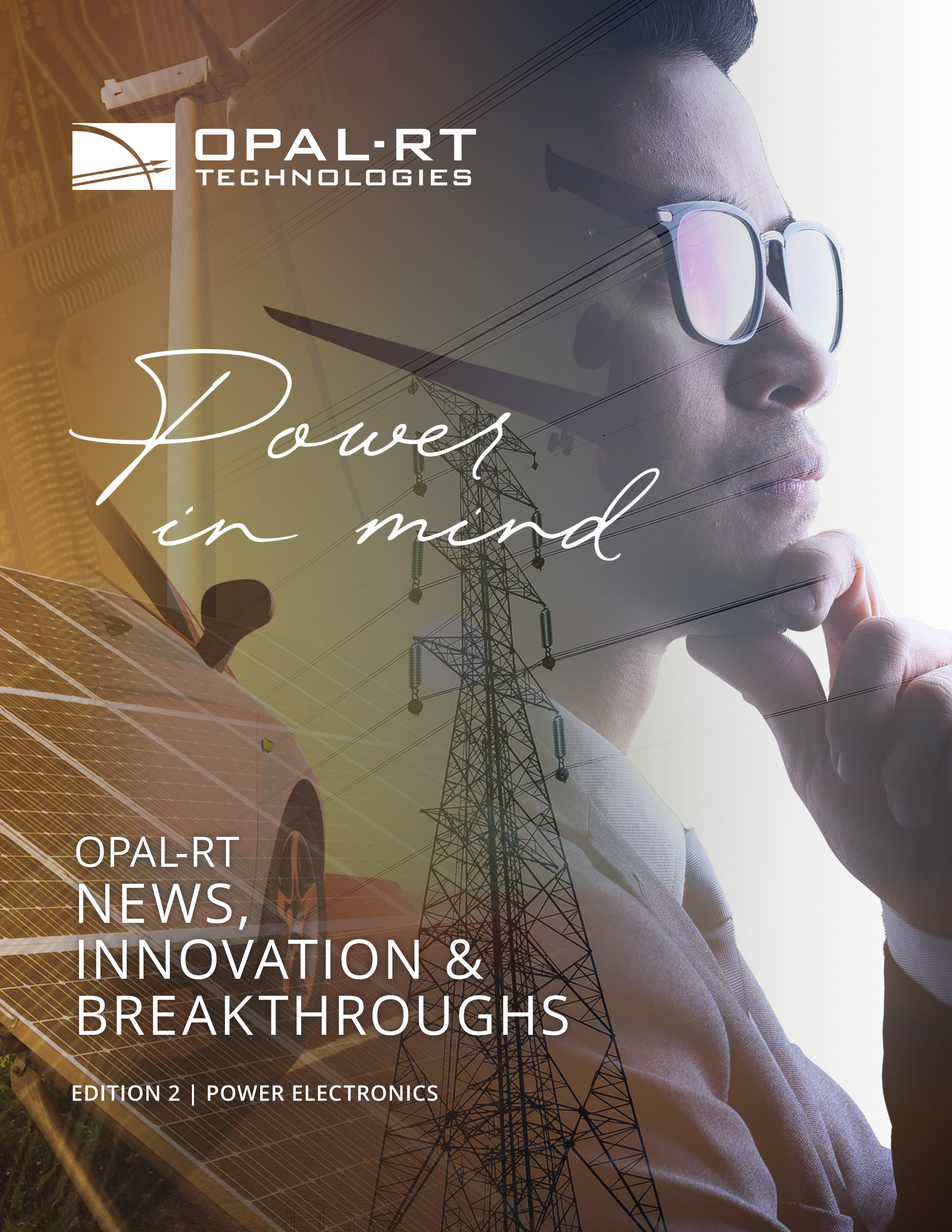


OPAL-RT TECHNOLOGIES

Power in mind

OPAL-RT NEWS, INNOVATION & BREAKTHROUGHS

EDITION 2 | POWER ELECTRONICS

Table of Contents

2019

OPAL-RT STI founded in Lyon, France

2018

OPAL-RT Germany GmbH founded in Nuremberg
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 Clients, Colleagues, Friends--

As co-founders of OPAL-RT, Lise Laforce and I are honored to get the chance to inform you of OPAL-RT's latest technical achievements—many of them due in part to the work of our clients, colleagues, partners, and collaborators, who directly contribute to bringing our power electronics technology to the next level, by pushing the envelope through feature requests, ground-breaking new research and productive collaborations of all types.

This year, in particular, is very exciting for us. There is a revolution underway in semi-conductors using SiC (silicon carbide) technology—one that enables electronic switches to work 10 times faster and with many times less heat loss.

Those who know me will know that I love to reflect on technological change and our shared future: brave new technological developments like this one will mean that energy production is increasingly cleaner, more robust and more sustainable. We are already seeing substantial requests for ultra-fast power electronics converters due to developments arising from this new technology.

OPAL-RT has always succeeded in providing real-time simulators ready for the newest semiconductors, and once more, we're designing real-time simulators for this new era, by developing an easier workflow and a more intuitive modelling experience through using a web-based graphical editor integrated with a powerful real-time database.

We continue to innovate by enabling the simulation of large microgrids with 1,200 nodes in less than 3 μs with three FPGAs—a world record. Users will appreciate the scalability our newest technologies have achieved through interconnecting several FPGA-based simulators with high-end INTEL multicore XEON Scalable Processors to simulate large power grids using ARTEMiS and SIMSCAPE Power Systems.

We've also introduced a bold new step in sampling (in our product eHS) that enables faster PWM integration in power electronics solving—simulating power electronics converters with PWM frequency up to 200 kHz using patent-pending time-stamping solver with 5 ns accuracy.

We're ready to develop and explore alongside this revolution as it happens, in real time, with our nanosecond power electronics solvers, our industry-leading experience in furthering FPGA simulation, our support for ultra-fast switching converters used across sectors, and the development of our new 4-Quadrant PHIL amplifier—already using SiC technology. The 4Q amplifier, to be released solo or integrated with our innovative microgrid test bench, has been developed as high-speed, low latency, and high-density for highly flexible use in the of high-fidelity PHIL test benches.

Faithful OPAL-RT users should know that our core values, mission statement and approach have gotten us this far, and that we have no intention of departing from them now. In 1997, my partner Lise Laforce and I founded OPAL-RT with the mission of "a real-time simulator on every engineer's desk". We built increasingly powerful simulators as we benefited from our accumulating experience along the way, and we've always made sure to earmark a significant yearly amount for R&D re-investment, of which we're justifiably proud.

Our power electronics innovation roadmap has always inspired us to tread new ground, to work with new ideas and their implementation, and to progress consistently further year after year.

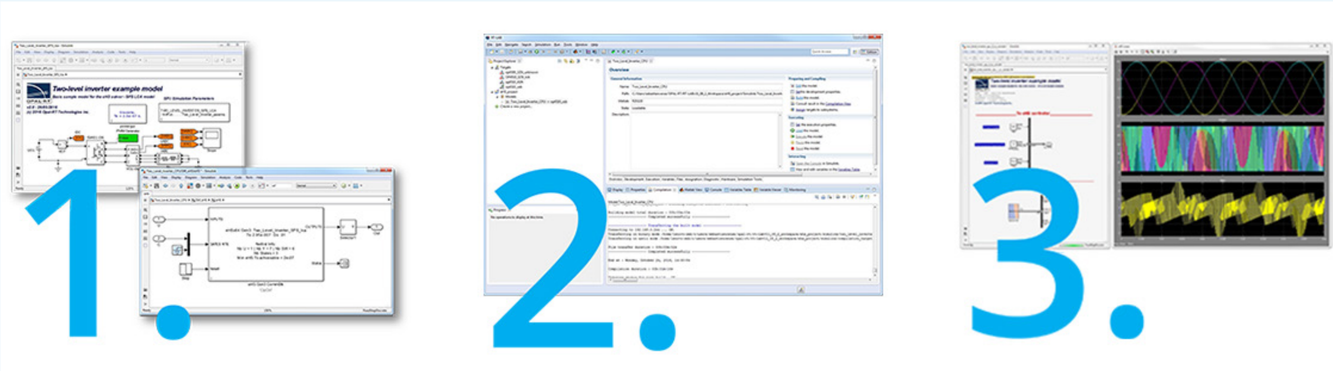
Jean Bélanger, President and CEO of OPAL-RT TECHNOLOGIES

FPGA-Based Power Electronics (eHS): The Right Toolbox For You To Do The Impossible

The Fastest FPGA-Based Power Electronics Toolbox in the Industry

Integrated directly with both OPAL-RT's & NI's real-time simulation platforms, eHS (OPAL-RT's FPGA-based Power Electronics Toolbox) is a powerful simulation tool for Hardware-in-the-Loop (HIL) testing. eHS enables the running of test sequences and on-the-fly changes to simulation parameters by using the Test Scenario feature. It allows the test engineer to jump from one set of component values to the next without stopping the simulation, and is the perfect system for all types of electrical conversion test applications.

From Modeling to Real-Time Simulation in Three Steps



Develop your power electronics diagram with Schematic Editor, or with your favorite circuit editor*.

Then, configure your I/O channels and compile your model for sub-microsecond time steps.

Finally, execute the real-time simulation and perform manual and automated tests.

* Supported circuit editors: Simscape Electrical™, PLECS, PSIM and NI Multisim.

The FPGA-Based Power Electronics (eHS) Toolbox is compatible with OPAL-RT's & NI's real-time simulation platforms

RT-LAB | HYPERSIM | NI VeriStand

SCHEMATIC EDITOR: EASILY BRING POWER ELECTRONICS MODELS TO REAL-TIME SIMULATION

OPAL-RT's new Schematic Editor is an intuitive user interface for building power electronics and is a part of eHS, the fastest FPGA-Based power electronics toolbox in the industry. It provides an advanced graphical editor and is integrated with OPAL-RT's & NI's real-time simulation platforms.

Button Header

Complete diagram actions quickly and easily.

Library & Model Browser

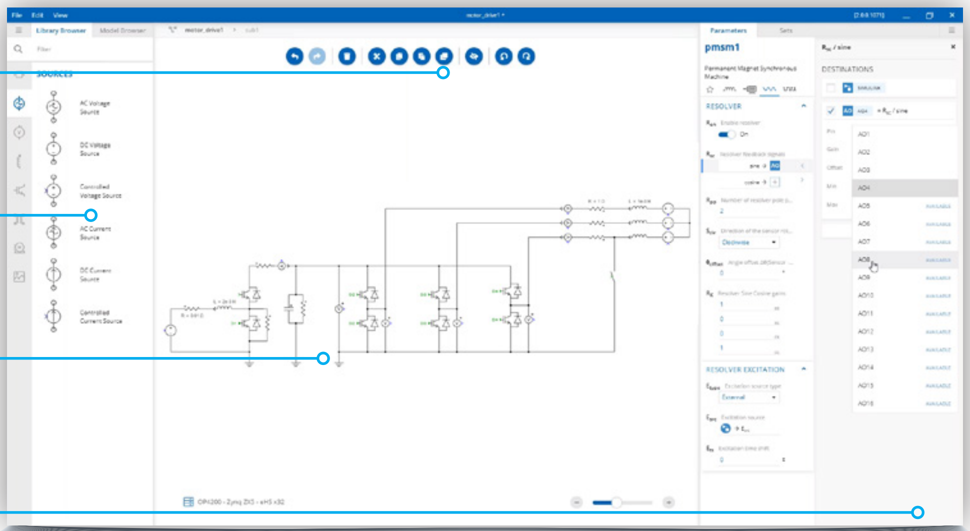
Integrate power electronics models with drag-and-drop components.

Work Area

Easily assembled and manipulated models.

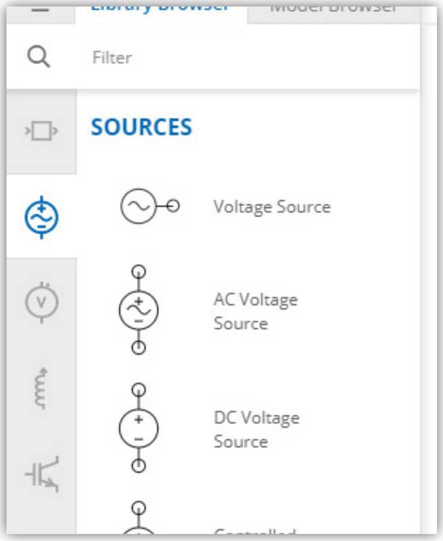
Parameters Side Bar

Edit parameters of the selected components.



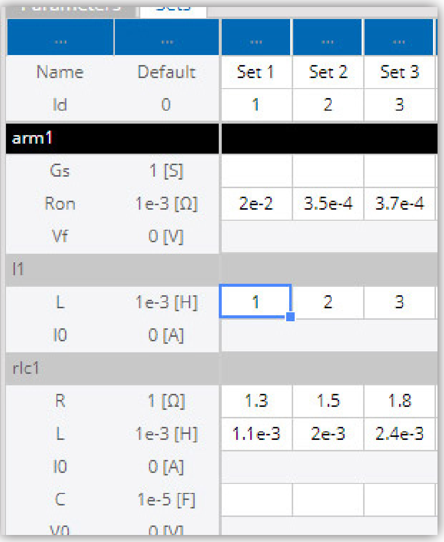
Library & Model Browser

Design power electronics models with ease through drag and drop components



Parameter Sets

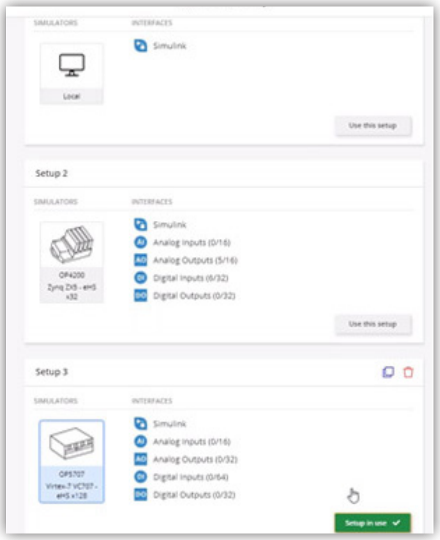
Select and apply parameter sets to test the model under various conditions during simulation.



Name	Default	Set 1	Set 2	Set 3
Id	0	1	2	3
arm1				
Gs	1 [S]			
Ron	1e-3 [Ω]	2e-2	3.5e-4	3.7e-4
Vf	0 [V]			
l1				
L	1e-3 [H]	1	2	3
I0	0 [A]			
rlc1				
R	1 [Ω]	1.3	1.5	1.8
L	1e-3 [H]	1.1e-3	2e-3	2.4e-3
I0	0 [A]			
C	1e-5 [F]			
V0	0 [V]			

Real-Time Simulator Setup

Access Setup for connection of analog and digital I/Os to the circuit measurements and control.



MULTI-FPGA SIMULATION OF A DISTRIBUTION SYSTEM USING FPGA-BASED POWER ELECTRONICS TOOLBOX (EHS)

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 proved to be a computing platform of choice for the simulation of distribution power systems when the power electronics systems with high switching frequencies are predominant.

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

REAL-TIME PERFORMANCE

FPGA-Based Solution	# eHS Solvers	Max. # 3-ph Switches	Max. # 3-ph Bus Bars	Time Step
1 Kintex 7 410T	2	Up to 96	129	
2 Kintex 7 410T	4	Up to 192	258	5 us
3 Kintex 7 410T	6	Up to 288	387	

Setup

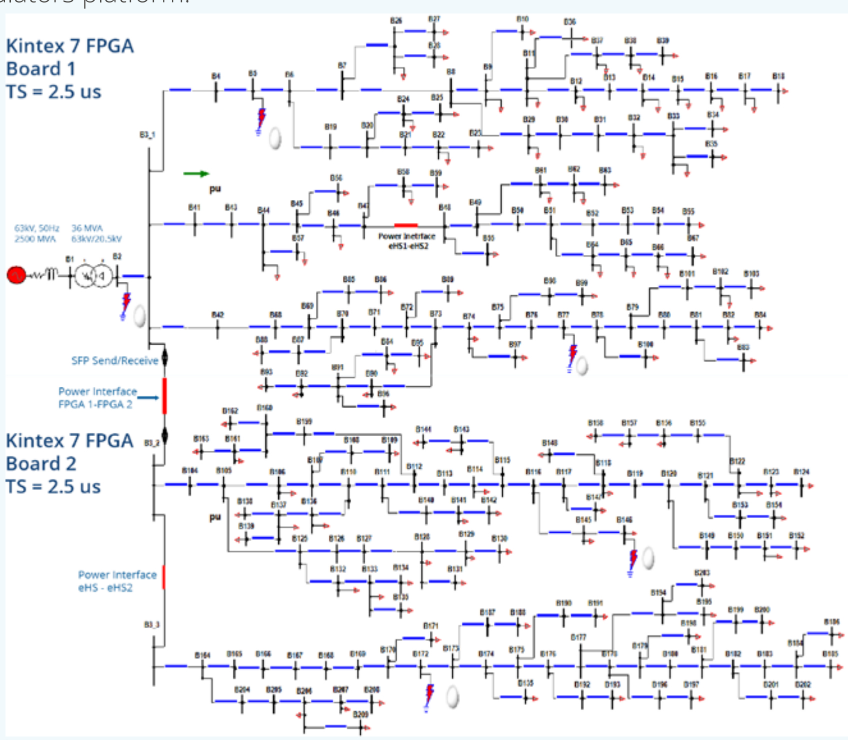
To demonstrate the effectiveness of the OPAL-RT platform, a large distribution network (DN) of 210 bus bars and a Microgrid (MG) are considered. The MG includes a solar panel and a battery energy storage system (BESS). The complete power system including the DN and MG is simulated using only two Kintex-7 FPGA boards with one OP4510 and one OP4520 FPGA simulators platform.

The controllers of the MG distributed energy resources (DER) are emulated using a Simulink model and executed on one core of the OP4510 simulator.

Several tests were performed on the MG and on the fast switching frequency converters.

The tests performed include:

- Test 1: Transitions from grid-connected mode to islanded 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 on the OPAL-RT OP4510 and OP4520 simulators

FPGA-BASED POWER ELECTRONICS TOOLBOX (EHS) COMPARISON CHART

Features	eHSx16	eHSx32	eHsx64	eHsx128
Targeted platforms	OP4200 (Zynq 7030)	OP4200 (Zynq 7030) OP4510 (Kintex7 325t)	OP4510 (Kintex7 325t) OP5700 (Virtex 7 485t)	OP4510 (Kintex7 410t) OP5607 (Virtex 7 485t)
Number of eHS core available	1	1	1 (OP4510) 3 (OP5700)	2
Number of inputs	16	32	64	128
Number of outputs	16	32	64	128
Number of switches	24	48	72	144
LCA capability**	Yes			
Maximum number of states**	84	112	168	344
Number of resistors	Unlimited			
Switches type supported	IGBT/Diode, Diode, Breaker, Thyristor, Ideal Switch			
Non-switching devices supported	Resistor, Inductor, Capacitor, Ideal Transformer, Mutual inductance, PI Line			
Calculation power	6.4 GFLOPS	12.8 GFLOPS	25.6 GFLOPS	51.2 GFLOPS
Maximum number of test scenarios***	Up to 512 scenarios			
Circuit editors compatible	Simscape Electrical™ (formerly SimPowerSystems™ and SimElectronics®), PLECS, PSIM, NI Multisim and OPAL-RT Schematic Editor			

* LCA stands for Loss Compensation Algorithm. This feature optimizes losses for standard topologies such as 2-level converter and NPC 3-level converter arms.

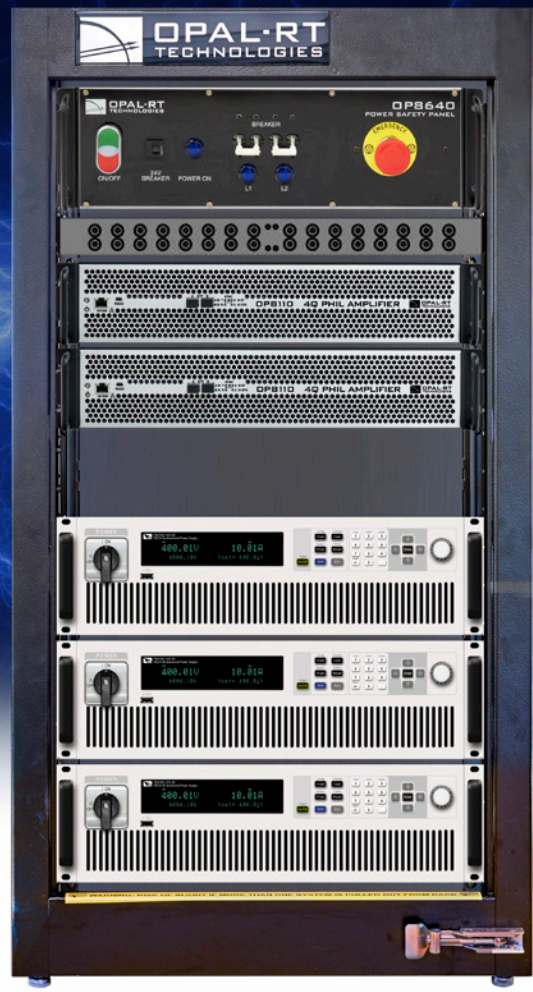
** Estimated values. The maximum number of states depends on the number of inputs and outputs that need to be computed as well. There is no hard coded limit.

*** The number of scenarios available for a given circuit depends on the circuit complexity.

OP1400 Series

4-Quadrant PHIL Amplifier

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



Introducing the OP1400 Series 4-Quadrant PHIL Amplifier: Optimize testing and validation of power systems and power electronics controls, in applications such as microgrid and protection.

The OPAL-RT OP1400 Series 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 OP1400 4-Quadrant PHIL Amplifier.

Key Features:

- High-fidelity 4-Quadrant PHIL Amplifier with 100% non-dissipative regeneration
- Available as 5, 10, or 15KW 3-phase modules with independent phases (other configurations available upon request)
- AC & DC 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

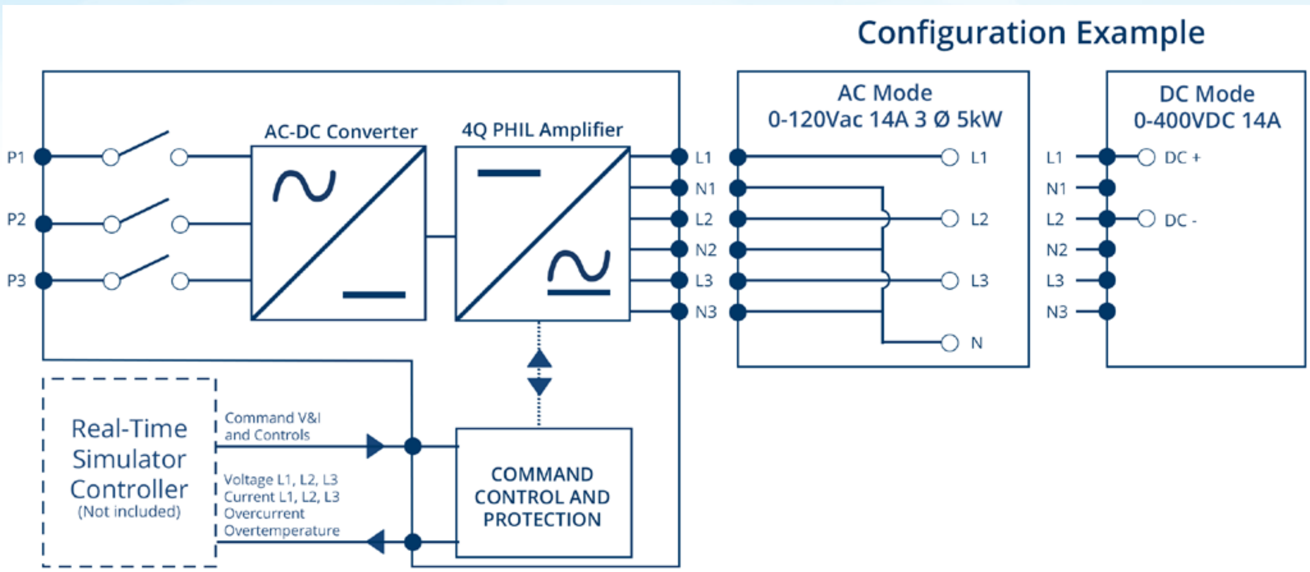
PRODUCT HIGHLIGHTS

- Innovative soft-switching cell based on SiC Transistors Technology
- Very high efficiency >96%
- 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

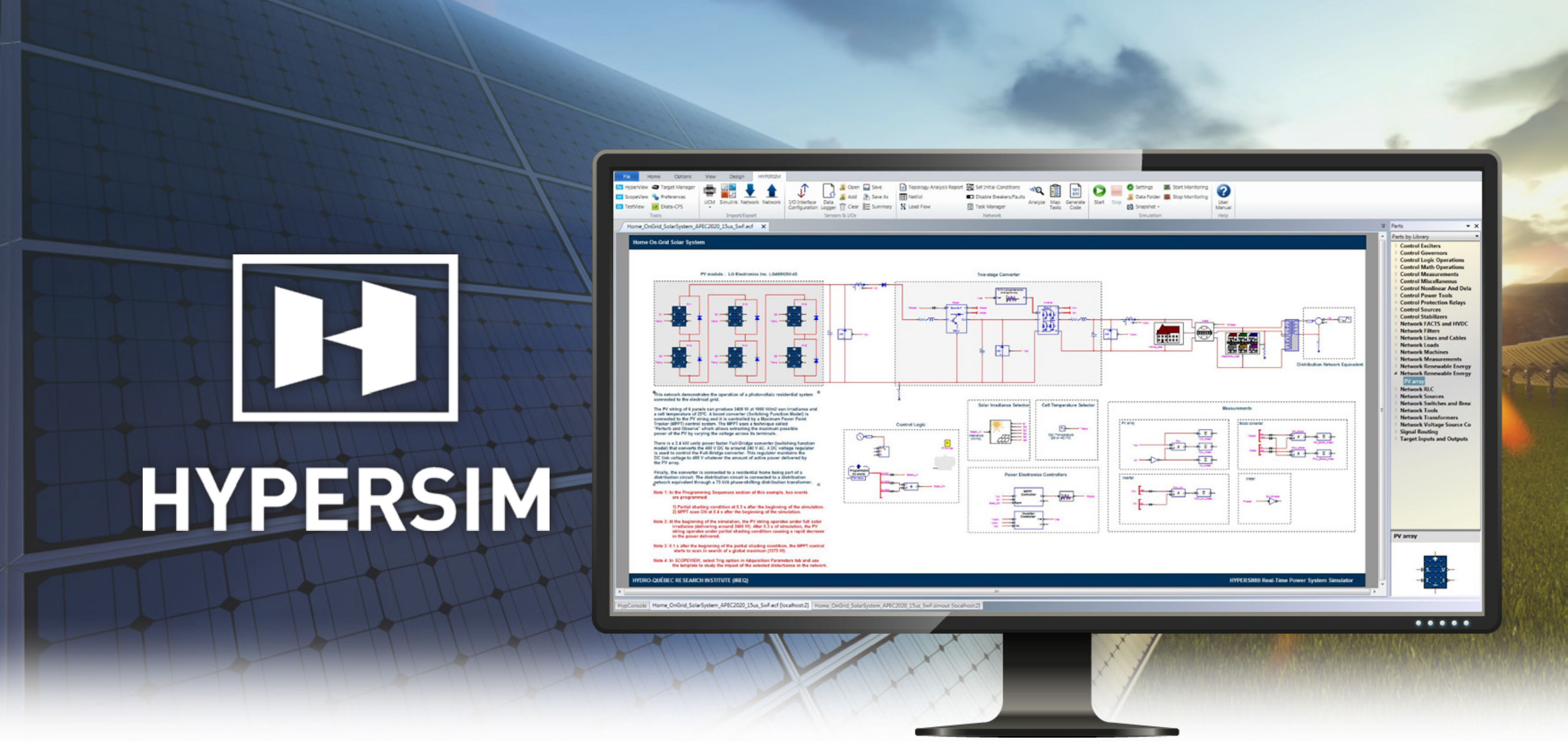
- RT-LAB Multi-Domain - Simulink-Based Software Platform: Ideal for research laboratories
- PHIL System Device Testing: Test your system controller, your algorithm or topology under real-world electrical conditions
- MicroGrid PHIL Testing: Create a microgrid topology where you can connect physical equipment.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

OP1400-10 | TYPICAL DIAGRAM 5KW / 120V

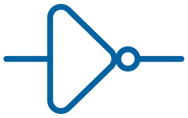


POWER MODULE SPECIFICATIONS

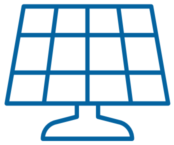
CHARACTERISTIC	OP1400-10	OP1400-20	OP1400-30	
	Configuration for 120Vrms			Configuration for 240Vrms
AC Mode Voltage Range (L-N)	0-120/208VRMS			0-240V/380Vrms
Total nominal Power	5KW at 120Vrms	10KW at 120Vrms	15KW at 120Vrms	10KW at 240Vrms
Maximum number of phase	3 phases	6 phases	9 phases	3 phases
DC Mode Voltage Range (DC+ DC-)	+/- 400VDC 1 DC ouput	+/- 400VDC 2 DC ouputs	+/- 400VDC 3 DC ouputs	
Current Range per phase	0-14 Arms			
Current Peak	20Apk			
Bandwith (Hz)	DC to 10 KHZ (-3db)			
Absorption capacity	100%, power regenered, no dissipation			
Cooling	Air forced			
Efficiency	90%			
THD (3dB)	0.5% @ 0 - 1kHz / 1% @ 1kHz - 2kHz / 2% @ 2kHz - 10kHz			
Slew Rate	5V/us, independant of the load			
Time delay Input to ouput	5.5us to 8.3us			



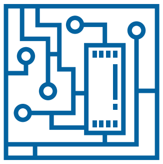
Home On-Grid PV Panel System Demonstration



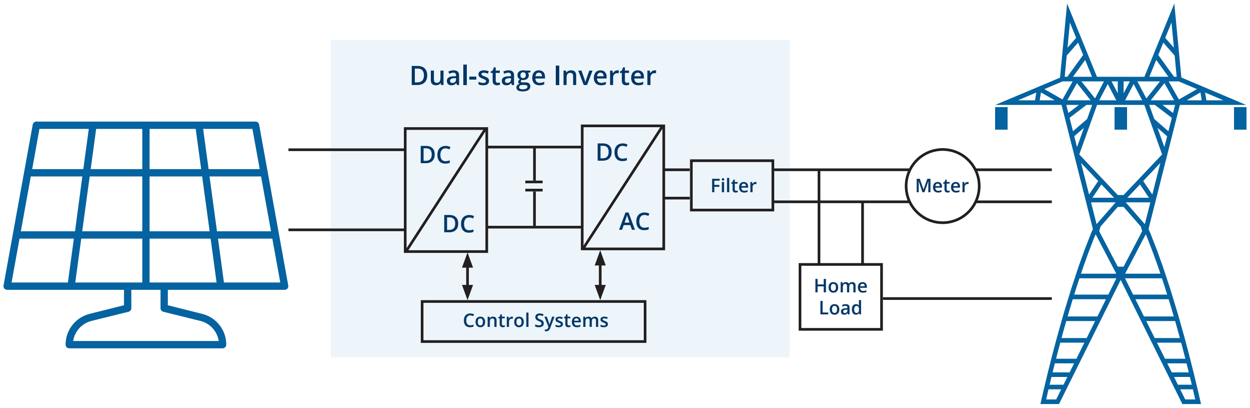
Dual-stage inverter (switching function model) + 6 PV panels with by-pass diodes running in real-time in 15 µs.



High fidelity PV model operation under partial shading conditions.

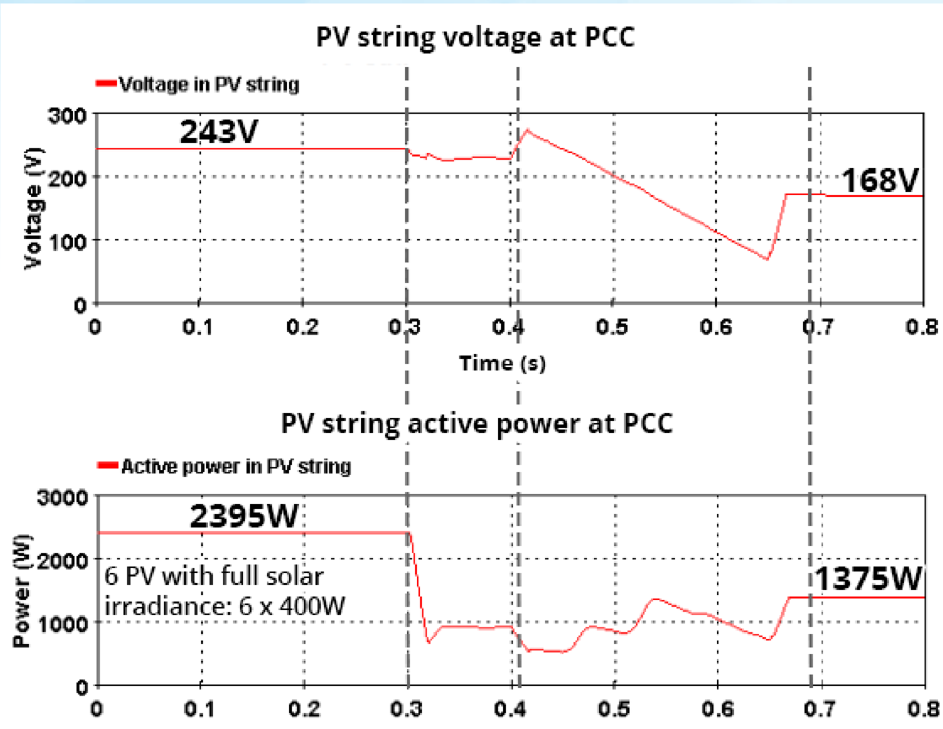


Simulink-based control systems.



- PV array produces 2400 W at 1000 W/m2 sun irradiance and a cell temperature of 25 C°.
- A Switching Function Model is connected/controlled by a Maximum Power Point Tracker (MPPT), using a 'Perturb and Observe' technique.
- Maximum power is extracted by varying the voltage across its terminals.

PV OPERATION UNDER PARTIAL SHADING

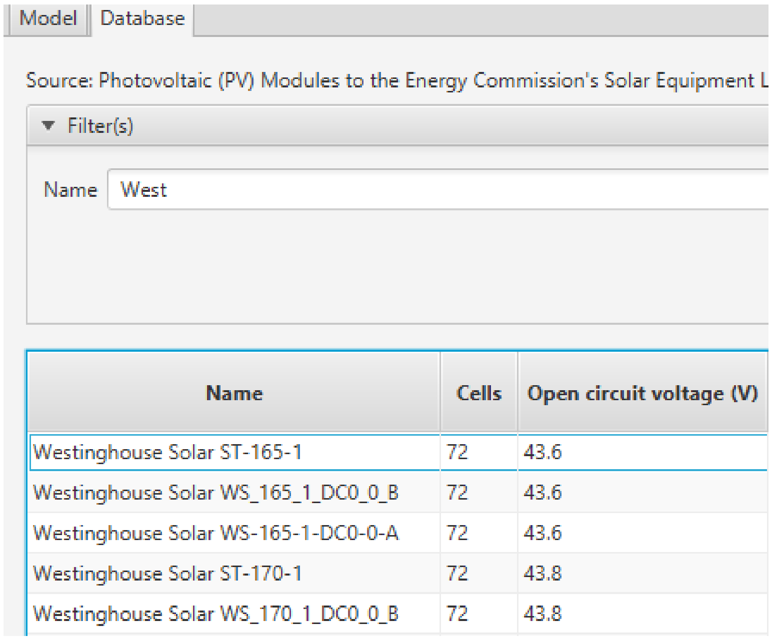


- Illustration, left, shows PV array under partial shading condition and MPPT operation.
- First vertical dotted line shows impact of partial shading.
- Second and third dotted lines show start and end of MPPT scan activity.

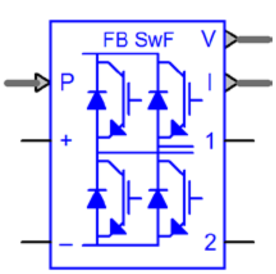
NEW FEATURES IN POWER ELECTRONICS LIBRARY & PV MODEL

New photo-voltaic (PV) component

- 21,000+ PV cell types supported.
- Based on the well-known five-parameter model for photovoltaic modules.
- High fidelity PV model capable of operating under partial shading conditions.
- Capable of switching operating temperature from 25C° to 45C° in real-time.



Name	Cells	Open circuit voltage (V)
Westinghouse Solar ST-165-1	72	43.6
Westinghouse Solar WS_165_1_DC0_0_B	72	43.6
Westinghouse Solar WS-165-1-DC0-0-A	72	43.6
Westinghouse Solar ST-170-1	72	43.8
Westinghouse Solar WS_170_1_DC0_0_B	72	43.8



Four new switching functions for VSC simulation

- Can validate complex control algorithms using Control-Hardware-in-the-Loop simulation.
- Allow the study of not only the renewable energy source but its effects on power system operation, especially where the intermittent energy source constitutes a significant part of the total system capacity.
- Are modelled so that harmonics fidelity and power balances are maintained.

DER MODELS ON HYPERSIM

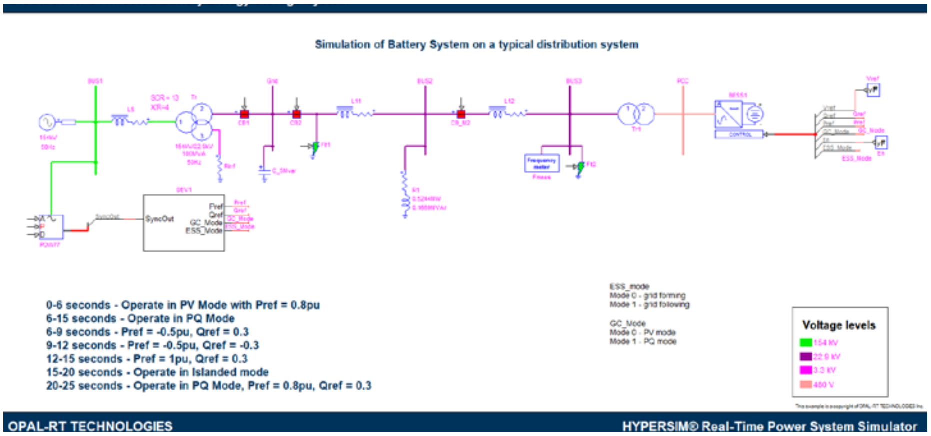
Addressing decentralized electric grid challenges with HYPERSIM

The growing interest in a more decentralized electric grid and new types of distributed energy resources (DER) has further increased 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 provides two approaches to including the study of DERs in complete and complex power system models:

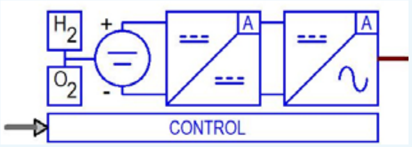
1) Average DER models:
Convenient for studies on interaction, supervision, protection and grid interconnection.

2) Detailed DER Models with FPGA-Based Power Electronics Toolbox (eHS):
For in-depth research and study on decentralized power electronics controls related to DERs.



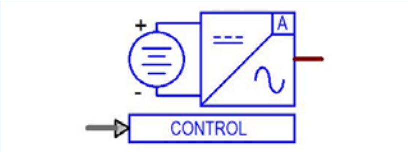
Distribution Connected Battery Energy Storage System with Average Converter

1) AVERAGE DER MODELS



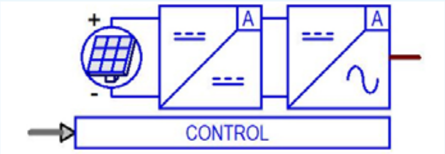
Fuel Cell Generation System Average (FCGS)

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

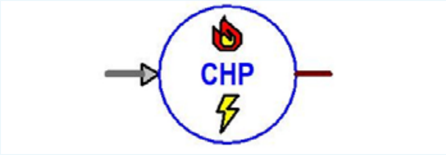


Battery Energy Storage System (BESS)

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: maximum power point tracking (MPPT) and 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.

2) DETAILED DER MODELS WITH FPGA-BASED POWER ELECTRONICS TOOLBOX (EHS)

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 shortly**

PROUD USERS OF OPAL-RT

OPAL-RT has gained the trust of over **800 customers**, including many Fortune 500 companies, academic institutions and laboratories. More than 2000 people are currently using OPAL-RT in more than 40 countries around the world.

SUCCESS STORY

OPAL-RT AND NI SOLUTION HELPS TO ENGINEER DC FAST-CHARGING SYSTEMS FOR EVs ON THE TRANS-CANADA HIGHWAY

UNIVERSITY OF TORONTO

ecamion POWER OVER ENERGY

Application

- Electric Vehicle Charging Stations

Related Products

- OPAL-RT FPGA-Based Power Electronics Toolbox (eHS)
- NI LabVIEW
- NI cRIO-9082

Type of Simulation

- Hardware-in-the-Loop (HIL)
- Rapid Control Prototyping (RCP)

OPAL-RT TECHNOLOGIES

INTRODUCTION

Electric Vehicles (EVs) have until now taken far longer to recharge than it takes to fill up a tank of gasoline, and yet they're becoming very popular. The missing piece has always been a fast recharge, say 20-30 minutes. This solution has been slow to evolve, because the existing infrastructure was not engineered for this challenge — either in speed or volume of electricity delivered.

Enter University of Toronto's Centre for Applied Power Electronics (CAPE), partnering with energy storage company eCAMION, in one of Canada's most ambitious EV infrastructure projects: build a DC Fast-Charging System (DCFCS) for EV charging stations on the Trans-Canada Highway: one of the longest highways in the world with a length of 7,821 km[1].

Team members of eCAMION and University of Toronto's Centre for Applied Power Electronics (CAPE)

CHALLENGES

The very concept of fast charging implies a large amount of energy in a short time (it's a bandwidth or throughput issue). University of Toronto's Professor Reza Iravani and his team from CAPE considered a new model, where electricity is stored in and discharged from local high-capacity batteries that are then refilled by the pre-existing infrastructure between users. These local battery storage units then become part of a larger system to reduce the impact of DC Fast-Charging Systems on the electrical infrastructure.

While this seemed to solve the throughput issue, the engineering challenges remained.

ELECTRIC GAS STATIONS

"...The idea here is to have large-scale, utility-grade battery systems to charge EVs," says Iravani. *"Drivers would charge their EVs from these large batteries—think of them like gas stations—in several minutes, and these stationary batteries would be gradually charged from the grid, based on the existing grid capacity.[2]"*

Dr. Reza Iravani - University of Toronto's Professor in the Department of Electrical & Computer Engineering (ECE), and founder of the CAPE

OBJECTIVE

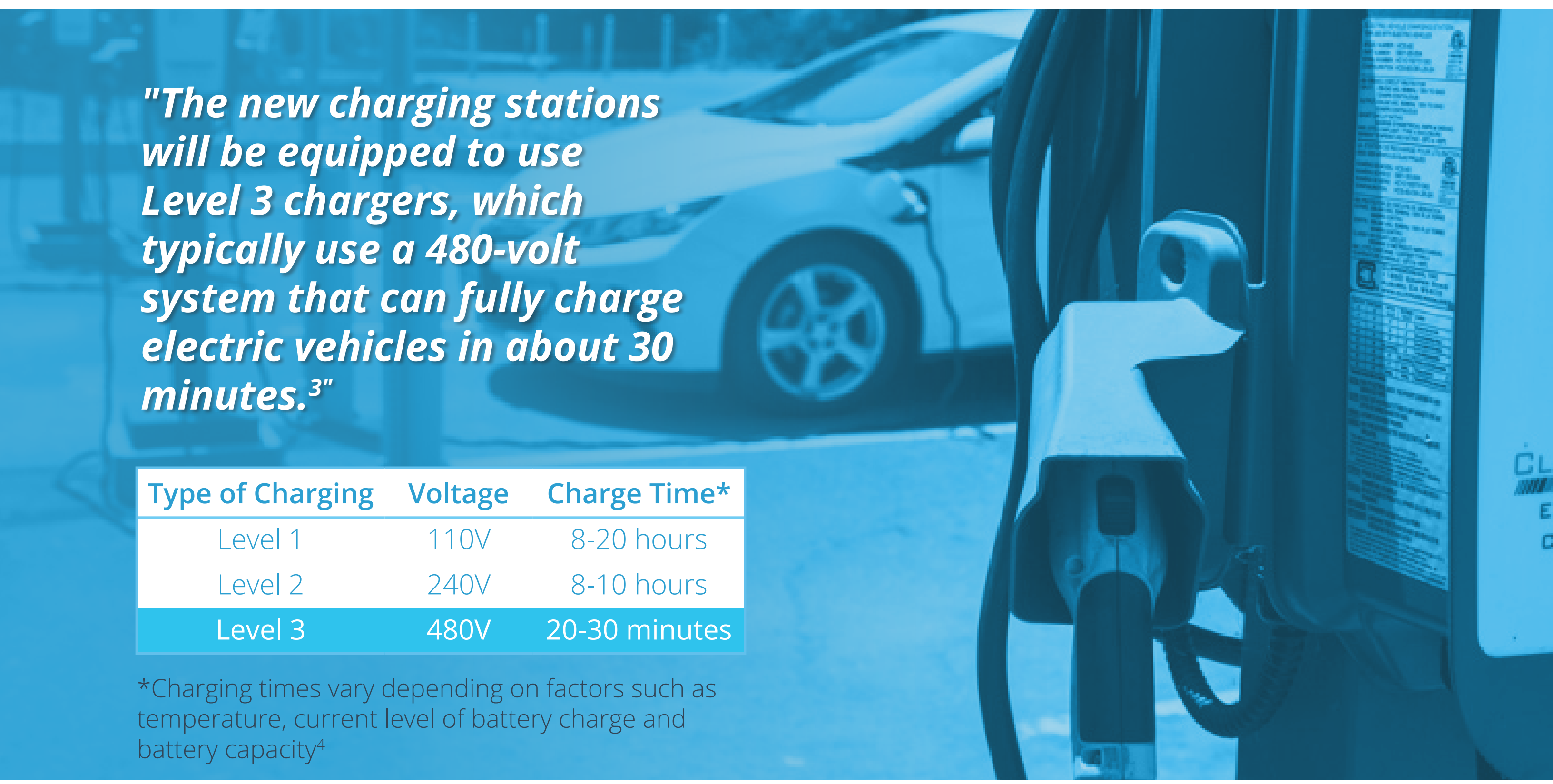
As the first and determining part of their challenge, CAPE's team needed to develop control algorithms for their DC Fast-Charging System (DCFCS), along with a local large-volume battery storage system. They decided to deploy the control algorithms on a cRIO-9082, a National Instruments' embedded controller (EC) for real-time simulation. When it came to the battery storage system, they partnered with eCAMION, a Toronto-based company with accumulated expertise in developing solutions for issues specific to EV adoption in existing infrastructures.

They also needed to simulate the power electronics model for the fast chargers, configure the power electronics converter, fine tune its controller design and complete development with a 60-kW prototype.

Due to the need for two fast-charging sequences (one from battery to car, the other from grid to battery afterwards), CAPE's team had to achieve higher-charging voltage by connecting two chargers in series, and implementing the Local Controller (LC) on the cRIO-9082.

Additionally, they had to develop and test (in real time and through HIL simulation) the Local Controller of the grid-interface's AC/DC converter on NI's cRIO-9082. Finally, they had to develop the Supervisory Control (SC) that coordinates the stations' Local Controllers.

Each new station was designed to consist of an energy storage system that uses large-format lithium-ion batteries and multiple outlets so that several cars can be charged at once. The stations are to be equipped to use Level 3 chargers, which typically use a 480-volt system that can fully charge electric vehicles in about 30 minutes. Level 2 chargers, found in homes and commonly seen in parking garages, use a 240-volt system and can fully recharge vehicles in about 8 to 10 hours.[3]

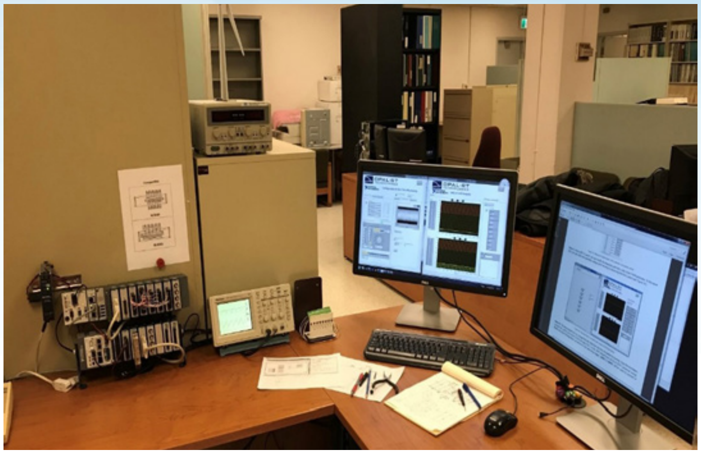


"The new charging stations will be equipped to use Level 3 chargers, which typically use a 480-volt system that can fully charge electric vehicles in about 30 minutes.[3]"

Type of Charging	Voltage	Charge Time*
Level 1	110V	8-20 hours
Level 2	240V	8-10 hours
Level 3	480V	20-30 minutes

*Charging times vary depending on factors such as temperature, current level of battery charge and battery capacity[4]

SOLUTIONS & DEVELOPMENT

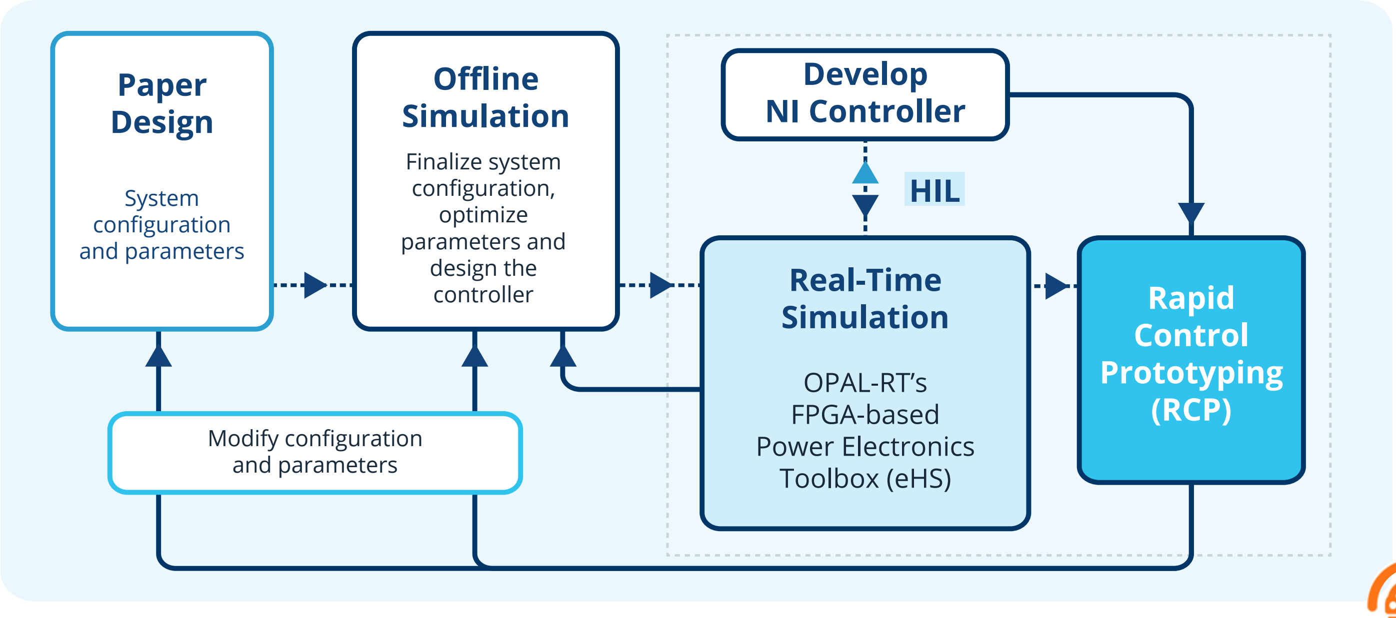


After starting the development process on paper to determine system configuration and parameters, CAPE's team went to offline simulation for finalizing the configuration, optimizing the parameters, and designing the controller.

They then went to OPAL-RT FPGA-Based Power Electronics Toolbox (eHS), for real-time simulation of the controller.

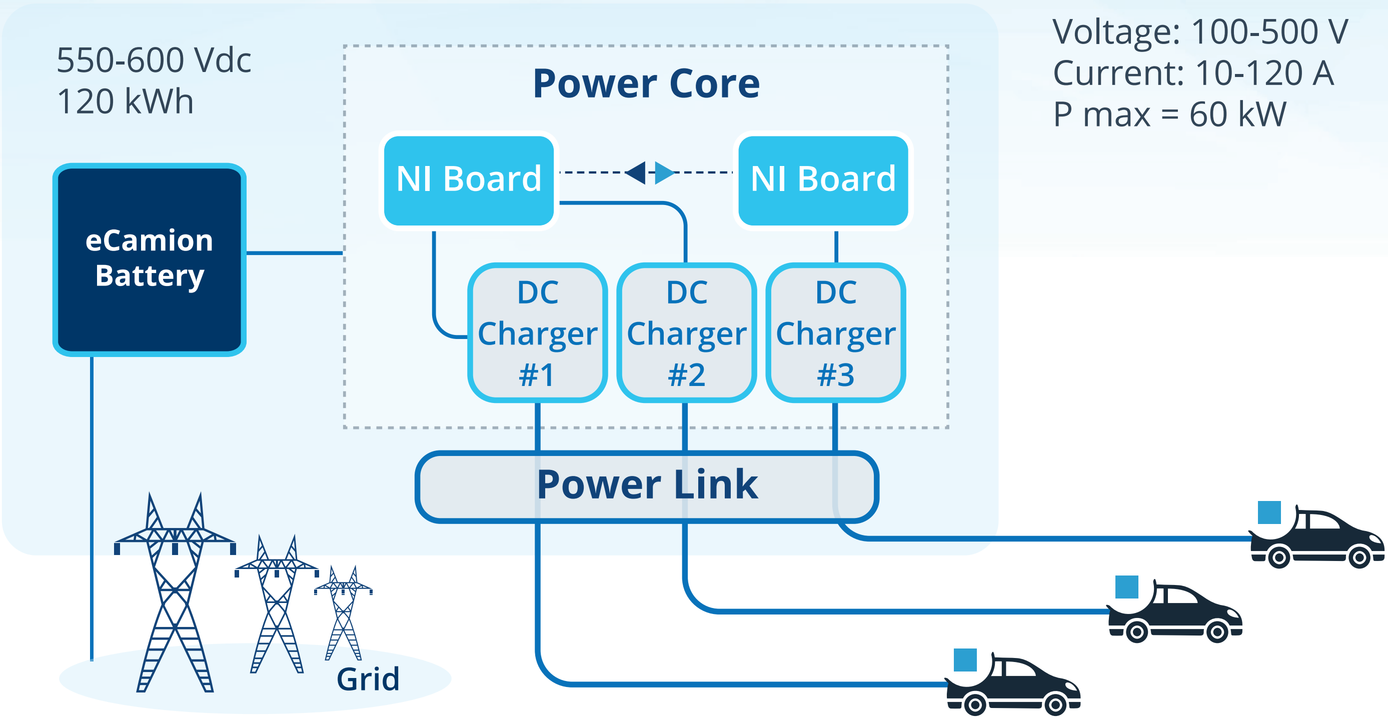
At this stage, an actual NI controller was introduced and simulated through HIL testing. In turn, this NI controller underwent Rapid Control Prototyping (RCP) to ensure that it functioned as required. This process was heavily iterative and alternated between simulation types as lessons learned from various stages were integrated into further testing iterations.

DEVELOPMENT PROCESS

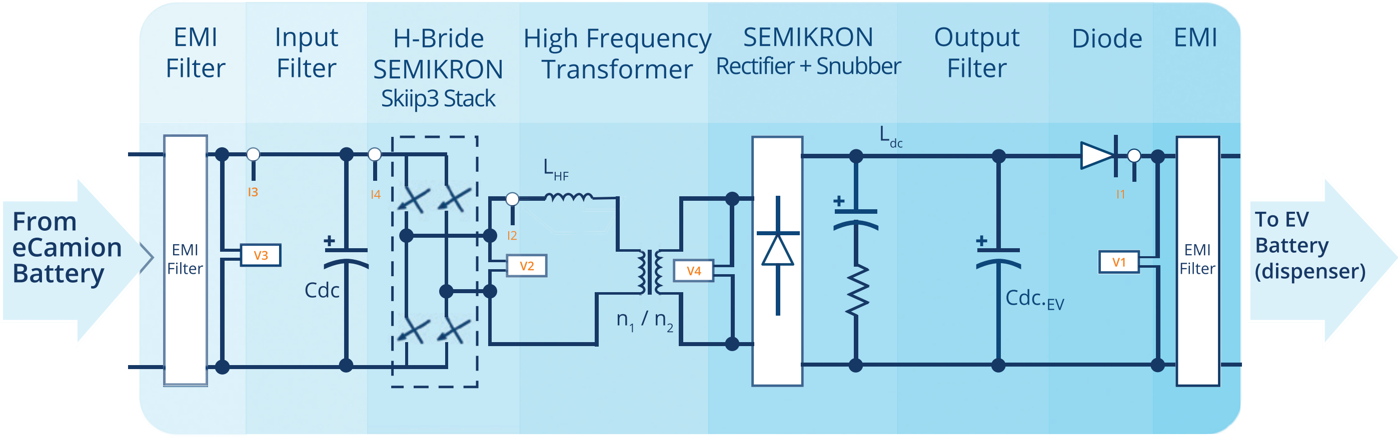


SOLUTIONS & DEVELOPMENT

CHARGING STATION: THREE CHARGER UNITS



CIRCUIT ELEMENTS OF ONE CHARGER UNIT (POWER CORE)



RESULTS

The final product was UL and ESA approved.

The final converter had been developed in less than two years (January 2018 to June 2019) and its final configuration involved:

- An isolated DC-AC-DC converter that enabled serial/parallel configuration at the EV end.
- 10 kHz in switching frequency that reduced the size of the output filter and the magnetics
- A phase-shift gating control strategy that provided soft-switching conditions
- Unidirectional power flow from the H-bridge at the front end and diode rectifier at the EV end

CONCLUSION

OPAL-RT's FPGA-based Power Electronics Toolbox (eHS) —used throughout the course of the development of the units—allowed the engineers to, in their own words:

- EXPEDITE the development process
- LOWER the development costs
- REDUCE the safety risks inherent in developing the systems at high voltage and currents

Project organizers estimate the EV charging network will reduce emissions by an estimated 0.7 million tonnes over the first five years of its operation[5].

OPAL-RT thus played a central role in **one of the most ambitious EV infrastructure projects yet to take place, worldwide**, through its FPGA-based Power Electronics Toolbox (eHS).

OPAL-RT hosted a webinar that had the participation of team members of the University of Toronto (Dr. Ali Nabavi and Mostafa Mahfouz), and eCAMION's VP Engineer (Rick Szymczyk).

This project received funding through the TargetGHG program, funded by Ontario's Ministry of Research, Innovation and Science (MRIS) and administered by Ontario Centres of Excellence (OCE), and through the Natural Sciences and Engineering Research Council of Canada (NSERC) as well as from eCAMION6, totalling $2.4M over three years.

1 https://www.roadtraffic-technology.com/features/feature-the-worlds-longest-highways/

2 https://news.engineering.utoronto.ca/reducing-range-anxiety-electric-vehicles-speeding-charging-time/

3 https://www.ecamion.com/fast-charging-stations-for-electric-vehicles-coming-to-trans-canada-highway/

4 http://www.mto.gov.on.ca/english/vehicles/electric/charging-electric-vehicle.shtml

5 https://www.canadianmanufacturing.com/manufacturing/energy-storage-firms-building-ev-charging-network-along-trans-canadahighway-197770/

SUCCESS STORY

MMC TEST BENCH: LABORATORY-SCALED (MULTI-TERMINAL) HVDC TO MODERNIZE THE EUROPEAN ELECTRICITY GRID

RWTH AACHEN UNIVERSITY

Application

- Modular Multilevel Converter (MMC)
- HVDC

Related Products

- HYPERSIM
- OP5707
- OP4510
- OP1210
- MMC Test bench

Type of Simulation

- Power-Hardware-in-the-Loop (PHIL)

INTRODUCTION

The need for both reliable and efficient long-distance transmission has been centrally important to the evolution and growth of Voltage Source Converter (VSC) High Voltage Direct Current (HVDC) transmission schemes over the past years.

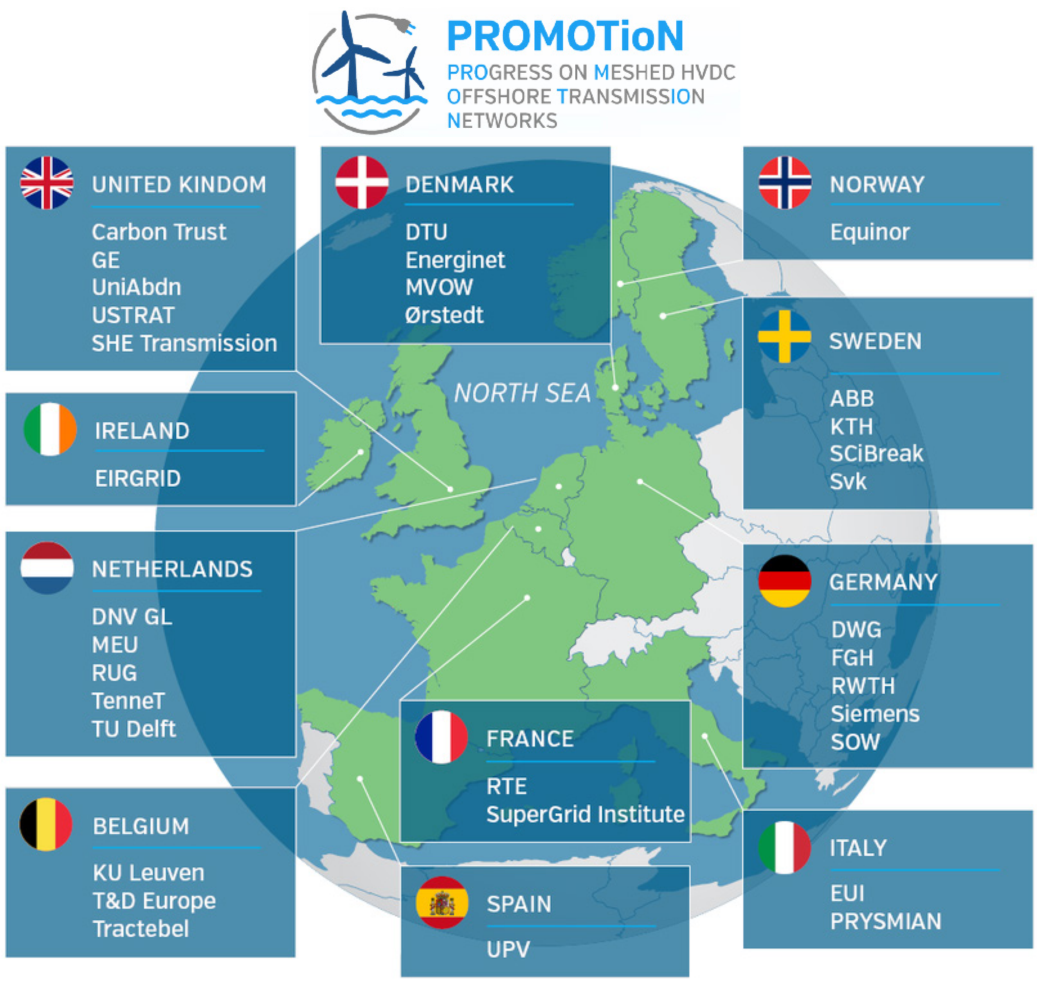
The most common type of VSC-HVDC converter is the Modular Multilevel Converter (MMC). MMC's distinctive topology provides a wide variety of features new to many grids, necessitating the use of increasingly sophisticated controllers.

It's not unusual for major and ambitious engineering infrastructure projects of such complexity to take a while to come to fruition. These typically involve advanced research and development (R&D), cutting-edge technology, and a lot of planning. Testing and validation of MMC's controls becomes crucial for R&D to develop accurate system models in a fast, reliable, and cost-effective way.

OPAL-RT TECHNOLOGIES was very proud to collaborate with RWTH Aachen University, located in Western Germany, in one of the most ambitious and exciting engineering projects in Europe: PROMOTioN (PROgress on Meshed HVDC Offshore Transmission Networks).

Started in 2015, the project encompasses 33 partners from 11 European countries[1], and aims to modernize the European electricity grid by developing meshed HDVC offshore grids based on cost-effective and reliable technological innovation[2].

OPAL-RT not only provided the modular multilevel converter (MMC) test benches to the Institute for High Voltage Equipment and Grids, Digitalization and Power Economics at RWTH University in Aachen, but also was closely involved in their integration and implementation.



THE GOALS & CHALLENGES

Multi-terminal HVDC offshore grids evacuating several gigawatts of wind power from the North and Baltic Seas are foreseen as part of a key solution within the modernization of the European electricity grid. The safe and reliable operation of such HVDC networks, however, causes new challenges for grid operators, grid planners and manufacturers.

One of the goals of this project is to study the new challenges linked with the control and protection of multi-terminal DC systems, as well as their interaction with continental transmission grids and wind power plants.

All the same, testing HVDC systems with full-scale conditions remains very challenging and, in many cases, impossible due to the limited access to existing infrastructure and high safety requirements.

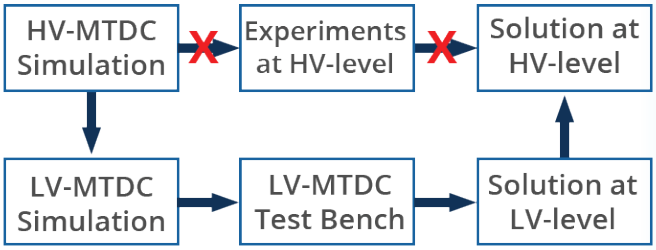
MAJOR OBSTACLE

"The integration of point-to-point and multi-terminal HVDC systems into existing AC transmission systems present novel challenges to transmission grid operators, grid planners and manufacturers. A major obstacle towards the realization of HVDC networks and complex integrated AC/DC systems is the limited experience regarding their operation and control as well as their interaction with the surrounding AC systems, such as continental transmission grids or offshore wind power plants." [3]

Philipp Ruffing, Team Leader DC-Systems at the Institute for High Voltage Technology - RWTH Aachen University

THE SOLUTION & IMPLEMENTATION

One solution, as presented in the schematic below, was to use a low-voltage multi-terminal DC test bench and to apply the solutions found at the low power level area to the high-power level domain.



High-voltage multi-terminal direct current (HV-MTDC)
Low-voltage multi-terminal direct current (LV-MTDC)

"The laboratory-scaled (multi-terminal) HVDC demonstrator – the MMC Test Bench – serves to address these issues. It is a unique laboratory, which is used for the investigation and demonstration of Modular Multilevel Converter (MMC) controllability in integrated AC/DC systems." [3]

THE SOLUTION & IMPLEMENTATION

To investigate the interactions between HVDC grids, offshore wind power plants and AC transmission systems, the low-voltage DC test system was embedded in a real-time simulation of the surrounding AC systems through the use of four-quadrant linear power amplifiers in a Power-Hardware-in-the-Loop (PHIL) setup, as illustrated below.

• The AC grid and wind farm simulation is running with HYPERSIM software on an OP5707 HIL simulator.

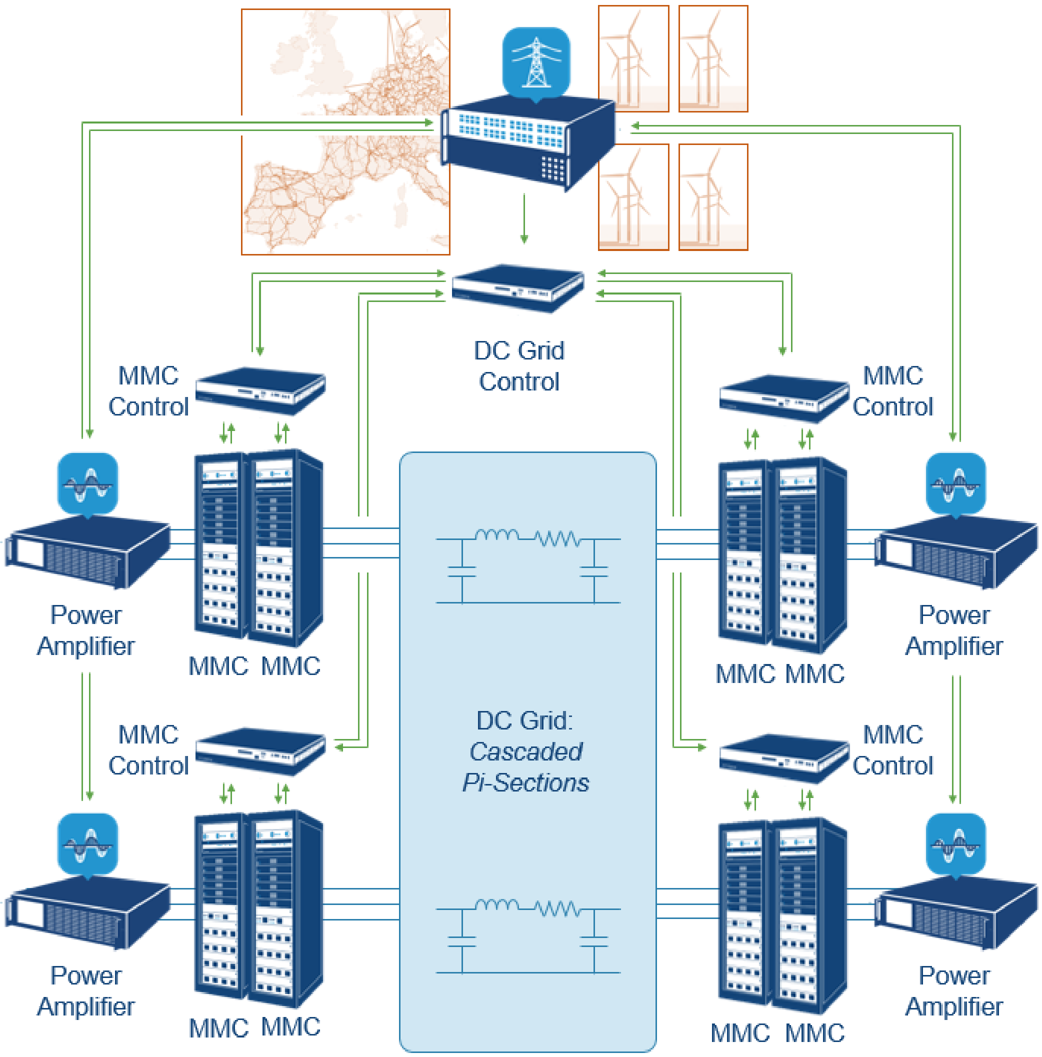
• The laboratory scale MMC converters are coupled with the simulation using four 21kVA linear power amplifiers from *Puissance Plus*.

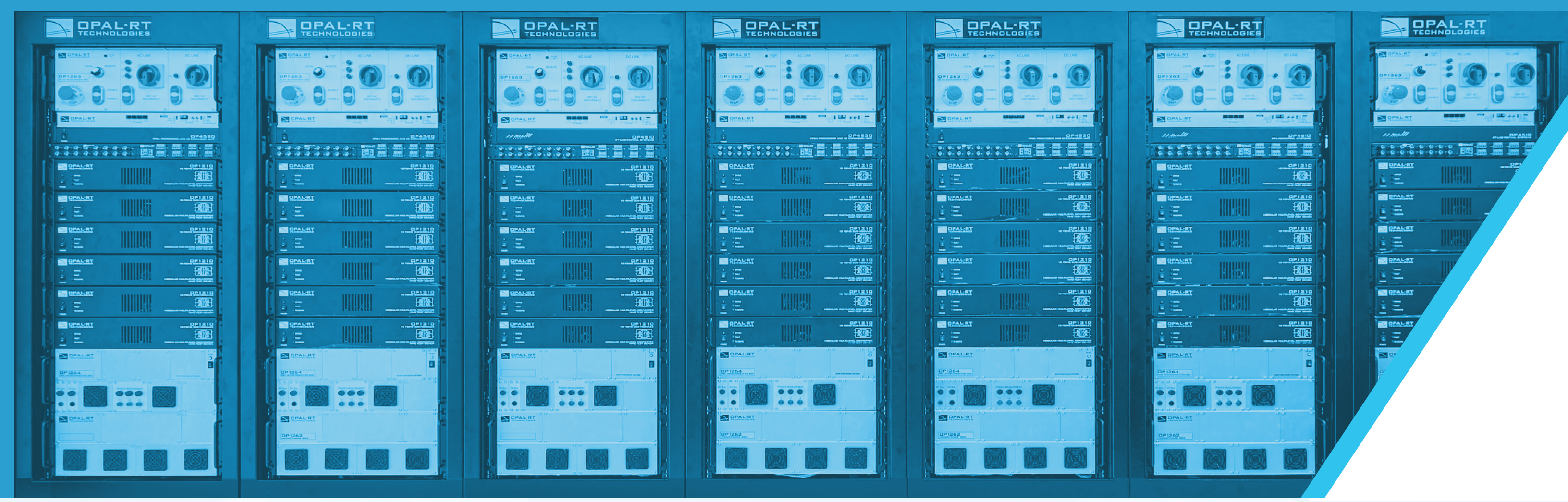
• The DC system has been emulated with PI sections and interconnects the various MMC test benches.

• The **high**-level control of the each MMC are implemented on the CPU and the **low**-level controls are implemented on the FPGA of an OP4510.

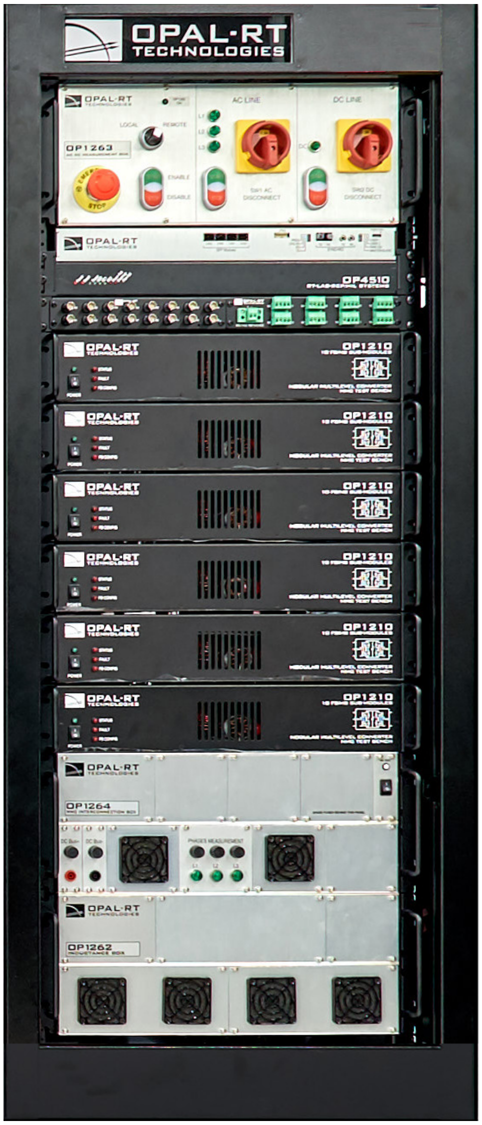
• Eight OPAL-RT Lab-Scaled MMC test benches are in the laboratory. Each of them is composed of an OP4510 for the low-level control and 6 times OP1210 boxes (each of them representing an arm of the MMC converter).

REAL-TIME SIMULATION





THE SOLUTION & IMPLEMENTATION



OP4510

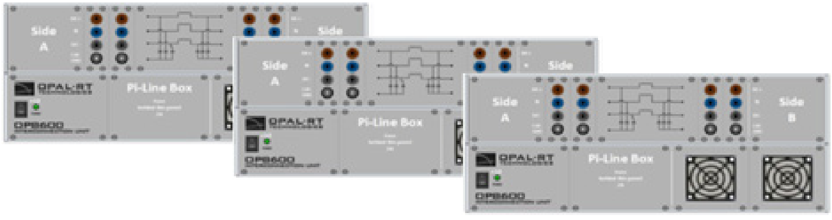
Equipped with the latest generation of Intel Xeon four-core processors and a powerful Xilinx Kintex 7 FPGA, the OP4510 delivers raw simulation power for both CPU-based real-time simulation and sub-microsecond time step power electronic simulation.

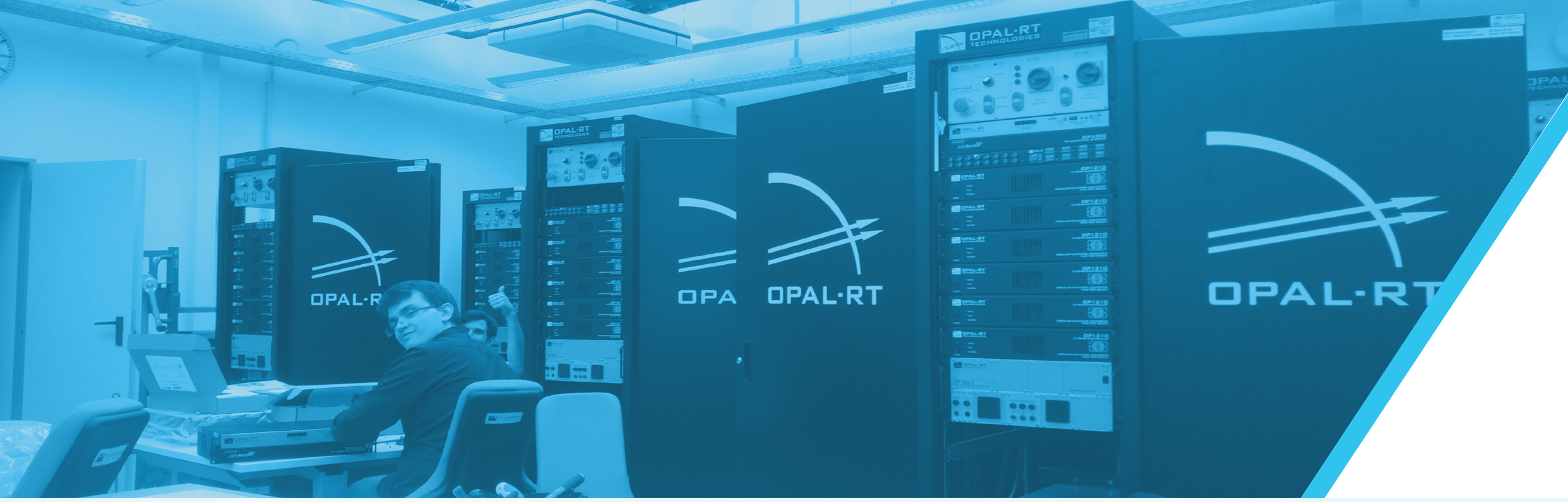
OP1210

The OP1210 box is composed of 10 submodules (thus 11 levels), has a nominal voltage of 400V and can be operated as a half-bridge or a full-bridge topology. The rated power of the lab scaled MMC is 6 kW. The flexible setup of the system enables studies in both monopole and bi-pole network configurations.

OP8600

Thirty-two PI sections are used to emulate the DC link, which can represent up to 800 kilometers in bipolar network configuration and 1600 kilometers in monopolar network configuration.





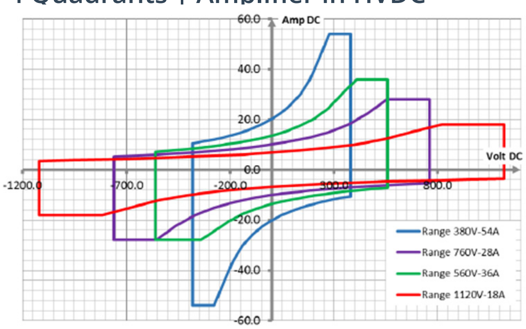
THE SOLUTION & IMPLEMENTATION

Power Amplifiers: *Puissance Plus* PA-3x7000VA

PA-3X7000 is a four-quadrant voltage amplifier with three phases: AC, AC+DC or DC. Its high electrical performance allows the testing or simulation of all kinds of generators or loads. Learn more at *www.puissanceplus.com*

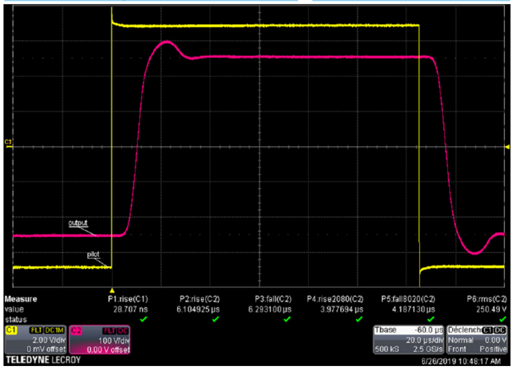
SPHEREA
PUISSANCE PLUS

4 Quadrants | Amplifier in HVDC



Bandwidth

Output Bandwidth	
Full scale	DC — 15 kHz
Small signals at -3 dB	70 kHz

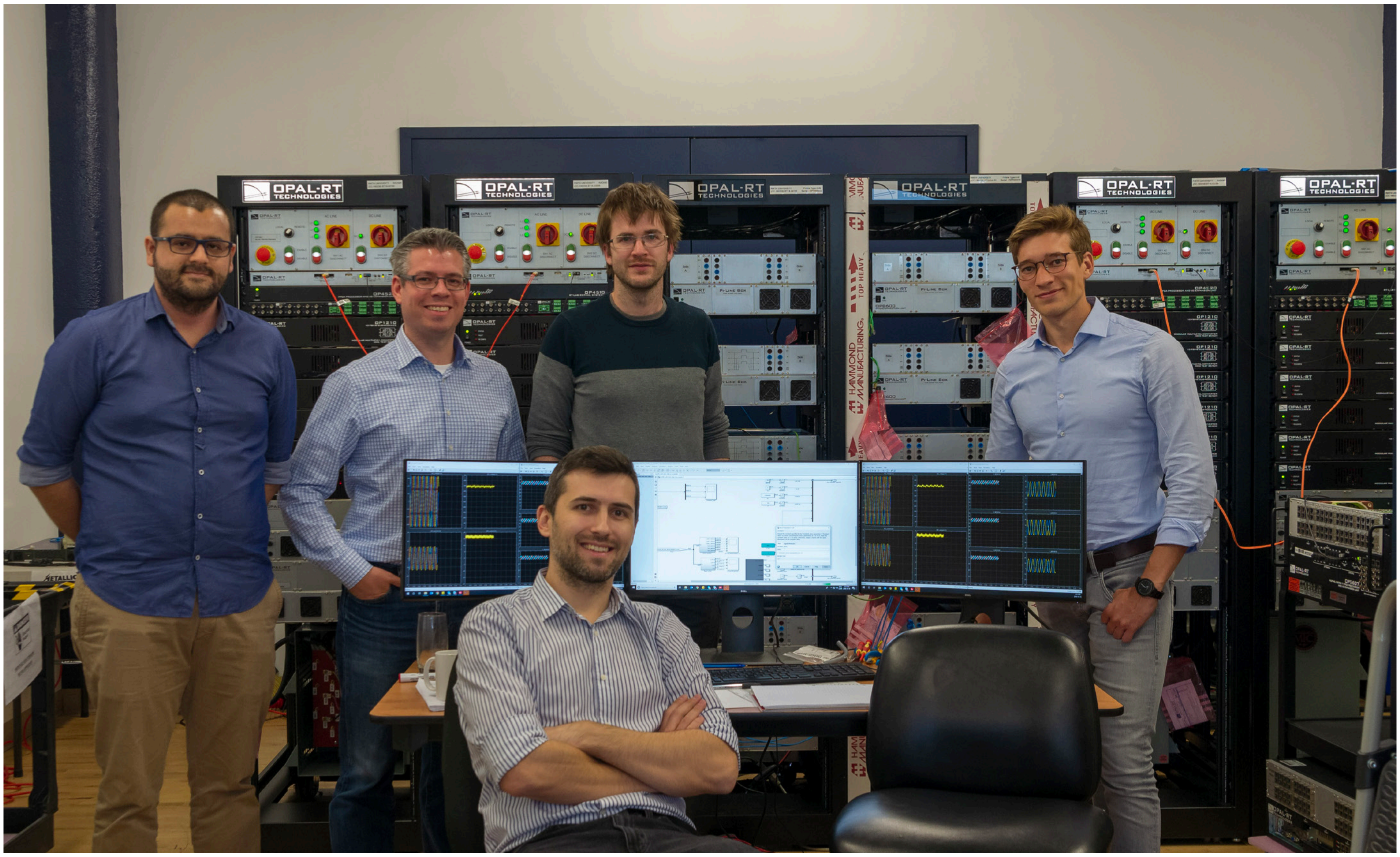


RESULTS

In July 2019, successful commissioning and testing of a multi-terminal HVDC demonstrator occurred, only 8 months after the successful Factory Acceptance Test at OPAL-RT's Montreal offices. This is, by any standards, an impressive amount of time for a project of this complexity.

Thanks to this MMC test bench demonstrator, some deep demonstration test cases are currently being investigated by RWTH such as:

- AC grid support such as control strategies for the provision of ancillary services
- Black-start capability of diode rectifiers connected to offshore wind farms
- Offshore wind park harmonic resonance analysis with MMC-HVDC connection
- DC faults handling in DC networks



Members of RWTH Aachen University and OPAL-RT in Montreal during the successful Factory Acceptance Test. From left, standing: Daniel Herrera, Matthias Heidemann, Jerome Rivest, and Philipp Ruffing; sitting: Nikola Stankovic. Photo by M. Heidemann.

[1] https://www.promotion-offshore.net/about_promotion/the_project_partners/

[2] https://www.promotion-offshore.net/about_promotion/the_project/

[3] https://www.iaew.rwth-aachen.de/cms/IAEW/Forschung/Infrastruktur-Tools/~dqtqn/MMC-Test-Bench/?lidx=1

ABOUT US

Founded in 1997, OPAL-RT TECHNOLOGIES is the leading developer of open real-time digital simulators and Hardware-In-the-Loop testing equipment for electrical, electro-mechanical and power electronic systems.

OPAL-RT simulators are used by engineers and researchers at leading manufacturers, utilities, universities and research centres around the world.

OPAL-RT's unique technological approach integrates parallel, distributed computing with commercial-off-the-shelf technologies.

The company's core software, RT-LAB, enables users to rapidly develop models suitable for real-time simulation, while minimizing initial investment and their cost of ownership.

OPAL-RT also develops mathematical solvers and models specialized for accurate simulation of power electronic systems and electrical grids. RT-LAB and OPAL-RT solvers and models are integrated with advanced field programmable gate array (FPGA) I/O and processing boards to create complete solutions for RCP and HIL testing.

OPAL-RT CORPORATE HEADQUARTERS
1751 Richardson, Suite 2525 | Montréal, Québec, Canada | H3K 1G6
Tel: 514-935-2323 | Toll free: 1-877-935-2323 | Fax: 514-935-4994

U.S.A.
OPAL-RT Corporation
2532 Harte Dr
Brighton, MI
48114, USA
Phone: 734-418-2961
Toll free: 1-877-935-2323
Fax: 1-866-462-5120

EUROPE
OPAL-RT Europe
196 Rue Houdan
92330 Sceaux
France
Tel: +33 1 75 60 24 89

GERMANY
OPAL-RT Germany GmbH
Bucher Straße 100
90408 Nürnberg
Germany
Tel: +49 (0) 911 38 44 52 02

INTELLIGENT TRANSPORTATION SYSTEMS
OPAL-RT Intelligent Transportation Systems
10 Vivier Merle boulevard
Lyon, France, 69393
Tel: +33 67 60 80 36 08

INDIA
OPAL-RT Technologies India Pvt. Ltd.
648/A-4/5, 2nd Floor,
OM Chambers,
100 Foot Road
Indiranagar 1st Stage
Bangalore, Karnataka
560038, India
Tel: 080-25200305
Fax: 080-25200105

WWW.OPAL-RT.COM