An open framework for real-time distributed real time simulation: tools and applications

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Panel: Dynamic Long-distance Coupling of Smart Grid Research Infrastructure, Models, and Laboratories for Distributed Real-time Assessment of Cyber-physical Energy Systems
Main Problem: Real-time simulation capacity

The Romanian transmission system alone has already more than **1500 network nodes**

One RTDS PB5 can handle ~30 3-phase network nodes. One rack can take 2 PB5 and RWTH has 8 racks → **480 nodes in total**
Our Solution: Pan-European Real-Time Simulation

- **Distributed co-simulation** to couple real-time simulators and share simulation capacity and hardware
- Distributed simulation allows participants to keep their **data confidential**
- Still **real-time** to interface with real hardware for prototyping

→ cause for new a problem
Pan-European Real-Time Simulation challenges & requirements

- **Latency** between simulators and simulation sites caused by distance between labs
- Different simulators generate different results and there is no reference implementation
- Compatibility with existing grid descriptions (CIM) → new simulator called **DPsim** as part of simulation platform

Latency between simulators interconnected through the web:

- Several ms

Different simulation results of a Dual Active Bridge (DAB): PLECS & RTDS

- Time in ms
- $i_{DC}$ in A

**Simulation** Web **Simulation**
A Meta-Simulator

• Ingredients for a global virtual testbed
  – A common model format
    for exchanging and retargeting models
  – Flexible interfaces
    for interconnecting a heterogeneous set of simulators and devices
  – A common user interface
    for collaborative editing, control and monitoring
  – Open solvers
    for verifiable and scalable simulations
RESERVE
Pan-European Laboratory Infrastructure

Pan-European Real-Time Simulation Infrastructure as part of project RESERVE (EU Horizon 2020)

Scenario from RESERVE project: Black line: Connection between Ireland and Germany as use case in this study, composed of 15 hops
Round-trip Time and Packet Rate

- RTT measurements between laboratories in Ireland and Germany
- Average RTT is 47.7 ms
- Latency is mainly caused by geographical distance!

Latency is mainly determined by the geographical distance

- Verify quality of connection:
  - RTT also depends on packet rate for exchanging simulation samples
  - Keep below congestion threshold to avoid packet loss

<table>
<thead>
<tr>
<th>Hop</th>
<th>Latency [ms]</th>
<th>Air line distance [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Modelled</td>
<td>Avg</td>
</tr>
<tr>
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<tr>
<td>15</td>
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</tbody>
</table>

RTT over communication hops

Cumulative probability of RTT

Rate (p/s)
- 100
- 1000
- 10000
- 15000
- 2500
- 4000
- 5000
- 7500
VILLASframework

Open source tool kit for distributed real-time simulation (GPLv3 license)

VILLASnode
- A gateway for real-time simulation data

VILLASweb
- A web-interface for planning, executing and controlling distributed simulations

DPsim
- A real-time simulation kernel for the EMT / DP domain

CIM++
- A library for parsing and compiling CIM to Modelica, GLM

Pintura
- Web-based Graphical Editor for CIM models
VILLAS Architecture

Workstation #1..n
- VILLAS web (frontend)
- Pintura (CIM editor)
- Web Browser

HTTP/Rest API
WebSockets

Public Server
- NGINX Web/Proxy Server
- Influxdb Database
- MongoDB (database)
- RabbitMQ Message Broker

VILLAS node (central)

Remote Lab #1..n
- Simulator
- API

Center for Wind Power Drives

ACS Lab
- Simulator
- RTDS Simulators

PGS High-Speed Test Bench

EtherCAT
Fiber

VILLAS fpga

CIM: Common Information Model
HTTP: Hypertext Transfer Protocol
API: Application Programming Interface
IP: Internet Protocol
ACS: Institute for Automation of Complex Power Systems
PGS: Institute for Power Generation and Storage Systems
VILLASnode Gateway

Hard- and soft real-time interfaces for Lab interconnections and HIL
VILLASweb Interface

Screenshot of VILLASweb user interface
Pintura Editor

A Web-based editor for CIM models

– Modern Web technologies:
  HTML5, SVG, XML/XSTL, JavaScript

Screenshot of Pintura Editor
CIM++ Deserialzer

- Automated generated open-source CIM Deserializer library for C++
- Very easy to use with original and extended IEC61970/68 versions
- Used by several projects: DPsim, CIM2GLM, CIM2Mod:
- Automated resolving of cyclic class dependencies
- Automated serialization code generation
CIM2Mod

Visual UML Editor

CIM UML Ontology

CIM C++ Codebase

CIM++ Code Toolchain

Adapted CIM C++ Codebase

CIM++ Unmarshalling Generator

CIM RDF/XML Topology Document(s)

CIM++ Deserializer

CIM2Mod

Template Engine

Modelica User

Modelica Libraries

Modelica Templates

Modelica Workshop

System Model
DPsim: Simulator for Distributed RT-Simulation

- Distributed simulation via integration with VILLASnode
- Latency
  - Dynamic Phasor & EMT solver for real-time
  - Simulate only envelope function and reduce required sampling rate
- Open source to serve as reference implementation
- Input directly from utilities via Common Information Model (CIM)
DPsim: Workflow

• Create grid model in Pintura or any other tool that supports the Common Information Model (CIM)

• Load data directly from the CIM file

• Use VILLASnode to interface the simulation to many other products

• Dedicated Python packages allow the control of simulations and post processing of simulation data
DPsim: Complex Models – Synchronous Generator

- Implementation of
  - Classic DQ and
  - Voltage-Behind-Reactance (VBR)

  synchronous generator models in Dynamic Phasors

- Coherent with Simulink and PLECS simulations

DQ and VBR synchronous generator models compared to Simulink for load change
Together, these tools provide essential components of a traditional real-time simulator.
Global Real-Time SuperLab
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.
### Global Real-Time SuperLab: Participants

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

- 8 Labs
  - 5 OPAL-RT
  - 4 RTDS
  - 1 Typhoon
- 2 TN
- 6 DN
- 1 HVDC link
- CHIL at USC
- 2 PHIL
  - NREL
  - SNL
GRTS Results #1: INL-USC

- Dynamic load/PV-profile in IEEE 123-bus distribution system (USC)

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

PV inverters are controlled to minimize reactive power at the main substation of IEEE 123-bus system
GRTS Results #2: INL-RWTH

• Reference for converter control of power in the HVDC link is decreased by 25 MW
GRTS Results #3: INL-NREL

- Wind turbines at NREL respond to over-frequency transient based on droop settings.

Simulation results at ss1-ss5

Active power at INL-NREL PCC

\[ \Delta P(\Delta f) \]

\[ P_{15} \]

\[ \Delta f \]

\[ \Delta f \]
Thank you for your attention

Most software tools are open-source and open for contributions:

https://www.fein-aachen.org/projects

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