OPAL-RT
REAL-TIME SIMULATORS

Enhancing Grid Stability Through OPAL-RT Real-Time Solutions

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OPAL-RT TECHNOLOGIES

AGENDA

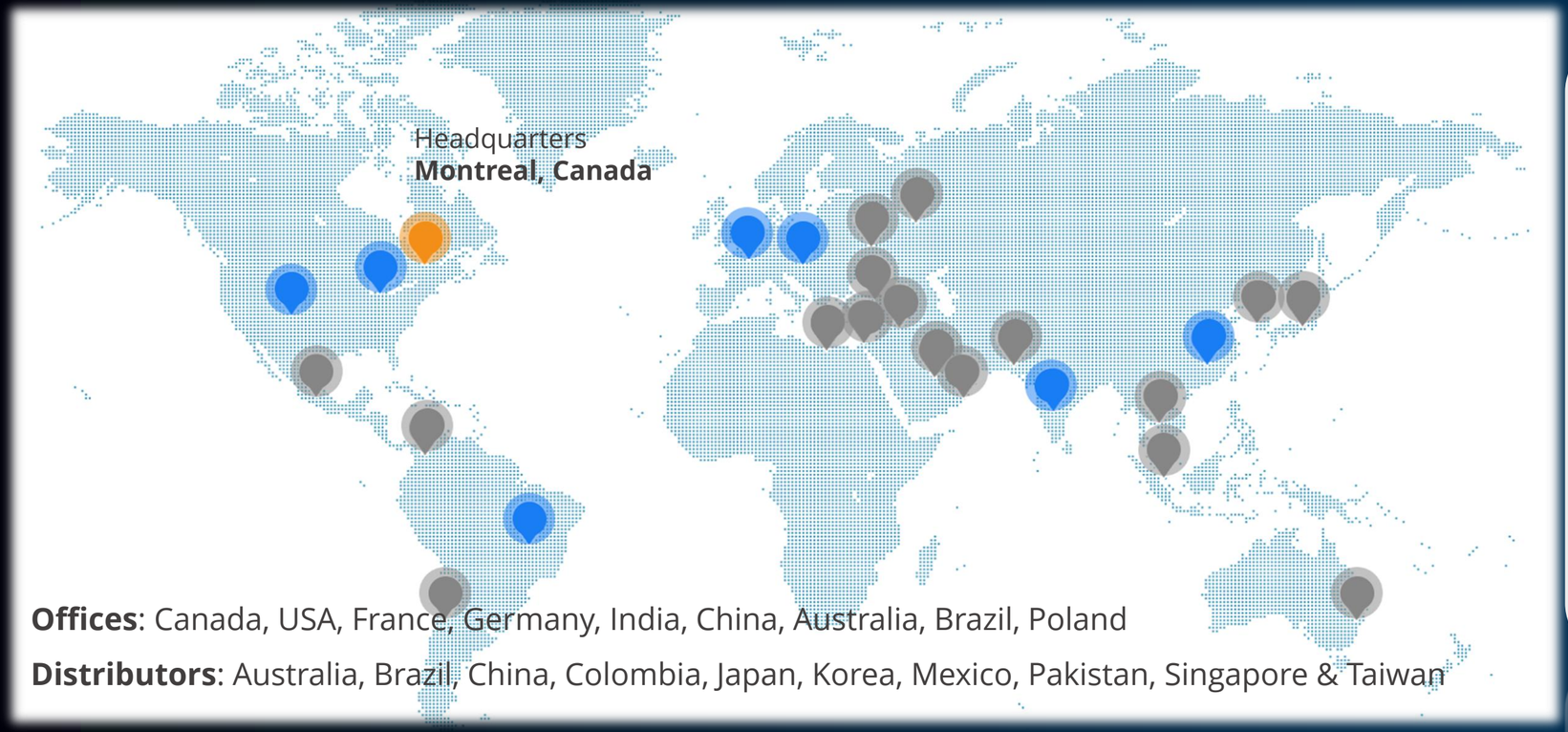
1. OPAL-RT TECHNOLOGIES
2. GRID EVOLUTION & CHALLENGES
3. APPLICATIONS
4. OPAL-RT SOLUTIONS

OPAL-RT TECHNOLOGIES

- OPAL-RT provides with high-end **real-time digital simulators**, scaling from compact portable devices to large integrated HIL test benches
- OPAL-RT systems are deployed for design, **validation and optimization of complex control, protections, PMU and SCADA systems**
- Used by our customers for **Control Prototyping, Hardware in-the-loop** and **Power HIL**
- Based on state-of-the-art technologies, OPAL-RT systems are **powerful**, **flexible** and **scalable**

OPAL-RT TECHNOLOGIES

OPAL-RT is **a software and hardware** company that believes in **empowering engineers and researchers** with accessible, cutting-edge, real-time simulation technology in order to accelerate the availability of greater products and more reliable energy generation, transmission and distribution.



Offices: Canada, USA, France, Germany, India, China, Australia, Brazil, Poland

Distributors: Australia, Brazil, China, Colombia, Japan, Korea, Mexico, Pakistan, Singapore & Taiwan

- **27 years** of innovation (1997)
- **425 employees**
- **400% growth** in 10 years
- **75% of orders** stemmed from **clean tech**
- **20% of profit reinvested in R&D** each year

MARKET SEGMENTS

OUR **EXPERTISE** DRIVES **INNOVATION**

CUSTOMERS

- Power Systems TSO/DSO (grids)
- Power electronics manufacturers (converters)
- Car makers & OEM
- Aerospace makers & OEM
- Universities & academic R&D

OPAL-RT TECHNOLOGIES

SOME CUSTOMERS

EVOLUTION OF THE GRID: INCREASINGLY DYNAMIC AND COMPLEX

Relative Complexity

1 s

10 ms

50 µs

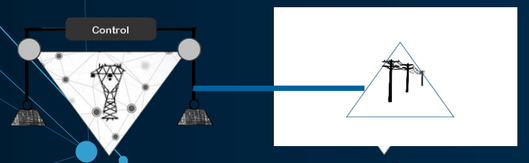
5 µs

Pre-1970s

Transmission Distribution

- High Inertia – slow reaction
- Passive Distribution
- Unidirectional distribution
- Schedulable generation
- Local, slow protection

Through early 21st Century



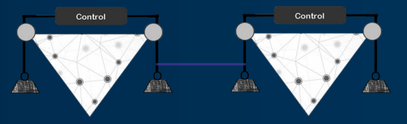
Transmission Distribution

- High Inertia – slow reaction
- Passive Distribution
- Unidirectional distribution
- Schedulable generation
- **Fast control and protection**
  Machine V Regulators
  HVDC, FACTS,
  Control & protection

- **Wide-Area Control & Protection**

- **Communication Systems**

Now



Transmission Distribution

- Low inertia – fast reaction
- **Active Distribution**
  - **Bi-directional distribution**
  - **Un-schedulable generation**

- Stability relies on interaction between:
  Fast Protection Systems
  Power Electronic Controllers
  HVDC, FACTS. SVC

- **More Wide Area Control & Comms**

- **Large numbers of power-electronics based Distributed Energy Resources (DERs)**

- **High dependence on communication systems**.

- **DC and AC/DC hybrid grids**

KEY ASPECTS OF GRID EVOLUTION

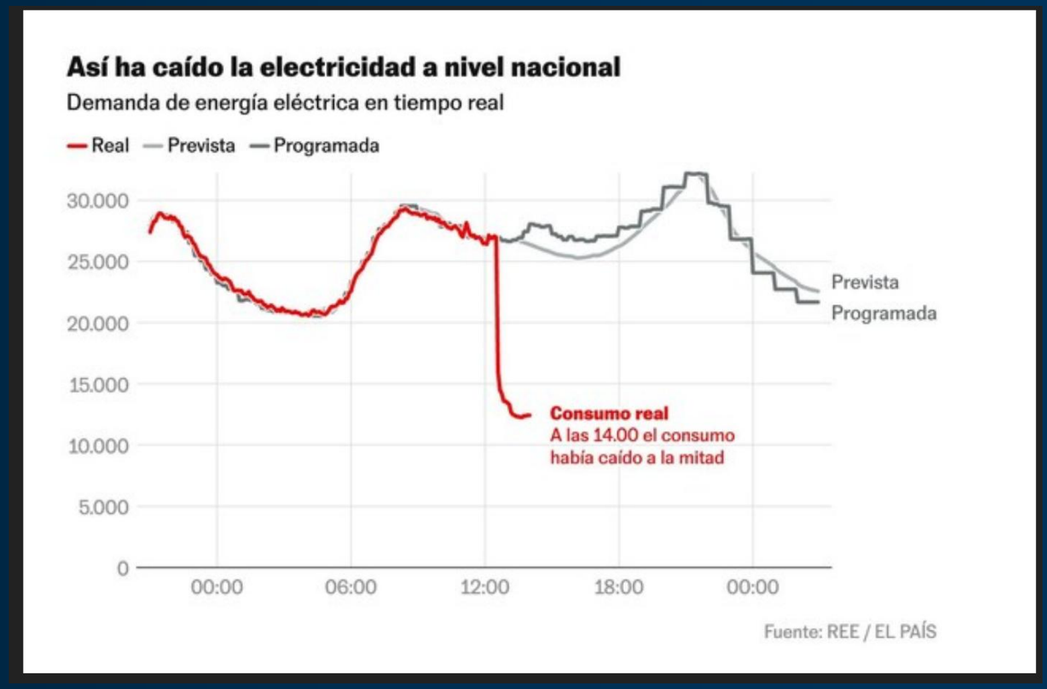
- Complex, multi-level, multi-time scale distributed control
- Communication and coordination
- Cybersecurity

OPAL-RT TECHNOLOGIES

SPAIN/PORTUGAL APRIL 2025

April 28, 2025, Spain and Portugal experienced a **major power outage**

At **12:33 PM**, a rapid loss of **2,200 MW** of electricity generation occurred in southern Spain. This sudden drop in grid frequency activated automatic load-shedding mechanisms. Shortly afterward, interconnections with France were shut down to prevent the imbalance from spreading, leading to the collapse of the Iberian electrical system (fr.wikipedia.org).



- **Role of Renewables and Grid Inertia**

60% of Spain's electricity came from renewable sources, mainly solar. (low **Mechanical inertia)**, making them less capable of stabilizing the grid during disturbances (fr.wikipedia.org)

- **Weak Interconnection with the Rest of Europe**

Spain’s interconnection capacity with the European grid is only **3% of its installed capacity**, far below the **15% target** set by the EU. This limitation reduced the country’s ability to import electricity to compensate for the sudden loss in generation (wired.com).

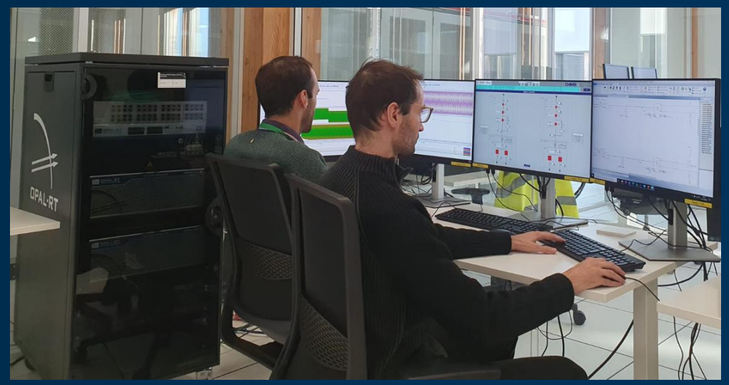
- **Interregional Oscillations and Desynchronization**

Frequency oscillations were detected between the Iberian grid and the rest of Europe **in the 30 minutes prior to the outage**. These fluctuations contributed to the **desynchronization** of the grid, worsening system instability (en.wikipedia.org).

In summary, the blackout was caused by a combination of factors: a sudden loss of generation, low grid inertia due to high renewable penetration, weak interconnections with the rest of Europe, and frequency oscillations.

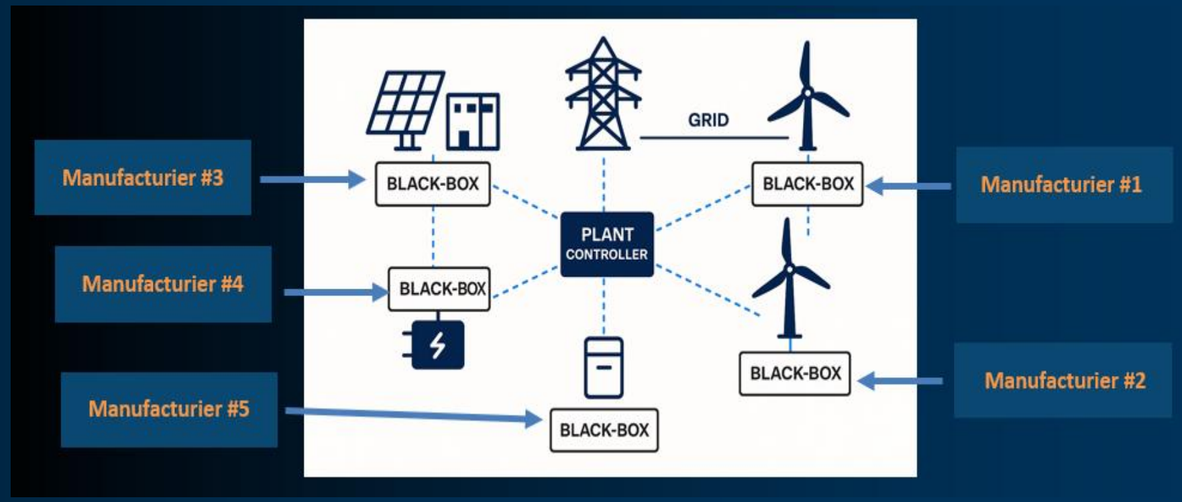
OPAL-RT TECHNOLOGIES

SOFTWARE-IN-THE-LOOP (SiL) TESTING



- Accurate interaction studies can only be performed with the actual control implemented by OEMs which contain sensitive IP

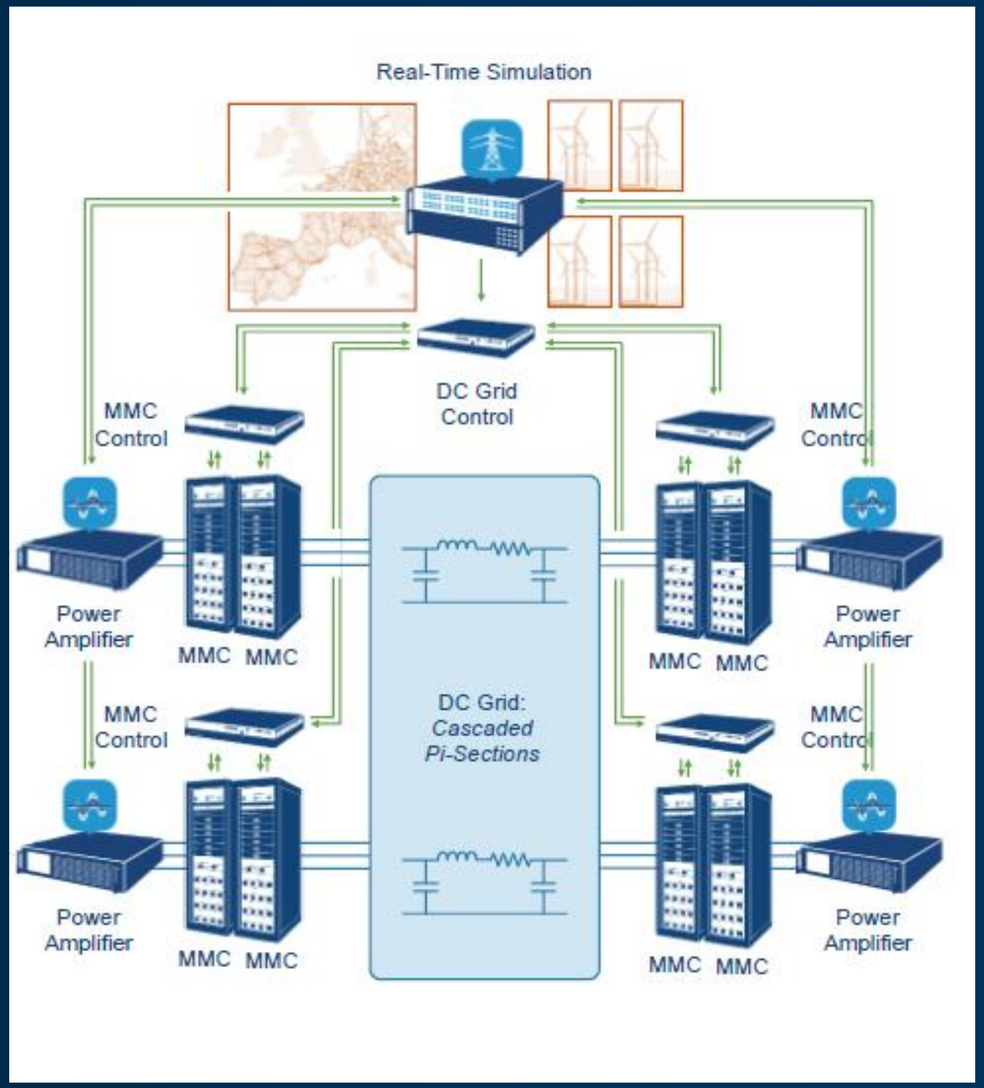
- TSOs are pushing towards interoperability, running compiled, black-boxed control code on real-time simulation platforms is a viable approach



OPAL-RT TECHNOLOGIES

PHYSICAL CONVERTER TESTING

- Grid-code testing of converters is needed, PHiL is moving from an academic subject to industrial testing
- Emerging test requirements for DC grids (protection, breakers …)
- Increasing number of power amplifiers that address different testing needs
- Low-latency, flexible interfaces to simulators are needed



OPAL-RT TECHNOLOGIES

CYBERSECURITY

- Cybersecurity of power grids is a topic of high importance in today's techno-political environment

- OPAL-RT's integration with EXata provides a very capable platform for analyzing, identifying and validating countermeasures against cyberattacks, but in its current form is not structured in a way to make its use clear and effective

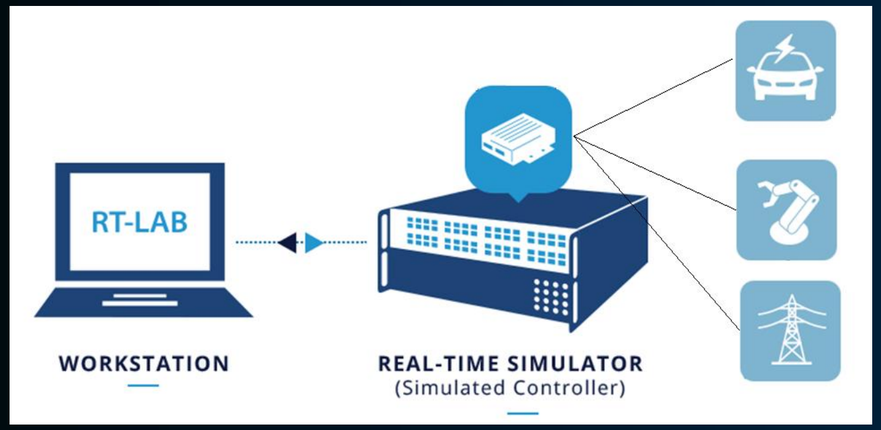
OPAL-RT TECHNOLOGIES

AGENDA

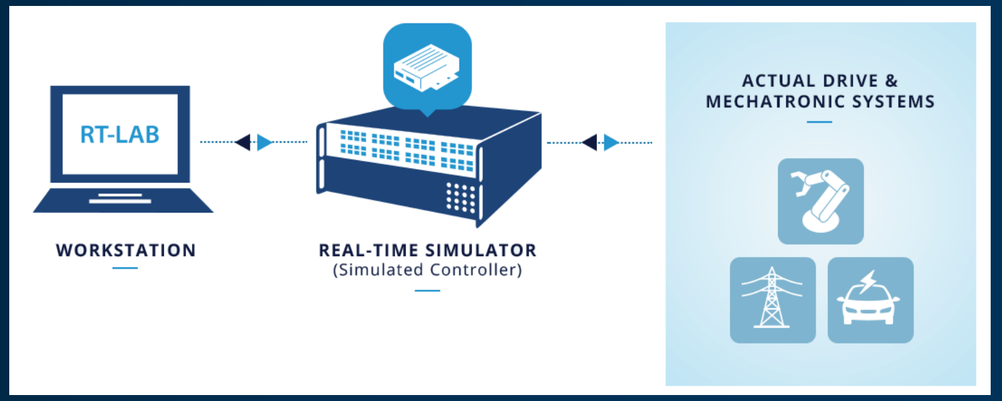
1. OPAL-RT TECHNOLOGIES
2. EVOLUTION OF GRID & CHALLENGES
3. **APPLICATIONS**
4. HARDWARE & SOFTWARE ARCHITECTURES

APPLICATIONS

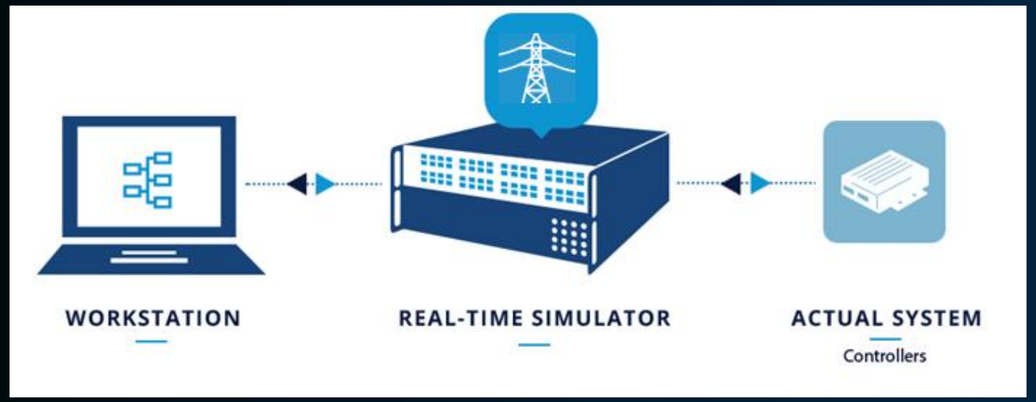
MODEL/SOFTWARE-IN-THE-LOOP



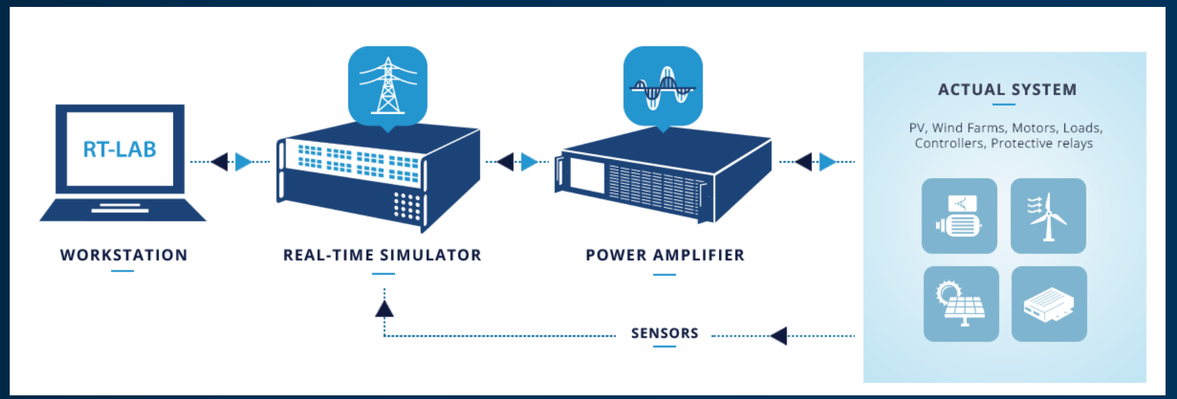
RAPID CONTROL PROTOTYPING



HARDWARE-IN-THE-LOOP



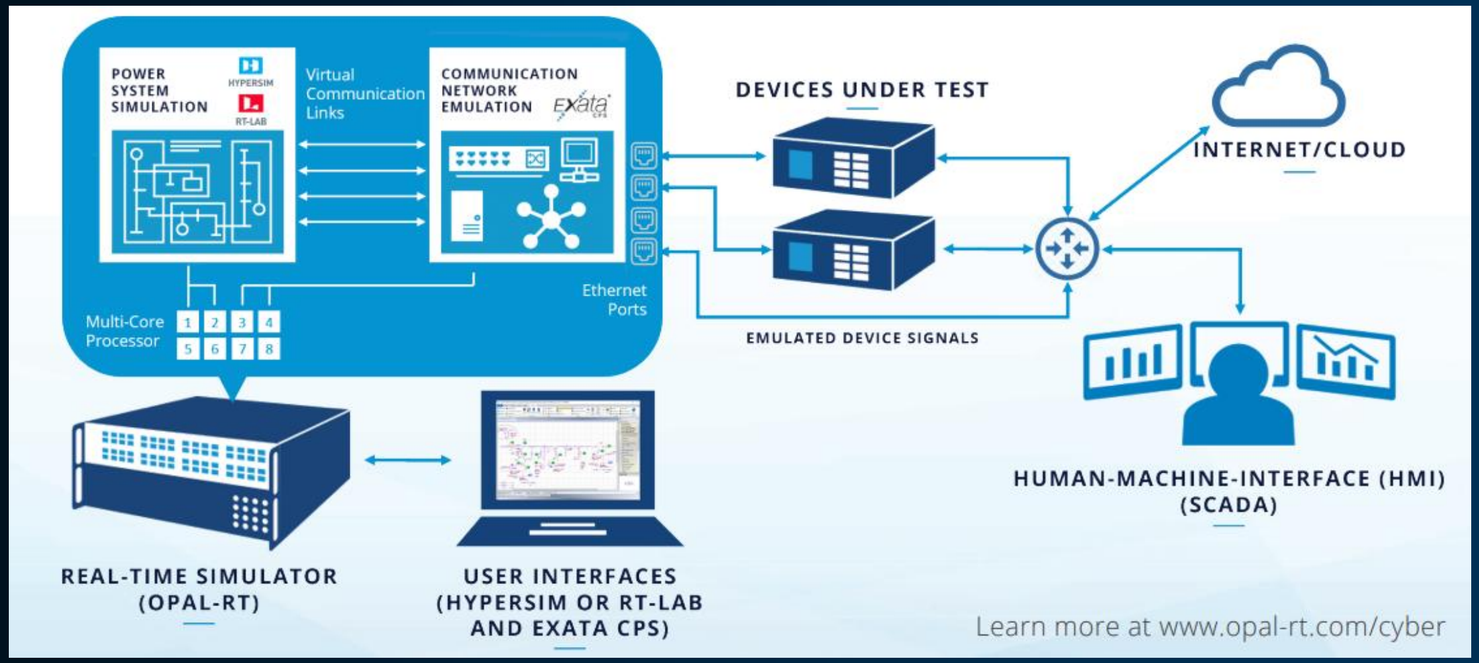
POWER HIL



OPAL-RT TECHNOLOGIES

CYBERSECURTY

OPAL-RT and **Keysight Technologies** have develop a state-of-the-art co-simulation testbed for power system and cybersecurity professionals performing in-depth studies into the impact of communication systems latency and failures and cyberattacks on the grid.



More information on EXATA

OPAL-RT TECHNOLOGIES

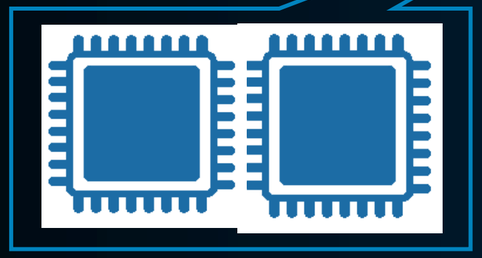
REAL-TIME SYSTEM ARCHITECTURE

Host PC
Model edition
Simulation management
Graphical interface

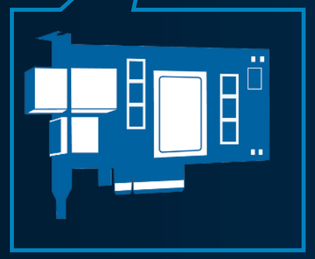
Ethernet

Simulator
Model execution
Data logging
I/O management

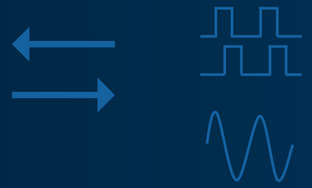
Various I/O boards & protocols available



CPU cores
ms - ~20µs
Different time steps per core



FPGA
I/O management &
< 1µs



Analog & Digital I/O

Device Under Test

OPAL-RT TECHNOLOGIES

HW OVERVIEW MAIN SIMULATORS

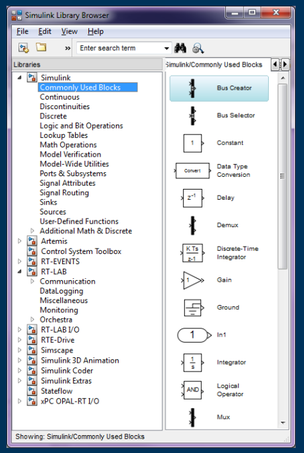
	Entry-Level Simulator	Mid-Range Simulators		High-End Simulators	
					
	OP4512	**OP4610XG**	**OP5705XG**	**OP5707XG**	**OP5033XG**
Rack Unit	2U	3U	5U	5U	4U
Compatible Software Platforms	RT-LAB | HYPERSIM	RT-LAB | HYPERSIM	RT-LAB | HYPERSIM	RT-LAB | HYPERSIM	RT-LAB | HYPERSIM
Available Software Toolboxes & Add-ons	ARTEMiS eHSx64/32 ePHASORSIM Orchestra RT-XSG	ARTEMiS eHSx64/32 ePHASORSIM Orchestra RT-XSG	ARTEMiS ePHASORSIM EXata CPS Orchestra RT-XSG	ARTEMiS eHSx128/64 ePHASORSIM EXata CPS Orchestra RT-XSG	ARTEMiS ePHASORSIM EXata CPS Orchestra RT-XSG
CPU Family	Intel® Xeon® E3	AMD Ryzen™ 5	2nd Generation Intel® Xeon® Scalable Processors	2nd Generation Intel® Xeon® Scalable Processors	2nd Generation Intel® Xeon® Scalable Processors
CPU Specifications	Available with the following configuration:* Xeon® 4 cores, 3.7 GHz	Available with the following configuration:* Ryzen™ 6 cores, 3.8 GHz	Available with the following configurations:* Xeon® 4 cores, 2.60 GHz Xeon® 4 cores, 3.80 GHz Xeon® 8 cores, 3.80 GHz Xeon® 16 cores, 3.30 GHz	Available with the following configurations:* Xeon® 4 cores, 3.80 GHz Xeon® 8 cores, 3.80 GHz Xeon® 16 cores, 3.30 GHz	Available with the following configurations:* Xeon® 4 cores, 2.60 GHz Xeon® 4 cores, 3.80 GHz Xeon® 8 cores, 3.80 GHz Xeon® 16 cores, 3.30 GHz Xeon® 44 cores, 2.10 GHz
XILINX® FPGA	Kintex®-7 410T	Kintex®-7 410T	Artix®-7	Virtex®-7 485T	Artix®-7 (optional)
SFP optical interface (GTX 5 Gbits/s)	4	4	4	16	4 (optional)
I/O modules with 16 analog or 32 digital signals	4	4	8	8	n/a
Available PCI Express Slots for communication cards	1	2	4 or 5**	4 or 5**	5 or 6**
Maximum number of I/O channels	140	140	256	256	n/a

* or equivalent ** depending on CPU configuration

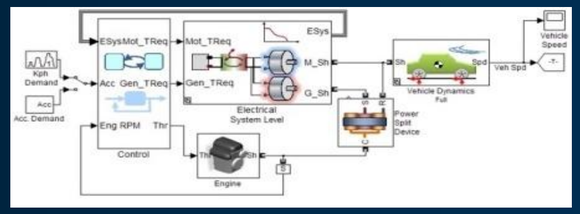
SOFTWARE RT-LAB / EMEGASIM

RT-LAB : Simulink-Model into real-time

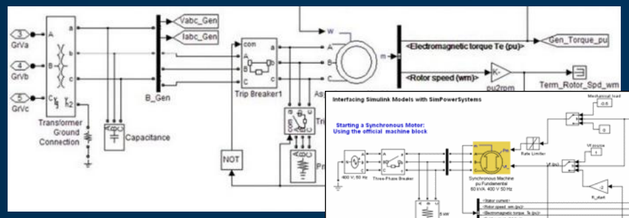
- Projects, models, GUIs management
- Compilation of models into RT executables
- Simulation management
- Data logging / data injection
- Customizable Dashboards
- I/O management
- Parameters modification
- Scripting for test automation (e.g. Python)

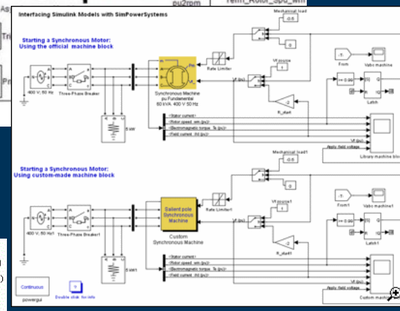


Physical models

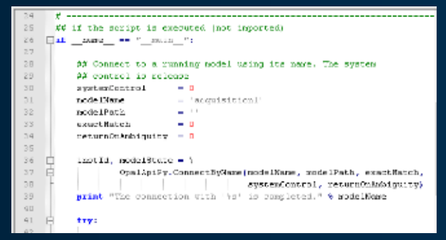


Electrical systems



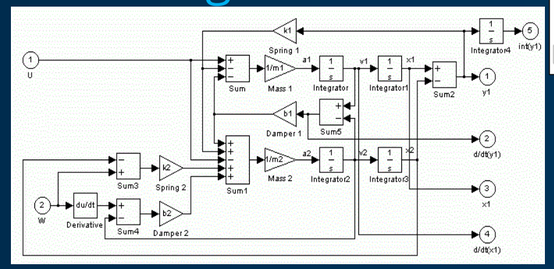


Code

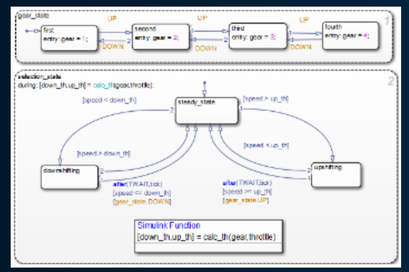


```
# -------------------------------------------------------------
## if the script is executed (not imported)
if __name__== "__main__":

    ## Connect to a running model using its name. The system
    ## control is release
    systemControl       = 0
    modelName           = 'acquisition'
    modelPath           = ''
    exactMatch          = 0
    returnOnAmbiguity   = 0

    rtmId, modelState = \
            OpalApiPy.ConnectByName(modelName, modelPath, exactMatch,
                                    systemControl, returnOnAmbiguity)
    print "The connection with '%s' is completed." % modelName

    try:
```

Algorithms



State diagrams



More information

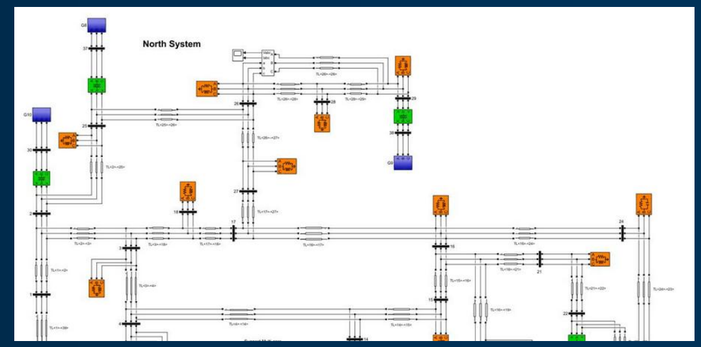
OPAL-RT TECHNOLOGIES

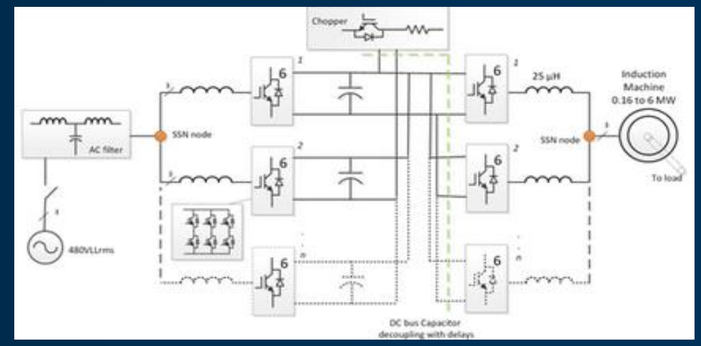
SOFTWARE : **RT-LAB/ eMEGASIM**

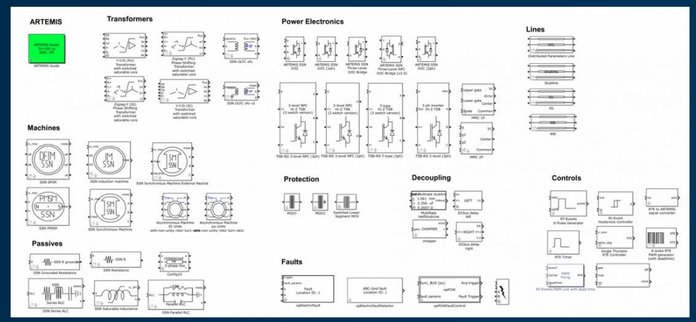
CPU EMT Simulation (20-50us),

Applications: Microgrid & Nanogrid systems, Generation, transmission & distribution systems

- **Simscape Electrical™ Compatibility**
- **Decouple Large Power System Models on several cores**
- **Simulate Complex Motor Drives & Converter Topology**
- **Extended Library of Optimized Real-Time Models**







EPHASORSIM : LARGE-SCALE POWER SYSTEM REAL-TIME SIMULATION

ePHASORSIM

Simulation type:	Phasor domain
Typical time step:	1ms - 10 ms
Compatible modeling environments:	Simulink, Excel, PSS®E, CYME, PowerFactory, Open Modelica, Dymola
Maximum tested real-time network size:	1,000,000 1-phase nodes
Maximum non real-time network size:	Unlimited
Capability per processing core:	10,000 nodes @ 10 ms

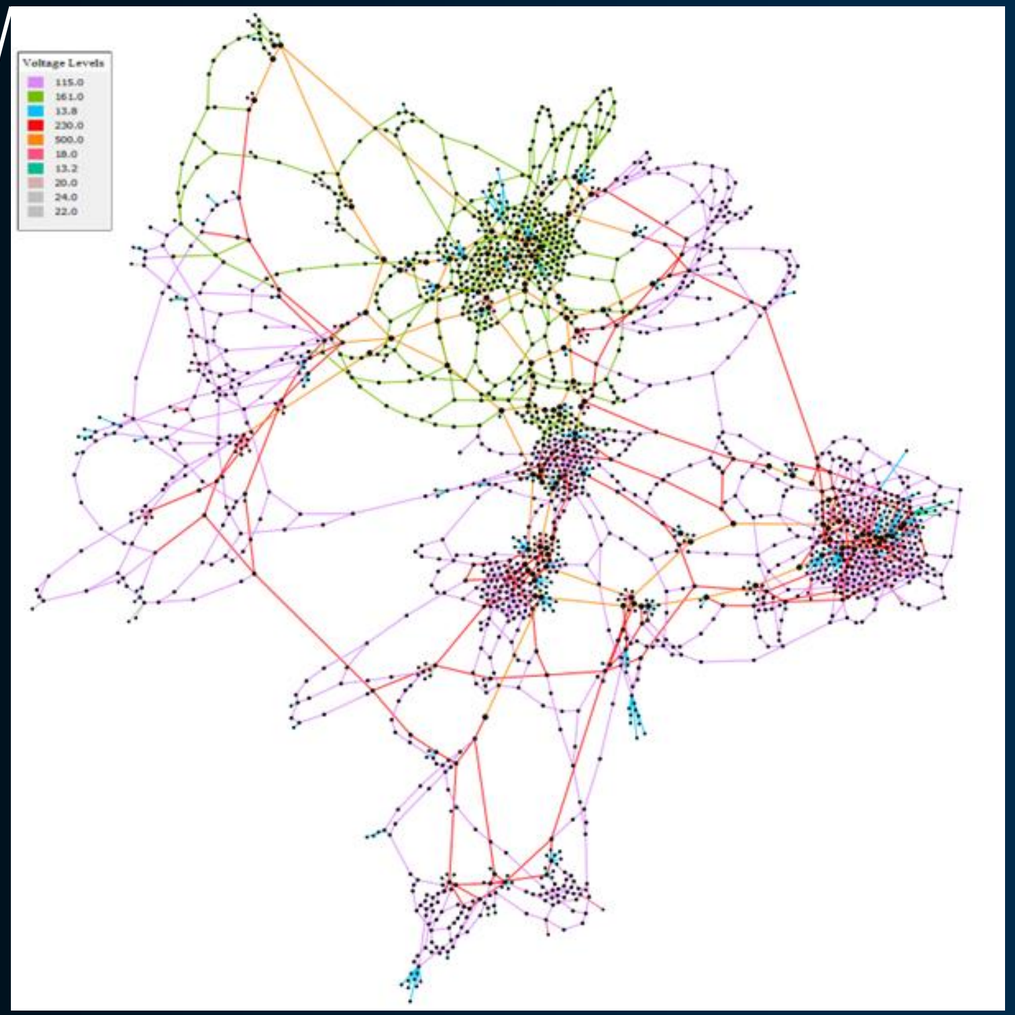
Target applications

OPAL-RT TECHNOLOGIES

RT-LAB SOFTWARE – EPHASORSIM

ePHASORSIM

EXAMPLE - 2000-Bus Synthetic Grid of Texas



Solver

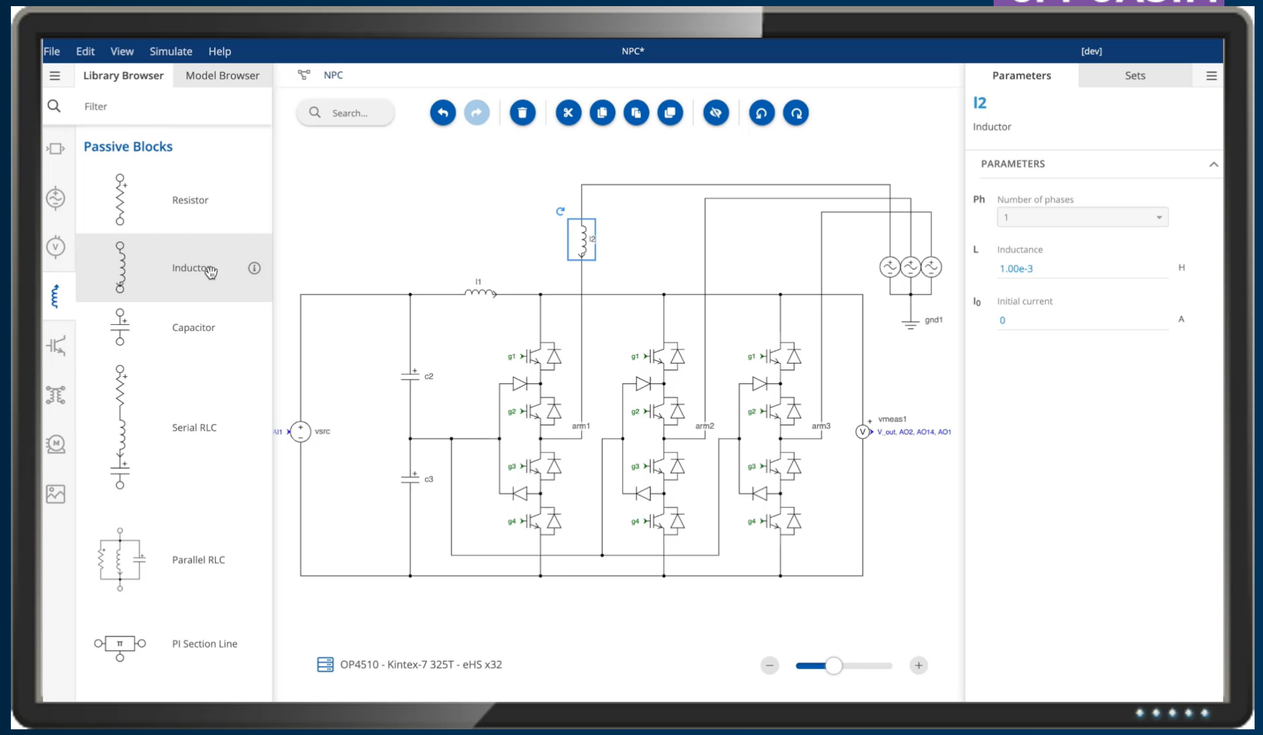
2000-Bus Synthetic Grid of Texas	
Model Time Step	4.7 ms
Number of cores	1
Singles phase nodes	2000
Generators	544
Transformers	861
Branches	2345
Loads	1350
Shunt	56

OPAL-RT TECHNOLOGIES

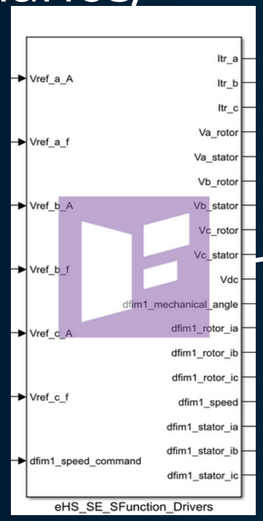
RT-LAB SOFTWARE – EFPGASIM

eHS solver

- Build your Electrical circuit editor for seamless, fast & accurate simulation on FPGA
- **No** VHDL coding
- Connected to hardware I/Os
- Possibility to modify electrical parameters during test scenarios



OPAL-RT Schematic editor



More information

Online documentation

TO SUM UP

- **Multi-application** real-time simulator: Same OPAL-RT device allows to perform model-in-the-loop, rapid control prototyping and hardware-in-the-loop allowing **fast and efficient return on investment.**
- **OPAL-RT real-time simulator software is fully compatible with MATLAB/Simulink and Simscape Electrical (SimPowerSystems).**
- **Import and simulate 3rd party software: PSSe / PowerFactory / PSCAD, EMTP, …**
- OPAL-RT **unique real-time solvers to achieve real-time performances**
  - eMEGASIM Artemis solver to simulate Simscape electrical grid models in real-time on several CPU cores (time step: 50us)
  - ePHASORSIM solver to simulate PSSe and PowerFactory models in phasor/RMS mode (time step: 20ms)
  - eFPGASIM eHS solver to simulate Simscape Electrical power electronics and electrical machines models on FPGA without using VHDL or HDL code (Time step below 1us)
- **Customizable Dashboards, Test automation capability**
- **Powerful, flexible and scalable real-time simulators**
- **Local technical support and distributors' network**

OPAL-RT TECHNOLOGIES

THANK YOU

OPAL-RT TECHNOLOGIES