OPAL-RT TECHNOLOGIES

*Power in mind*

# OPAL-RT NEWS, INNOVATION & BREAKTHROUGHS

IEEE PES GM 2019 EDITION

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# OPAL-RT TECHNOLOGIES

## 2019
OPAL-RT STI founded in Lyon, France

## 2018
Winner of the 2018
"PRIX INNOVATION PME" award

## 2017
OPAL-RT TECHNOLOGIES' 20th anniversary

## 2016
Launch of the OP4200 simulator
for power electronics, electric drive
and other real-time applications
Winner of the 2016 Mercuriades Awards

## 2012
HYPERSIM – Hydro-Quebec agreement
ISO 9001:2008, quality management systems
OPAL-RT India Private Limited founded
OP7000 Multi-FPGA Platform

## 2011
Modular Multilevel Converter-based HVDC simulator,
with 3300 I/O ch in 25us / 40kHz
OP5600 HIL platform

## 2010
RT-LAB 10 with Eclipse based interface
ARTEMiS State-Space Nodal solver

## 2009
OPAL-RT EUROPE founded
Wanda BOX with OP5142 (Spartan 3)

## 2008
RT-LAB BERTA Test Bench
Real-Time 2008: the 1st annual OPAL-RT
international user conference

## 2007
eMEGAsim real-time power grid simulator

## 2005
RT-XSG FPGA development system
Electric Hybrid Vehicle project with Denso

## 2004
OPAL-RT Corporation (USA) founded
OP6000 TestDrive for automotive ECU testing
1st Electric Hybrid Vehicle project with
Toyota 10us / 100kHz

## 2002
1st OPAL-RT FPGA-based (VirtexII) I/O cards

## 2001
ARTEMIS 50us
1st contract with General Electric

## 2000
Flight simulation model
for the Embraer 170 Jet

## 1999
RT-EVENTS
FORD engine simulation

## 1998
RT-LAB 1.0, Canada Arm 2 simulator
for Canadian Space Agency

## 1997
OPAL-RT TECHNOLOGIES founded
by Jean Bélanger & Lise Laforce
7 employees

# A Word from the President

**Esteemed PES Attendees & Colleagues, Friends--**

We are thrilled that OPAL-RT is once again in attendance at PES, one of the biggest conferences for Power Systems every year worldwide, and one I look especially forward to as someone who remains passionately devoted to technical innovation.

As always, we are honored to get the chance to meet our industrial clients, academic researchers and end-users and interact with respected new colleagues, partners and collaborators who directly contribute to bringing our power system technologies to the next level, by pushing the envelope through feature requests, groundbreaking new research and collaborations of all kinds.

This year, we're announcing new milestones and progress as we find ourselves further exploring rewarding, exciting areas for us, and ones where we've made great strides—microgrid developments, ever-larger networks, cybersecurity innovations, FPGA breakthroughs--yet with new features, new partners, and new approaches.

OPAL-RT is the pre-eminent leader in real-time power system simulation across various crucial Power Systems domains, and we've both gained a lot of traction and enjoyed great success here, stretching back to 1997 and, by all indications, progressing far into the future.

**Our power system innovation roadmap has always been driven by the following credos, which inspire us to tread new ground, and to progress consistently further year after year:**

**Going Bigger:** By offering our ePHASORSIM product with new capabilities, our phasor domain tool continues to excel at working with larger, more challenging networks with an integrated transmission-distribution system benchmark of up to 110,000 buses in real-time.

**Going Safer**: Today's electric power grids are benefitting from new 'intelligent' technologies and evolving rapidly to provide greater efficiency and performance. These new technologies, however, can make electric power grids vulnerable to increasingly sophisticated cyberattacks. That's why we are working with SCALABLE Network Technologies to provide new products to test the successful protection and resistance required for overcoming these potential attacks. Microgrid controllers from General Electric and SEL are also demonstrated.

**Going Faster**: A trio of areas—traveling wave relay applications, DER penetration into the grid, and microgrid technology itself—have shown they require fast real-time simulation on FPGA. FPGA technology has always helped OPAL-RT to go faster, and it provides a great deal more accuracy to power electronics real-time simulations--and we continue to push the envelope on this technology. The simulation of a 1,200-node distribution system with a time step of less than 5 us will be demonstrated.

OPAL-RT users should know that our core values and mission statement and approach have gotten us this far, and that we have no intention of departing from them now: a real-time simulator on every engineer's desk; commercial off-the-shelf hardware elements powerfully integrated with the benefit of years of experience; flexibility and scalability across all of our offerings; and a significant yearly re-investment in R&D, of which we're justifiably proud.

**I wish you a great PES and continued success and Innovation!**

**Jean Bélanger, President and CEO of OPAL-RT TECHNOLOGIES**

# New DER Models on HYPERSIM

## Addressing decentralized electric grid challenges with HYPERSIM

The growing interest in a more decentralized electric grid and new types of distributed energy resources (DER) further increase the research on distribution networks. HYPERSIM is the preferred system to analyze interaction of new DER implementation to the bulk grid to ensure system reliability during both normal operation and response to disturbances.

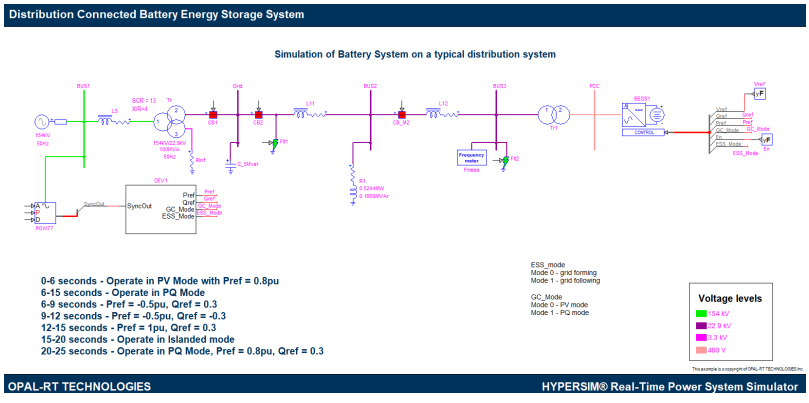
HYPERSIM 2019.1 now provides two approaches to include the study of DER in complete and complex power system models:

### 1) Average DER models:

Convenient for studies on interaction, supervision, protection and grid interconnection.

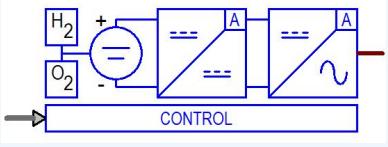
### 2) Detailed DER Models with eHS & New Schematic Editor:

For in-depth research and study on decentralized power electronics controls related to DER.



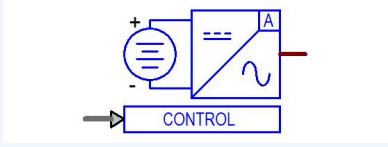

Distribution Connected Battery Energy Storage System with Average Converter

## 1) AVERAGE DER MODELS



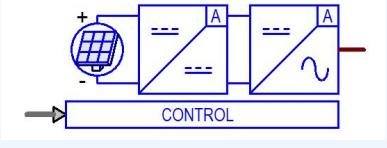

**Fuel Cell Generation System Average (FCGS)**

The FCGS features a fuel cell connected to an inverter via a boost DC-DC converter.




**Battery Energy Storage System (BESS)**

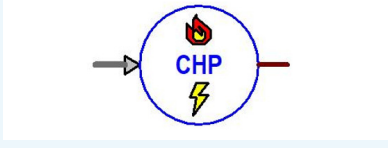
The battery energy storage system features a battery connected to an inverter via a second order DC filter. The inverter is connected to the grid via a RL choke filter.




**Photovoltaic Generation System (PVGS)**

The PVGS features a PV array connected to an inverter via a boost DC-DC converter. The boost converter controls the PV array in two modes of operation:

1) maximum power point tracking (MPPT)
2) curtailment.

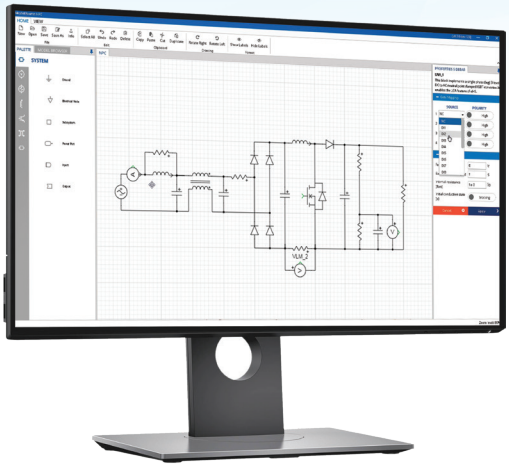



**Distribution Connected Battery Energy Storage System with Average Converter**

In this example a one stage battery energy storage system (BESS) is modeled. The BESS is connected to a typical distribution system and several scenarios are implemented demonstrating the BESS operation in grid following and grid forming modes. The interface converter of the BESS is an average inverter model.

# New DER Models on HYPERSIM (continued)

## 2) DETAILED DER MODELS WITH EHS & NEW SCHEMATIC EDITOR



OPAL-RT presents eHS—our Power Electronics Solver on HYPERSIM: a hybrid CPU and FPGA platform showcasing a powerful nanosecond solver. Our optimized, real-time, power electronics solver (eHS) for electrical and electronic test applications, now runs on our flagship simulation tool.

Time step below 20 us/50 kHz

Transients and harmonics below 20% or (1/Tstep) or about 10 kHz

Co-simulation mode with very large grids simulated with time step of 20us to 50us on multi-CPU computers

## The Best of Both Worlds

| eHS X128 | HYPERSIM |
|---|---|
| • Powerful floating-point solver facilitates simulation of an electric circuit on FPGA, without needing to write mathematical equations. | • Real-time simulation of vast power systems: more than 5,000 3-phase buses on a single simulator, without sacrificing precision. |
| • Capacity to run up to 144 coupled switches* per eHS core for real time simulation fidelity, without artificial delays. | • No need to waste time manually splitting models on available cores; HYPERSIM optimizes models to run on available resources. |
| • PWM frequencies input and output up to 200 kHz, the fastest power electronic solver in the industry. | • Prepare your model on a laptop, offline if desired, and benefit from the full speed of all available cores. |
| • Very low latency from PMW inputs to analog output: crucial for the accuracy of fast HIL control systems. | • Test automation tool reports: run thousands of tests overnight and records the results (including mathematical analysis) for later review. |

***All eHS versions will be available soon**

# Breakthrough in the Multi-FPGA Real-time Simulation on Distribution Grid

**Power grids in general, are complex systems and their electromagnetic transient simulation requires the computation of large matrices. The only way for a real-time simulator to handle the simulation in real-time is to split the grid model over multiple computation units.**

FPGA-based real-time simulators have been proven to be one of the computing platform of choice for the simulation of distribution power system with the power electronic systems with high switching frequencies are predominant.

To avoid the tedious FPGA design workflow, OPAL-RT proposes eHS, an automated FPGA-based computing engine consisting of a pre-compiled hardware processor that converts a SimPowerSystems circuit into binary data used by eHS.

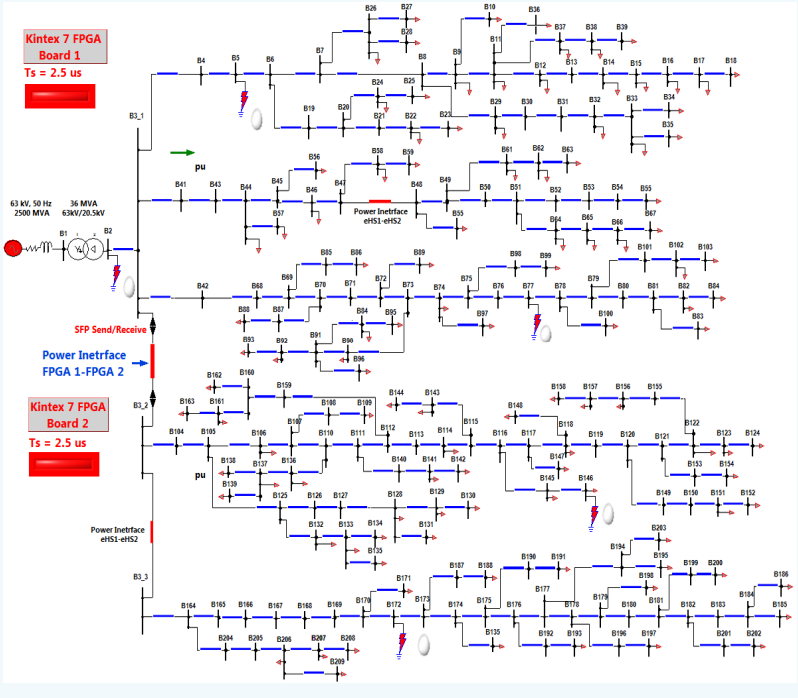

| REAL-TIME PERFORMANCES | | |
|---|---|---|
| 1 Kintex 7 325T | 64 | 4.85 us |
| 2 Kintex 7 325T | 210 | 2.5us |
| 3 Kintex 7 325T | 340 | 2.7 to 4 us |

## Setup

To demonstrate the effectiveness of the OPAL-RT platform, a large distribution network (DN) of 210 bus bars and a Microgrid (MG) are considered. The MG includes a solar panel and a battery energy storage system (BESS). The complete power system including the DN and MG is simulated using only two Kintex-7 FPGA boards with one OP4510 and one OP4510 and one OP4520 FPGA simulator platform. The controllers of the MG distributed energy resources (DER) are compiled and real time simulated using a 3.5GHz Intel processor.

Several tests were performed on the MG to evaluate the FPGA-Based platform to handle simulation including fast switching frequency converters. The tests performed include:

- Test 1: Transitions from grid-connected mode to the island mode under different operation points.
- Test 2: Load shedding tests in island and grid connected modes.
- Test 3: Step changes on PQ Reference in grid connected mode.




Large distribution network of 210 bus bar with 2 OP4510/OP4520 Kintex 7

# OP8110 | 4-Quadrant PHIL Amplifier

**High-speed and low-latency** closed loop communications for digital real-time simulation


## Introducing the OP8110 4-Quadrant PHIL Amplifier: Optimize testing and validation of power systems and power electronics controls, protection and proof of concept.

The OPAL-RT OP8110 is a 4-Quadrant Power Amplifier featuring high-speed and low-latency closed loop communications for real-time digital simulation. It is designed to be used as a Power Hardware in the Loop (PHIL) testing tool in combination with an OPAL-RT simulator to form a complete PHIL testing solution.

Enhance operational safety and develop safer products and systems with OPAL-RT's OP8110 4-Quadrant PHIL Amplifier.

### Key Features:

- High-fidelity 4-Quadrant PHIL Amplifier with 100% non-dissipative regeneration
- Up to two 5kW 3-phase modules with independent phases
- Voltage and Current Mode
- Overload, short circuit and over temperature protections
- Specially designed for real-time PHIL applications, such as, powergrid, motor or DER emulator
  - Large Signal Bandwidth: DC to 10kHz (-3dB), 0.5% THD
  - Integrated coupling inductors
  - Integrated voltage and current measurements transferred to PHIL models

### PRODUCT HIGHLIGHTS

- Innovative soft-switching cell based on SiC Transistors Technology
- 120Vrms/14A per AC phase with neutral
- Very high efficiency >96%
- Compact form factor (2U rack mount)
- 100% regeneration
- Low output harmonic distortion (THD):
  – THD <0.5% for DC to 2kHz, full power
  – THD <2% for 2kHz to 10kHz, full power

### APPLICATIONS

- RT-LAB Simulink-based Simulator: Ideal for research laboratories.
- PHIL System Device Testing: Test your system controller, your algorithm or topology under real-world electrical conditions.
- MicroGrid PHIL Testing: Create a microgrid topology where you can connect physical equipment. Analyze its interaction with other emulated DER and power grids (photo-voltaics, wind turbines, batteries, load).

## APPLICATIONS

### Power Module Interface

- 2x 3-Phases with neutral
- 2 independent Bipolar DC power supply with mid-point

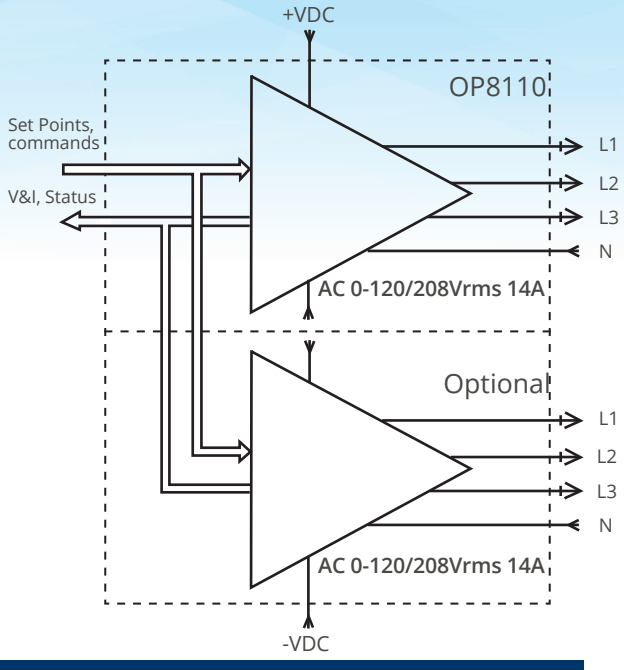
### High Speed Communication Link

- 2 SFP, optical, full duplex, 6.6Gbps
- 3 Plastic Fiber Optic Link, 250Mbps
- 1 RJ45 Ethernet port, 10/100/1000

### Other Interface

- 1 Optical Synchronization, Tx and Rx
- 8 Status LED
- 1 Serial Port
- 2 DIP Switches (Boot mode Selection)

## OP8110 DIAGRAM




## POWER MODULE SPECIFICATIONS

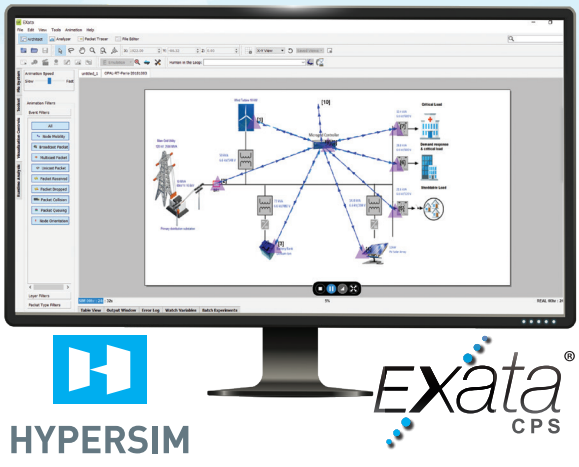
| CHARACTERISTIC | UNIT | PA |
|---|---|---|
| Nominal Output RMS Voltage (ph-gr/ph-ph) | Vrms | 120 / 208 Vrms |
| Pout - W/phase | W | 1700 W |
| Pout - Total for 3-phases | W | 5000 W 3ph |
| Nominal Output Current | Arms | 14 Arms |
| Peak current (steady-state) | A peak | 20 A peak |
| Peak current (100ms) | A peak | TBD |
| Frequency bandwidth | kHz | DC to 10kHz (-3db) |
| Nominal load Power Factor (PF) at nominal power | | |
| Power Efficiency | % | ≥ 96% |
| Environment temperature | °C | 10 °C - 40 °C |
| Electromagnetic Compliance | | FCC Part 15A |
| Max current on chassis GND and power GND connections | mA | < 5mA |
| Nominal Input DC Voltage | VDC | 500 VDC |

| POWER RATING AS FUNCTION OF FREQUENCY | | |
|---|---|---|
| DC to 240 Hz | % of nominal | 100% |
| 240 Hz to 2 kHz/2 kHz to 5 kHz | | 100% |
| 5 kHz to 10 kHz | | 50% |

| HARMONIC DISTORTION | | |
|---|---|---|
| Voltage / Current output THD (DC-2 kHz) | % of nominal Voltage | <0.5% |
| Voltage / Current output THD (2-10 kHz) | | <2% |

# Cyber-Physical Simulation Testbed for Power Systems

OPAL-RT and SCALABLE Network Technologies present a state-of-the-art co-simulation testbed for power system and cybersecurity professionals needing to perform in-depth studies into the impact of communication systems and cyberattacks on the grid.




The testbed combines two well-recognized COTS software tools fully integrated for real-time Cyber Physical Simulation (CPS):

- HYPERSIM® for Power Grid simulation
- Exata CPS for communication network and cyberattack simulation

Both software run on the same OPAL-RT real-time simulator and connect to each other virtually permitting the user to emulate communication connections from virtual devices within HYPERSIM and to route them via EXata CPS to external devices.

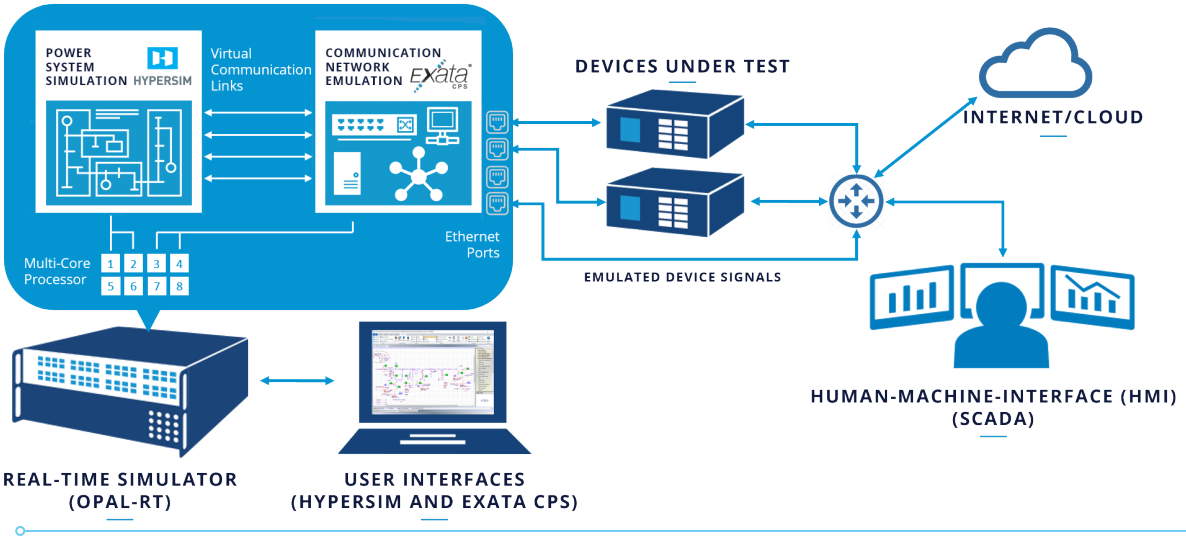
A major benefit of this testbed is the reduction of the overall communication latency when supporting time-criticial applications involving protocols such as IEC 61850 GOOSE and C37.118.

Plug-and-play Cyber-Physical System (CPS) co-simulation for Power Systems on one platform

DoD-proven high-fidelity communication network and cyberattack emulation with low latency for fast protocols

Simple graphical configuration for connections between emulated devices, communication nodes and external devices

## CYBER-PHYSICAL SYSTEM (CPS) CO-SIMULATION



# EXata CPS Features

## Standard Packages & Features

Developer
- Design Mode
- Visualize Mode
- Analyser for Statistical Analysis

Cyber (see Cyberattack/defense list)

Wireless

Packet sniffer interface

Multimedia and Enterprise

Scenario Player

## Optional Libraries

Advanced Wireless

Cellular

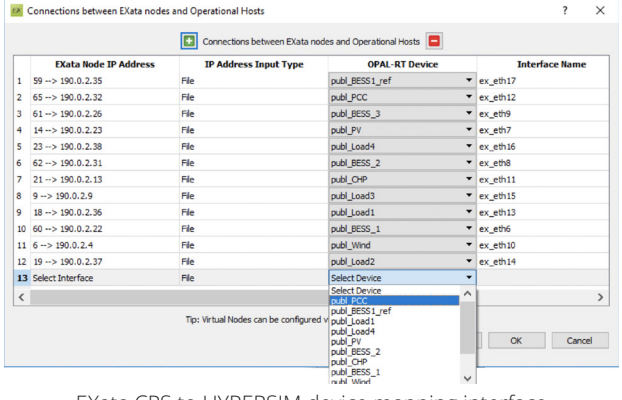
Federation Interfaces

LTE

Sensor Networks

UMTS Networks

Urban Propagation




EXata CPS to HYPERSIM device mapping interface

## Supported Cyberattacks

Denial of Service (DoS)

Man-in the-middle attacks

Packet Modification

Passive Attacks
- Eavesdropping
- Network Scanning
- Port Scanning
- SIGINT

Jamming Attacks

Vulnerability Exploitation Attacks
- Attacks to corrupt files and databases
- Hacking attacks

Virus and Worm propagation attacks

Rootkit and Botnet attacks

Backdoors/holes in the network perimeter

Communications hijacking attacks

Coordinated and Adaptive Attacks

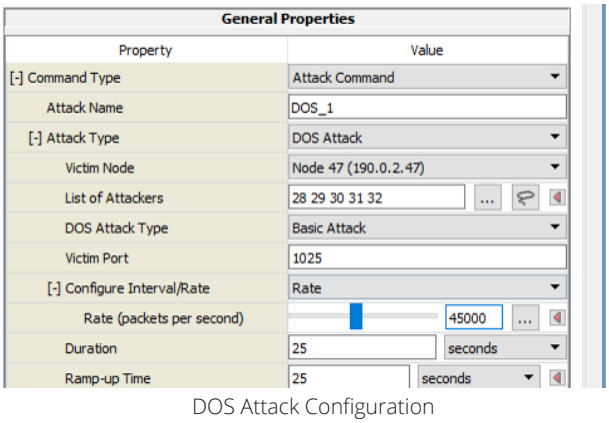
## Available Cyberdefense Models

Firewalls

Intrusion Detection System (IDS)

Anti-Virus System (AVS)

Security Logs and Audit Trails




DOS Attack Configuration

# OPAL-RT Requirements

## Required Simulator Hardware

OPAL-RT Real-Time Simulators with:
- 8 or more processing cores
- OPAL-RT--optimized CentOS Operating System

OP5031

OP5600

OP5707

## Required Software

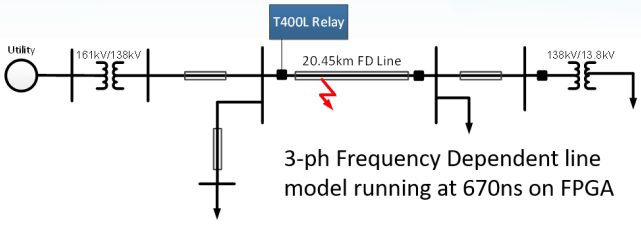
HYPERSIM 2019.2 or later

EXata CPS v1.0 or later

One or more communication protocols including:
- IEC 61850-8-1 GOOSE
- DNP3
- IEC 60870-5-104
- C37.118
- OPC-UA
- Modbus TCP

# Traveling Wave Relay Testing Using HIL

OPAL-RT has achieved the first FPGA-based Hardware-in-the Loop (HIL) test of traveling wave fault locators using a three phase power grid model simulated at a time step of 670 ns using phase domain frequency dependent transmission line. OPAL-RT's objective is to bring to the protection market an advanced traveling-wave test system.



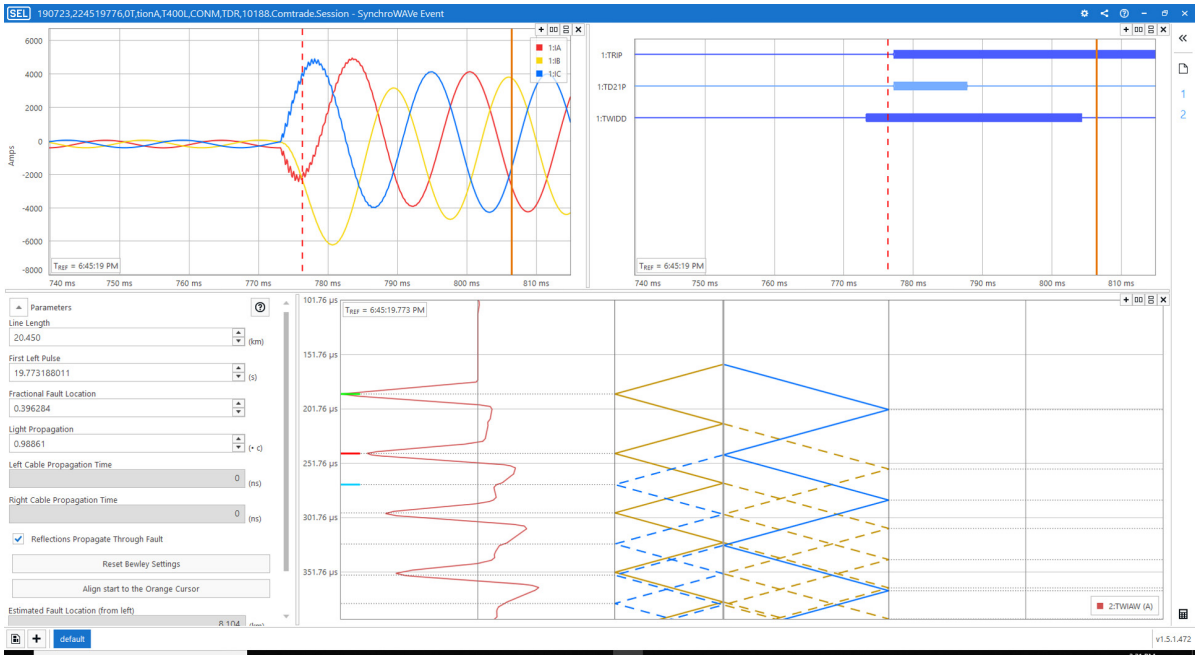


$V_{L\_abc}$, $I_{L\_abc}$

Low level analog signals at 1MHz


## Traveling-Wave Testing Solution

HIL Traveling-Wave Testing Solution is the ideal testing approach for the latest TWFL technologies. However, the real-time power grid model needs to be executed at a high sampling rate which is one of the main reason why line models need to be simulated on FPGA.




*Recorded data from SEL T400L with a Fault performed by OPAL-RT HIL at 40%*

HYPERSIM
On Demand

# HYPERSIM On Demand
## EMT Simulation


### THE PLATFORM FOR ACCELERATING COMPLETE EMT SIMULATION BEFORE GOING TO REAL TIME

OPAL-RT presents HYPERSIM On Demand, a simulation platform to accelerate the prototyping, development and testing of power system equipment.
The solution that enables parallel execution of simulation tests on multiple cloud simulators also offers staggering performance gains over standard EMT simulation software.

Use only what you need, when you need it, with commitment-free pay-as-you-go pricing.

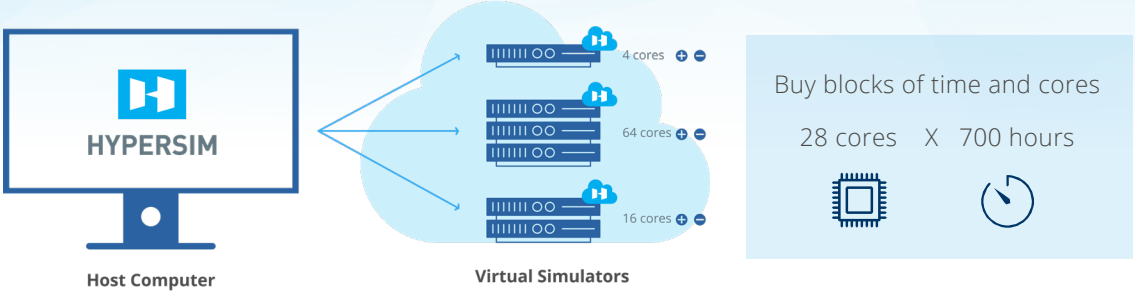
Run models and scenarios on your virtual simulators, then use your own machines for the rest.

Extend your model simulation abilities by as much as required, for as long as required.

## Features & Benefits

- Use **HYPERSIM On Demand** for simulations that require substantial CPU power—for short time periods.
- Take advantage of our massively parallel resources, available as you need them, and as your budget permits.
- Make simulation resources available for your large project, side-stepping the usual concerns about the time and/or money required for permanent licenses or hardware infrastructure.
- Spread one massive simulation—that might hypothetically run for hours, days, or even weeks—across as many cores as required, until it's done.

# Return on Investment | HYPERSIM On Demand




## Cost of Ownership
## Cloud-based vs. In-House Server

### Permanent Licences

- Cumulative cost of permanent licences on in-house server and services (red for line)

### Cloud Services

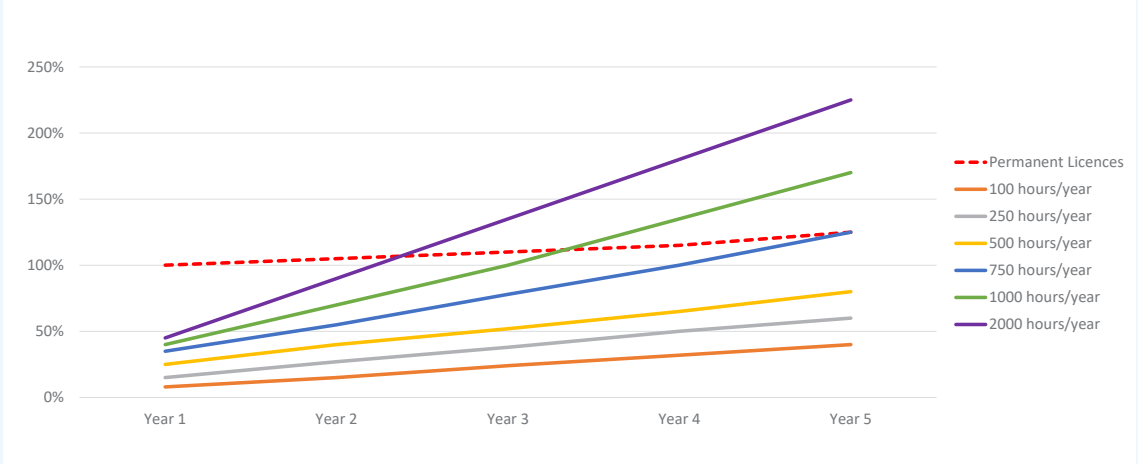
- Each line below represents the yearly usage (hours/year) of HYPERSIM On Demand and the associated cost

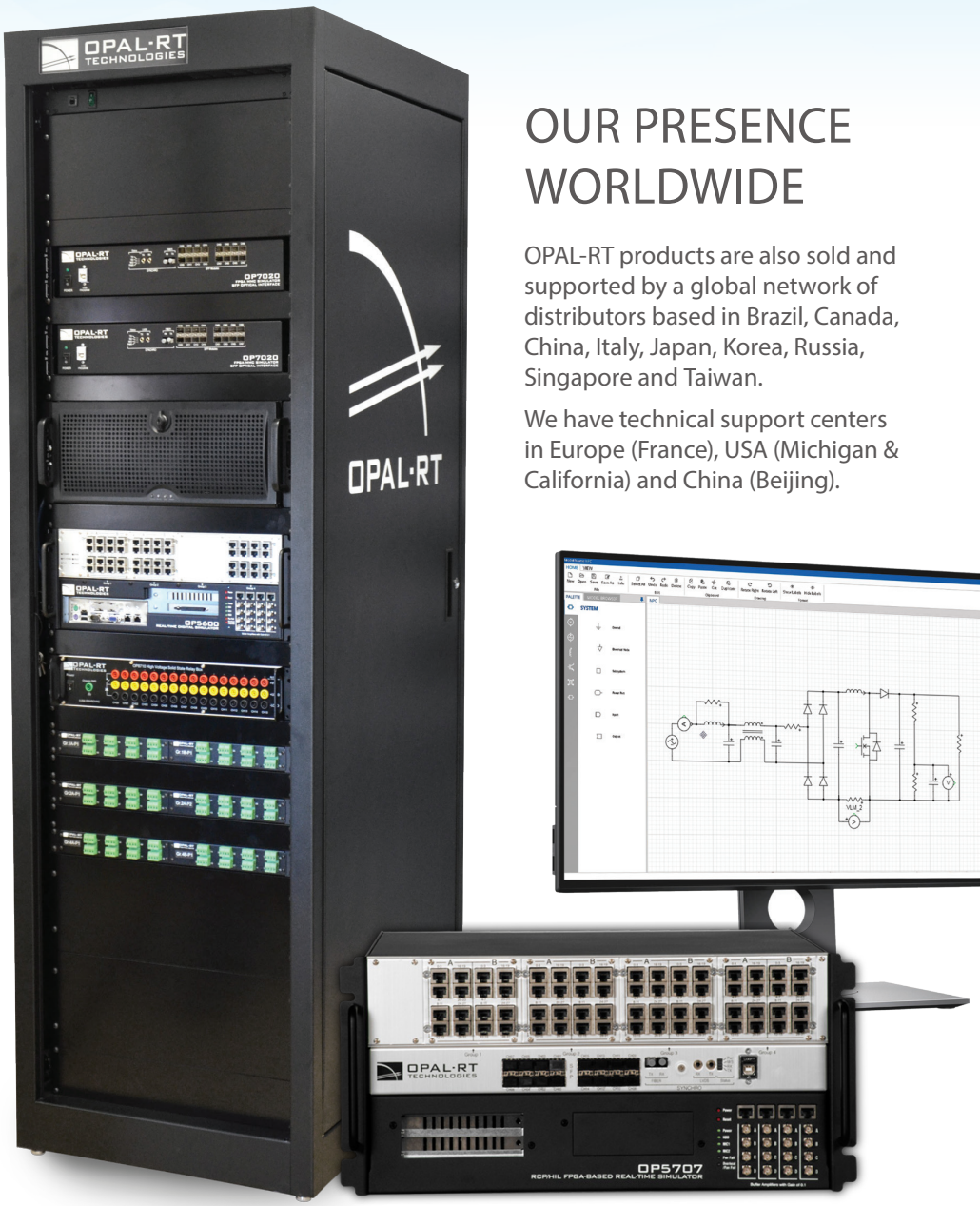
### In-house Server

- May likely be cheaper for steady intence usage over a long period

### Cloud-based Solutions

- Eliminate the infrastructure costs (room cooling, maintenance, upgrade)
- Facilitate software upgrade
- Increase flexibility and scalability on demand
- Enable to start small and increase the processing capability as needed






# OUR PRESENCE WORLDWIDE

OPAL-RT products are also sold and supported by a global network of distributors based in Brazil, Canada, China, Italy, Japan, Korea, Russia, Singapore and Taiwan.

We have technical support centers in Europe (France), USA (Michigan & California) and China (Beijing).

# RT SPOTLIGHT

## GLOBAL REACH, LOCAL PRESENCE

**Zürich**
September 17-18, 2019
Power Systems & Power Electronics

**Shanghai**
September 18-20, 2019
All Industries

**San Francisco**
September 27, 2019
Automotive & Transportation

For the past 10 years, OPAL-RT's conferences have attracted hundreds of attendees from around the world. We would like to welcome you to RT Spotlight, which are local events hosted by OPAL-RT that will bring to the stage the well known experts in real-time simulation to share their knowledge and insights with engineers and researchers around the globe.

We're pleased to announce that RT Spotlight will take place on three continents, in the countries: Switzerland, China and the United States! Don't miss the opportunity to explore numerous networking opportunities, and expand your knowledge learning from renowned experts.

## Why should you attend RT Spotlight?

- Get inspired by the latest trends in real-time simulation
- Expand your knowledge learning from renowned experts
- Explore numerous networking opportunities
- View live demos
- Have fun enjoying our exquisite dining and entertainment