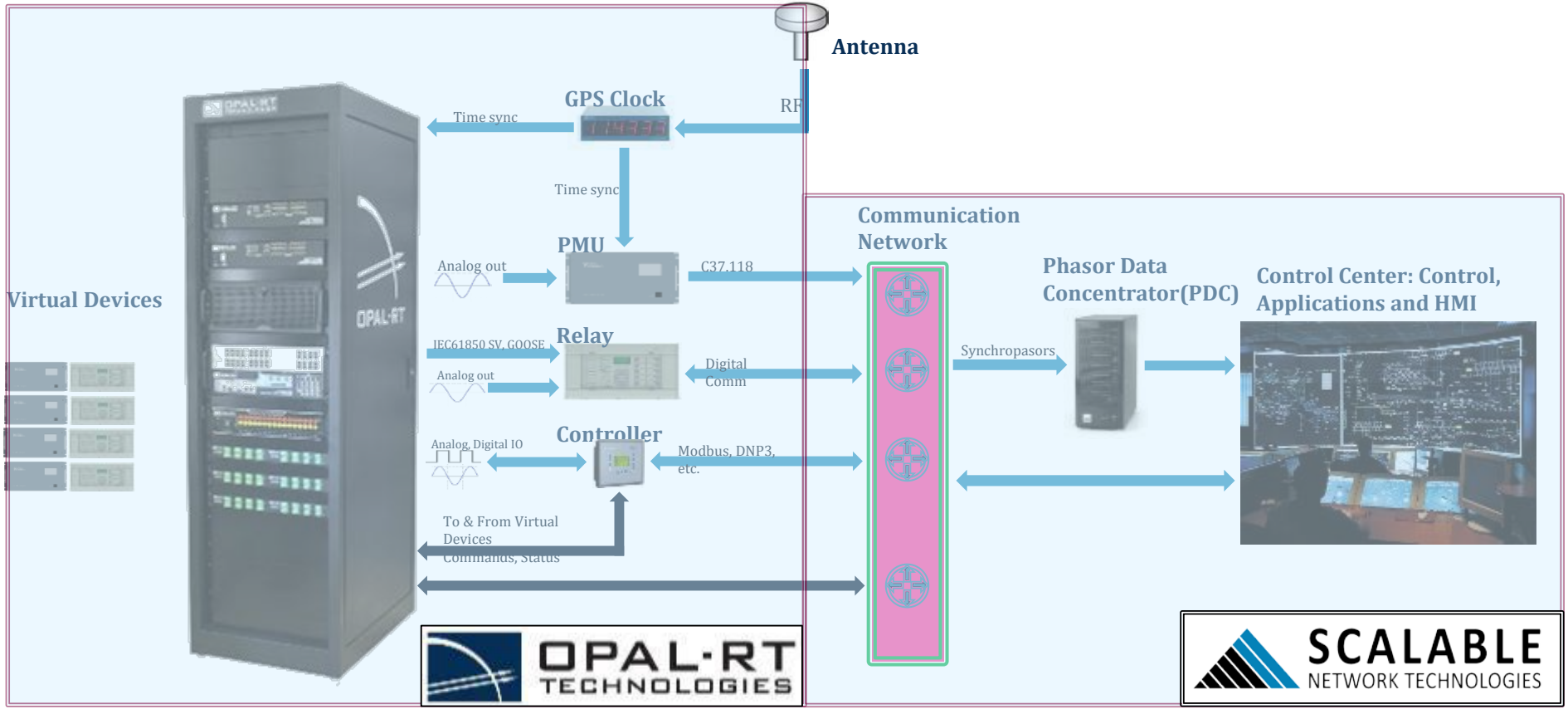
- Transmission: IEEE 118-bus
- Distribution: IEEE European Low Voltage Test Feeder (2700 nodes)
- Grid = 1 x T + 40 x D







Cyber-Physical Co-Simulation: OPAL-RT + SCALABEL



Recorded demo…

1. ePHASORsim is simulating the power system and it streams bus voltage measurements in C37.118 format
2. A repeated fault happens every 1 second and it is cleared after 80ms
3. The monitoring screen can capture the streams
4. A DoS attack is lunched though SCALABLE network emulator to disrupt the communication
5. This cause mentoring application cannot see anymore the impact of repeated fault because the data is dropped

Thank You…

Question?