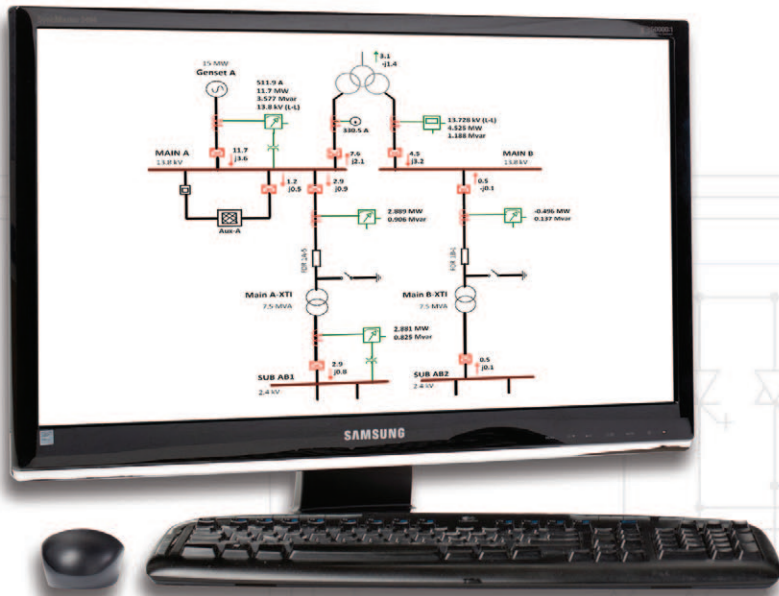# eMEGAsim™

## Real-Time Digital Simulator for Power System Engineers

Design and Test Protection Equipment, Relays and Power Electronic Controllers

Hardware-in-the-Loop Solutions for Generation, Transmission and Distribution Systems Study and Test
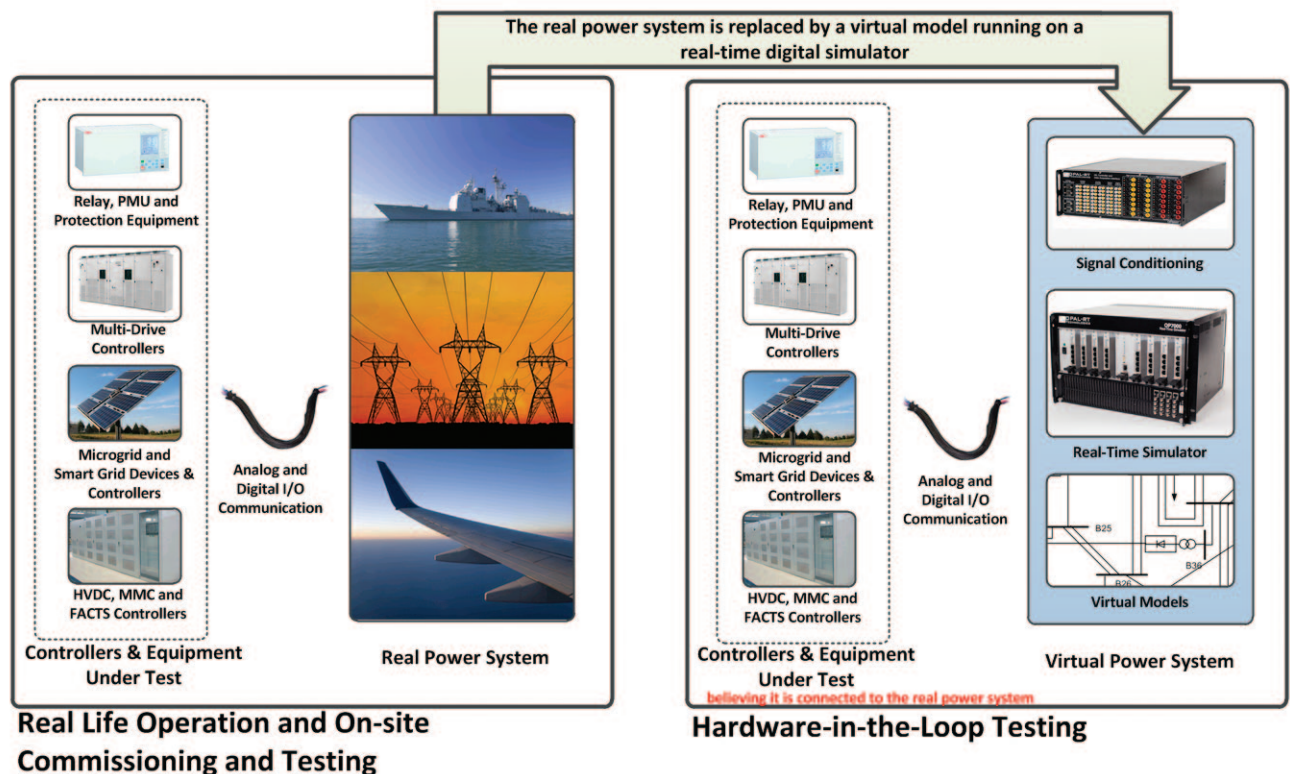
OPAL-RT
TECHNOLOGIES

**opal-rt.com**

## Hardware-in-the-Loop Simulation for Developing and Testing Control and Protection Equipment Used in Power Grids and Power Electronics Systems

Hardware-in-the-loop (HIL) or controller-in-the-loop simulation is a technique used to develop and test controller and protection systems. The goal is to verify and certify the functionality, performance, quality and safety of the controller and protection system software program. To achieve that, actual control and protection equipment under tests are connected to a simulator through current and voltage interfaces in the same way as in real life. The simulator simulates with great accuracy and high fidelity the steady-state and transient behaviour of the modelled system under normal and faulty conditions. By recreating reality, the controller is "fooled" into believing it is wired to the real physical system. It then becomes possible to obtain all the flexibility needed to test the controller and protection equipment under any operating conditions. Power hardware-in-the-loop (PHIL) is the HIL concept extended to power components. In PHIL simulation, I/Os require high power flows to test power converters, generators, FACTS, and so on.

The successful and reliable implementation of PHIL and HIL simulations requires sound models, fast program execution, with reaction times below a few microseconds and fast I/O communication, so the controller and protection system is tested in conditions identical to those it would be submitted to in reality. You also need a set of tools that allow you to monitor and interact with the simulator and visualization tools to interpret results (scope, graphs, data logging, etc). In addition to its scalability, these are the key features of OPAL-RT's eMEGAsim (tm) real-time digital simulator.



The real power system is replaced by a virtual model running on a real-time digital simulator

Relay, PMU and Protection Equipment

Multi-Drive Controllers

Microgrid and Smart Grid Devices & Controllers

Analog and Digital I/O Communication

HVDC, MMC and FACTS Controllers

Controllers & Equipment Under Test

Real Power System

**Real Life Operation and On-site Commissioning and Testing**

Relay, PMU and Protection Equipment

Signal Conditioning

Multi-Drive Controllers

Real-Time Simulator

Microgrid and Smart Grid Devices & Controllers

Analog and Digital I/O Communication

B25

HVDC, MMC and FACTS Controllers

B26

Virtual Models

Controllers & Equipment Under Test

believing it is connected to the real power system

Virtual Power System

**Hardware-in-the-Loop Testing**

## From Analog to Fully Digital Simulators: a proven reliable approach

HIL simulation for power grids has been used for decades to test new power system design, mainly for high-voltage transmission systems, and to test new power electronic devices intended to stabilize power systems (FACTS) and to interconnect systems using HVDC. Before 1990, HIL simulation was traditionally performed using analog simulators, which where rather expensive and difficult to operate. Fully digital real-time simulators were developed in the nineties by several research centers to decrease the cost of power system simulators and to facilitate their maintenance and operation.

Fully digital, real-time simulators, such as the e*MEGA*sim™, have been commercially available since 2000, effectively replacing expensive analog simulators for the simulation of power grids using thyristor-based power electronic systems. At the time, the typical time step used was 50 microseconds. However, modern power grids and distributed generation systems now use fast IGBT-based (or IGCT, IGO, ...) converters, which require sub-microsecond time steps to achieve acceptable accuracy. e*MEGA*sim™ was designed to meet the challenges of simulating very large power systems equipped with both conventional and very fast IGBT-based power converters and FACTS systems.

## Advantages of HIL and PHIL

### Helps Support Proof-of-Concept
- To demonstrate and sell new ideas and projects.
- To perform preliminary design and cost estimation.
- To perform R&D work and product development.

### Decrease Cost and Time to Design and Test New Protection, Control and Power Electronic Systems
- When actual systems or test benches are not available.
- With several engineering and testing teams are working in parallel.

### Increase System Reliability by Increasing Test Coverage
- By testing systems under both fault and normal operating conditions that are impossible or impractical to perform with actual systems or physical test benches.
- By performing integration tests to evaluate interaction with other control, protection and power electronic systems.

### Increase System Performance
- By using automated tests to optimize control parameters for several contingencies in less time.
- By using Monte Carlo test methods to find and solve random problems that are difficult to replicate.

### Increase Component Life
- By using random techniques to evaluate the worst stresses on power electronic and passive equipments, as well as transmission lines.
- By measuring the impact of stresses on control and protection system behavior.

### Decrease Time and Cost of System Commissioning and Troubleshooting

### Increase the Effectiveness of Professional Training and Education

# *eMEGA*sim™ overview

## *eMEGA*sim™ for Power Grid and Power Electronic Systems

*eMEGA*sim™ is a scalable real-time digital simulator that integrates cutting edge multi-processor real-time super computers, model libraries, accurate high speed solvers, and a wide range of fast and versatile I/O modules, that meet the demanding requirements of precise large power systems, renewable energy systems, and power converters HIL simulation. *eMEGA*sim™ is ideal for large AC and DC power systems, distributed generations, and complex industrial power systems.

*eMEGA*sim™ empowers engineers to efficiently design and test power systems controls, FACTS, monitoring tools, electronic systems, controller relays, and protection equipment efficiently with faster time-to-market while reducing cost.
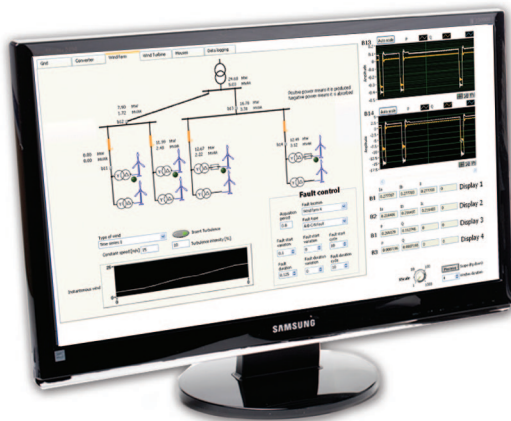
**Test and Development Software Running on a Host PC**

*eMEGA*sim™ Real-Time Digital Simulator

**Wind Turbine Controller Under Test**

# e*MEGA*sim™ Integrates Advanced Software and Hardware Technologies to Achieve Ultrafast, Accurate, and Reliable Real-time Simulation of Very Large Systems.

## Exhaustive Power System and Power Electronic Model library

- Simulates electromagnetic and electromechanical transients of AC and DC power grids found in aircraft, spacecraft, trains, wind farms, electric ships and power generation, transmission and distribution systems.

- Simulates VSC, FACTS, HVAC, HVDC, MMC, smart grid and microgrid systems.

- Incorporates elaborate electric block libraries to simulate machines, drives, lines, transformers, motors, load, or any element forming power systems, power electronic components, controller systems, and protection equipment and relays.

- Provides an interface with SimPowerSystems, Plecs, SimScape, and EMTP-RV to take advantage of models and solvers available in industry-standard simulation tools.

- Provides an interface with MATLAB and Simulink for development, prototyping and testing of protection equipment, relay and controller systems in closed-loop.

## Advanced Solver for Maximum Accuracy and Flexibility

- Comes with a unique multi-rate solver that ensures simulation of the highest number of switches without compromising on accuracy.

- Simulates complex systems with hundreds of three-phase buses with time step below 50 microseconds.

- Simulates on FPGA board electric circuits with time steps as low as 100 nanoseconds

- Simulates transients and fault conditions difficult or impossible to do on physical systems.

- Optimized for parallel, off-line and real-time simulation.

## Most Advanced Processing Technologies and I/O modules

- Can scale up to 96 3.3-GHz processors as well as thousands of I/O channels using standard 10-Gbits/s PCI Express DOLPHIN switch to interconnect several 12-processor INTEL computers and I/O modules.

- Supports the fastest XILINX VIRTEX 6 FPGA chips for I/O management and to execute model subsystems with time steps below 100 nanoseconds and timing accuracy of 10 nanoseconds.
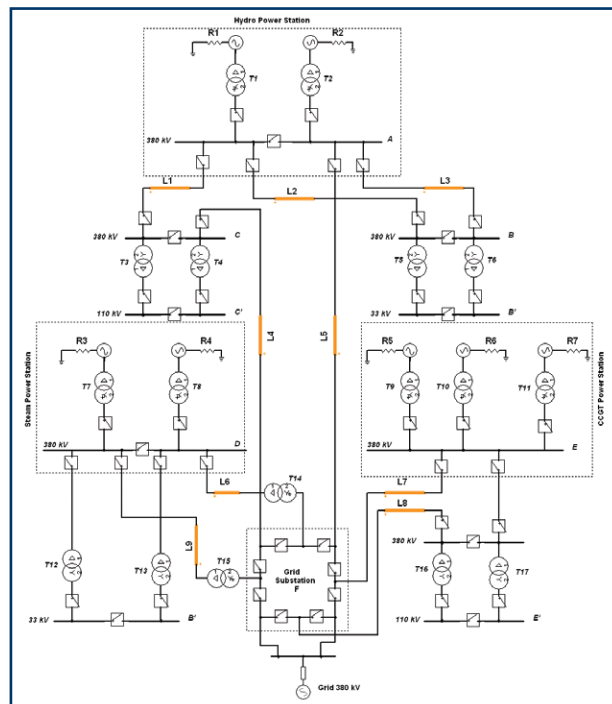


**Power System Simulated with e*MEGA*sim™**

# e*MEGA*sim™ software platform

## Use e*MEGA*sim™ Software to Take you from Model-Based Development, Right Through to Real-Time Simulation.

RT-LAB is an industrial grade, open, scalable real-time software platform for engineers who need to use mathematical models of dynamic systems built using MATLAB/Simulink and SimPowerSystem for real-time simulation, control testing and related applications. It provides tools for running simulations of highly complex models on a network of distributed run-time targets, communicating via ultra low-latency technologies, in order to achieve the required performance.
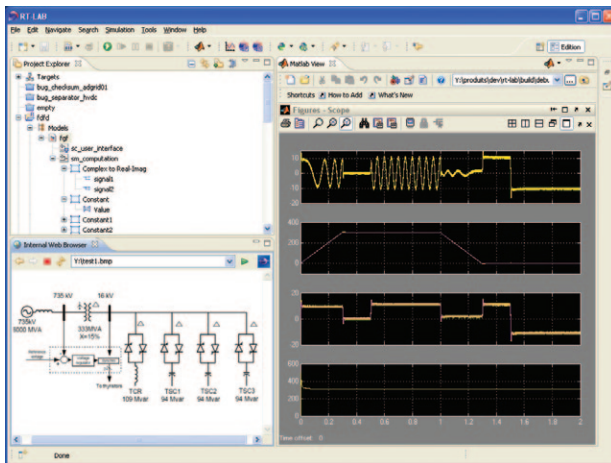


**RT-LAB User Interface**

### RT-LAB Integrated Simulation Environment

RT-LAB™ is OPAL-RT's flagship integrated simulation environment for real-time applications. It enables engineers to conduct distributed parallel computing for real-time simulation of large and complex models for hardware-in-the-loop and rapid control prototyping (RCP) applications. With its interactive interface, RT-LAB™ provides all the required functionalities to configure and manage simulator functions and interact with running simulations. On-line parameter adjustment, signal acquisition, data logging and scopes are examples of commonly used features making model development and testing easier.

### ScopeView

ScopeView is a data acquisition and signal processing software that is optimized for visualisation and analysis of e*MEGA*sim™ results. It may be used to simultaneously load, view and process data from applications such as EMTP-RV, MATLAB and Comtrade.

ScopeView also possesses advanced mathematical post-processing capabilities and is able to save and load templates associated to customized sessions of similar simulations.
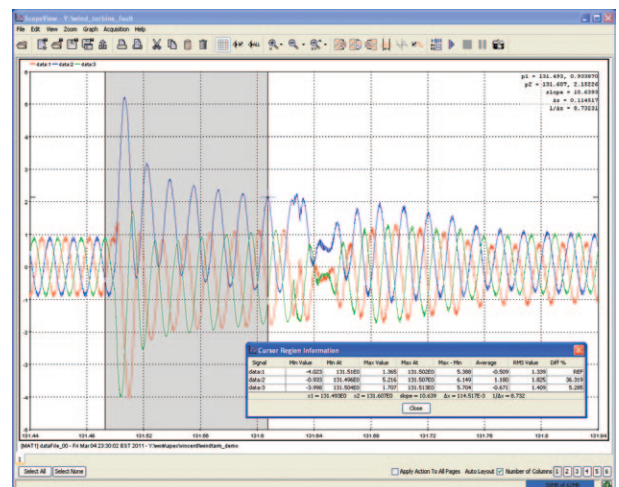


**ScopeView Signal Processing Software**

## Test Automation Software

e*MEGA*sim™ comes with a complete set of modules, based on Python, TestStand and MATLAB software, to perform reproducible automated tests and Monte Carlo analysis. With a minimum of programming skills, users can create open-loop and closed-loop testing of the hardware under test at an early development stage.

- Create complex execution sequences.
- Generate random test vectors to simulate complex transient and fault conditions.
- Generate detailed reports and charts.
- Present and display results with a custom user interface in real-time.
- Store data to external database.
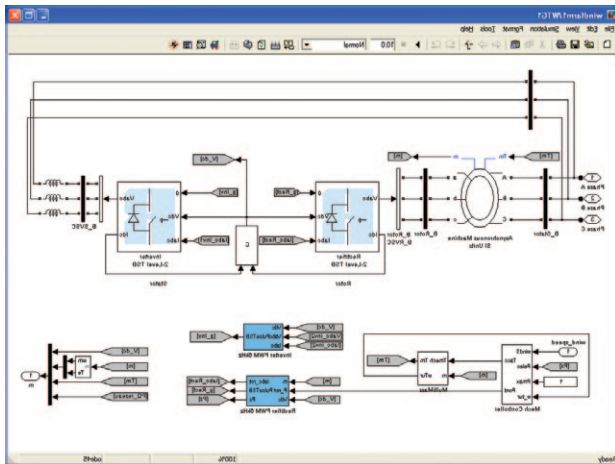


e*MEGA*sim™ Takes Full Advantage of MATLAB, Simulink and RTW

## Third-Party Product Connectivity and Integration

RT-LAB allows several commercial software to quickly interface with the e*MEGA*sim simulator including:

- Modelling tools: Plecs, EMTP-RV, Dymola, Matrixx/SystemBuild, Statemate, CarSim, TruckSim, EMTP-RV, JMAG, Cruse-RT, Boost-RT, LMS AMEsim, Easy-5, GT-Power, Simulink, SimPowerSystems, SimScape, StateFlow, C/C++, FORTRAN, etc.
- Test automation software: TestStand, Python, SystemTest, etc.
- Visualisation and monitoring software: LabVIEW, ScopeView, Altia, Panorama, PcVue, Wonderware, OPC server, etc.
- Support API languages: C/C++, Java (MATLAB), LabVIEW and TestStand.
- Office suite: Word, Excel, etc.

RT-LAB™ is based on the popular Eclipse™ integrated development environment (IDE). The Eclipse community has thousands of third-party plug-ins that users can add to their RT-LAB™ installation, providing extensions to the environment. Users can also program their own add-ons.
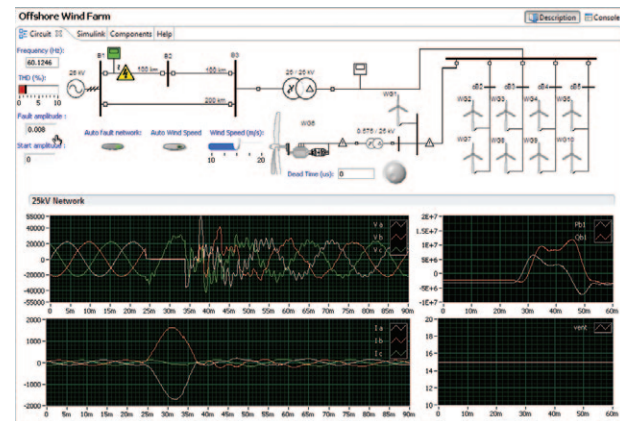


Interface LabView with e*MEGA*sim Simulator

7

# eMEGAsim™ blocksets and solvers

## Electrical and Power Electronic Models

e*MEGA*sim™ includes a rich model library that lets you create detailed and accurate models for all components that make up large power grid and power electronic systems. It includes detailed block components for electrical, mechanical, magnetic and control devices such as transformers, loads, generators, motors, lines and cables, AC feeders, voltage source converters and much more. e*MEGA*sim™ also provides a complete set of real-time solvers optimized for real-time simulation, allowing you to accelerate simulation and also to simulate complex transient and fault conditions that are difficult or impractical to achieve with a real system.
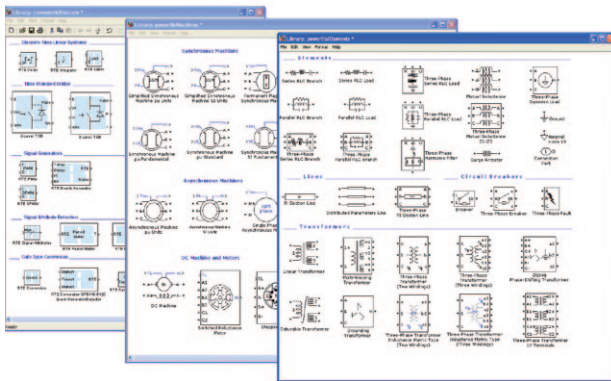


### Motor Models with High Simulation Accuracy for all Applications

e*MEGA*sim™ supports the complete libraries of motor models included in SimPowerSystems, and developed and tested by the Institut de recherche d'Hydro-Québec. It includes a wide range of alternating and direct current motor models used in all types of drives (DC, direct DC, single phase AC, poly-phase AC, PWM and variable frequency AC) required in automotive, aerospace, industrial and military applications. Permanent magnet synchronous motor (PMSM), brushless DC (BLDC) and induction DQ motor models are typical examples that can be easily parameterized and tightly integrated into your simulation. Highest accuracy is achieved by executing the simulation with a time step below 10 microseconds for medium speed motors using standard INTEL processors or below 250 nanoseconds using FPGA chips.

### Complex and Detailed Voltage Source Converters

e*MEGA*sim™ provides an unsurpassed precision block set for power electronics and high frequency switching devices used in voltage source converters (VSC) such as two-level and three-level converters, multi-drive systems, and matrix converters. Users can easily develop complex drive and power electronic circuits including filters, RLC components and other electrical devices.

FACTS devices and modular multilevel converters (MMC) require solvers that enable simulation of thousands of fast switches. This places very large demands on the real-time computation, that must be capable of dealing with the inherent effect of changing the circuit topology, concomitant with the requirement for small time steps. e*MEGA*sim can meet these stringent requirements and maintain sufficient precision as well as minimize delays between the control signals and the feedback from the simulators below 20 and 50 microseconds and simulate dead-time effects.
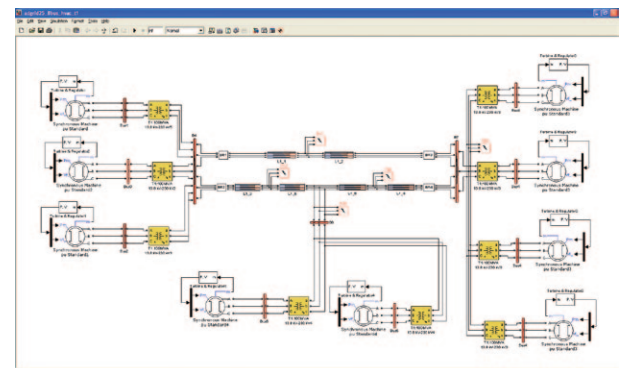


**HVAC System with 12 Buses**

## Specialized Solvers for Large Applications and Optimal Use of Electrical Models

OPAL-RT produces specific electrical and power electronics simulation solvers whose algorithms take full advantage of parallel computing. Developed by foremost industry experts, *eMEGA*sim™ solvers help Simulink and SimPowerSystems™ users attain very high computational speed, stability, and fidelity, whether off-line or in real-time.
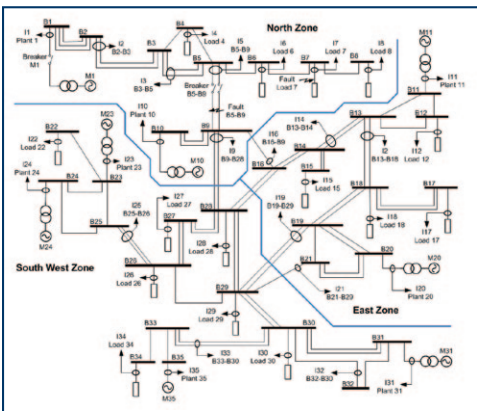


**HVAC Transmission Network**

## Simulation of Fault Conditions

OPAL-RT's advanced and unique solvers allow the simulation of very complex transient and fault conditions on motor terminals and on semi-conductor devices such as IGBT or DC and AC buses. Users can also simulate active and natural rectification modes of AC-DC converters.
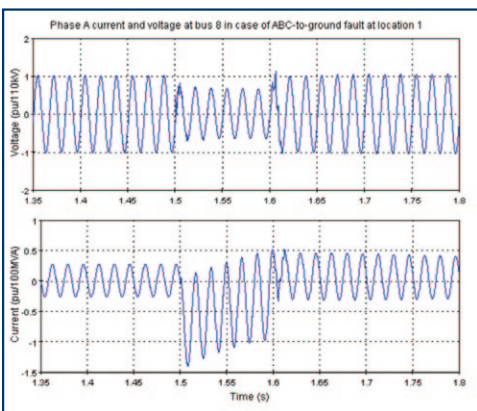


**Phase A Current and Voltage during a ABC-to-ground Fault on a Transmission Network**

## Microgrid and Distribution Systems with Small Lines

The real-time simulation of microgrid and distribution networks poses an additional challenge to real-time simulation since many lines are very short with transport delays much smaller than achievable time steps. A new method, called State-Space-Nodal, was developed to enable the parallel and real-time simulation of systems with very short lines without adding artificial delay, thus increasing simulation accuracy with respect to the traditional technique of adding a line with one time step delay.
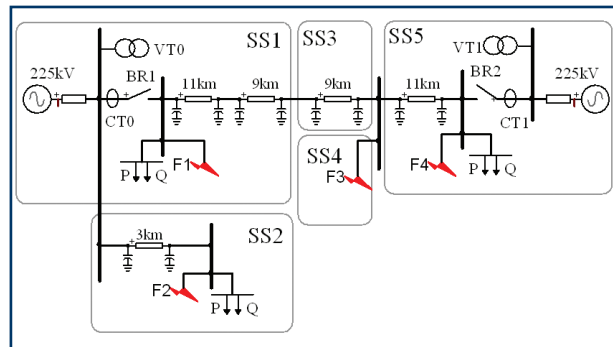


**Distribution Network with Short Lines**

# *eMEGAsim*™ hardware platform

## Fast Analog and Digital I/O Interface

*eMEGAsim*™ includes fast analog and digital I/O modules specifically designed for power systems and power electronics real-time digital simulation. Their low latency and high sampling rates combined with short time steps ensure the best overall cycle time possible to interface controller, protection equipment, relays or any external devices.

### Convenient and Flexible I/O Connectivity with OP5600 platform

The *eMEGAsim*™ basic chassis comes standard with 256 I/O channels for convenient, reliable, rapid, and cost effective connection to any external device. Each I/O provides a wide range of generic functionalities, used for signal acquisition, measurement, processing and generation required by power electronic systems. *eMEGAsim*™ also lets you create custom signal generators and data processing algorithms using FPGA-based reconfigurable I/O.

The *eMEGAsim*™ chassis comes with 6 PCI expansion slots to provide more flexibility to add I/Os and communication devices from other brands (CAN, LIN, FlexRay, ARINC, MIL-STD-1553, RS-232, GPIB, Profibus, reflective memory, etc), as well as to interconnect more *eMEGAsim*™ simulators in a cluster.

High Performance OP7000 Chassis
The *eMEGAsim*™ simulator can also be equipped with the OP7000 chassis that adds FPGA computation power and fast analog and digital I/O modules. The OP7000 chassis can contain 9 Virtex 6 FPGA boards interconnected with very fast communication links. It also provides front-access I/Os boards and signal monitoring. All I/O signals are fully configurable and programmable.





**OP5600 and OP7000 Simulator Chassis**

**Medium-Size** *eMEGAsim*™ **Enclosure with Optional Accessories**

## Integration of FPGA for the Fastest Performance

The computational power required to run complex power electronics models and support the accurate solvers developed by OPAL-RT relies on the latest Field Programmable Gate Array (FPGA) technology provided by Xilinx. The e*MEGA*sim™ comes standard with an OP5142 equipped with a Spartan 3 FPGA. For ultrafast large model execution in floating point, users can request a Xilinx board that comes standard with a Virtex 6 FPGA Target.
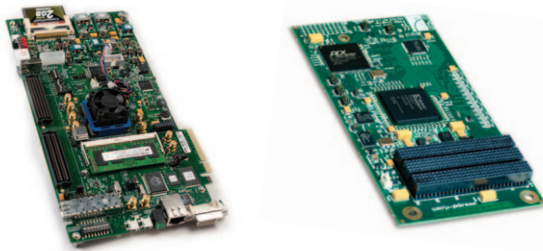


**ML605 Virtex 6 FPGA I/O card**

**Spartan 3 FPGA I/O card**

## Full Range of Optional I/O Accessories

The e*MEGA*sim™ chassis can be optionally connected to I/O interface accessories such as mapping boxes, breakout boxes (BOB), screw terminals, DB37 connectors, fault insertion units (FIU), load simulators, amplifiers, etc.



**OP8660 High Power Signal Conditioning Module**

## I/O Monitoring Made Simpler and Safer

A revolutionary embedded technology allows each analog and digital I/O connector to reproduce and isolate electrical signals from the back I/O connectors to the front test point (TP) connectors. This lets you connect any monitoring device without disturbing the electrical signal on the back connectors. For additional monitoring capability, every I/O point can be mapped from any TP connectors to an array of 16 mini-BNC TP connectors. This adds versatility and flexibility when connecting I/O channels to the monitoring equipment.

## IEC 61850 Compliant Protection Equipment

When testing IEC 61850 compliant protection equipment, standard analog and digital signals are replaced by sampled values (SV) and GOOSE messages. These protocols run on a TCP/IP network using high speed switched Ethernet and simplify the connection of the equipment with the simulator since no amplifier is required.
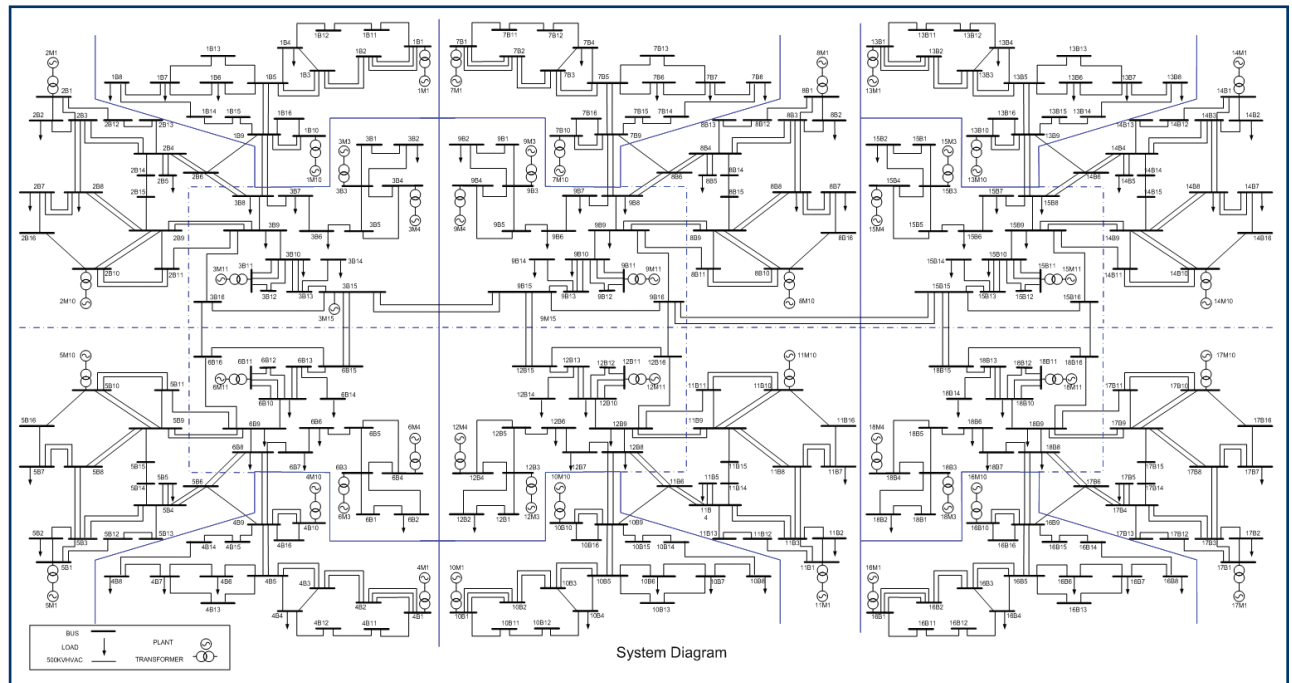


**Small-Size e*MEGA*sim Portable Enclosure for On-site Testing**

# *eMEGAsim*™ applications

## Large Scale Power System Simulation

### Client Need

Simulate very large power systems found in generation, transmission and distribution applications with the highest accuracy and performance.

### Typical Application



System Diagram

**A 330-Bus 500kV Transmission Network**

## Solution

- By using the *eMEGA*sim simulator, simulate the electromagnetic transient of a large 3-phase power transmission system including, for example, 500 buses, 700 transmission lines, 75 generation plants and 125 loads using two standard 12 core OP5600 chassis at 50μs.

- Simulate the transient stability of a very large power transmission system including 10000 buses, 3000 generators at 10ms with the phasor simulator.

- Load flow, short circuit, transient stability, optimal power flow, and contingencies analysis can easily be done with an *eMEGA*sim simulator.

- Simulate modern house distribution systems with multiple energy sources and energy regeneration capability including, for example, primary and secondary distribution systems, several feeders, and 900 houses for a total of 4000 electrical elements.

- Simulate a power system with very low time step, such as 10us, when required, or simulate models in "off-line mode" and Windows or Linux operating systems.

## Technology Summary

- The fastest electrical network solver, called ARTEMiS, for real-time transient simulation of large power system and power electronic converters.

- The Dolphin adapter board to form the fastest supercomputing clusters and to simulate very large power systems.

- The fastest and most accurate phasors solver for real-time simulation of transient stability or large transmission power system.

- The latest Intel® Core™ i7, 2nd generation, computer processor for extreme performance and smart parallel computing and multi-tasking.

- Scale-up to 96 3.3 GHz processors or more as well as thousands of I/O channels.
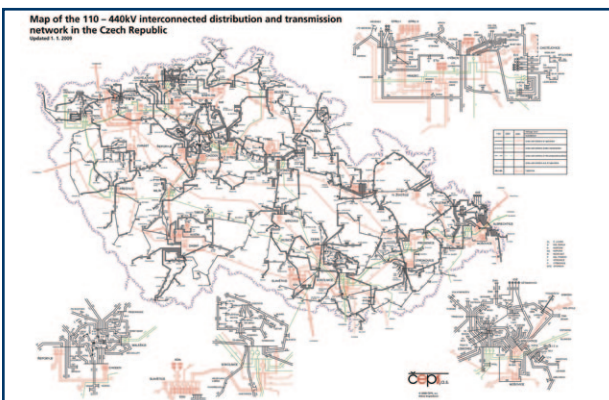
**The CEPS Transmission System**
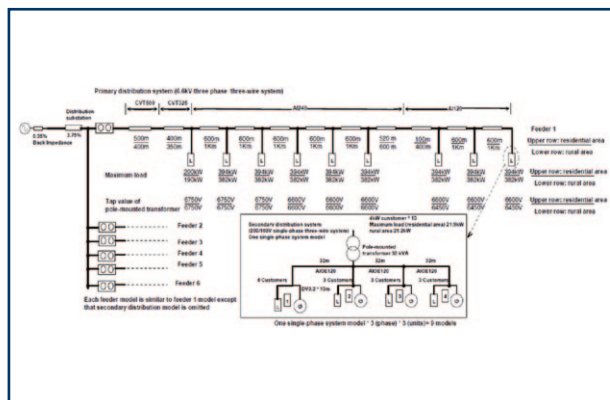
**A Distribution Network with 900 Houses**

## Modular Multi-Level Converter (MMC) System

### Client Need

The MMC system has many advantages over conventional voltage source converters (VSC) and can therefore be used in DC power transmission, microgrid, or renewable energy applications. While MMC's distinctive topology offers many new features, it also necessitates sophisticated controllers that are difficult to test without a versatile platform that can simulate and interface thousands of power switches signals.

### Typical Application
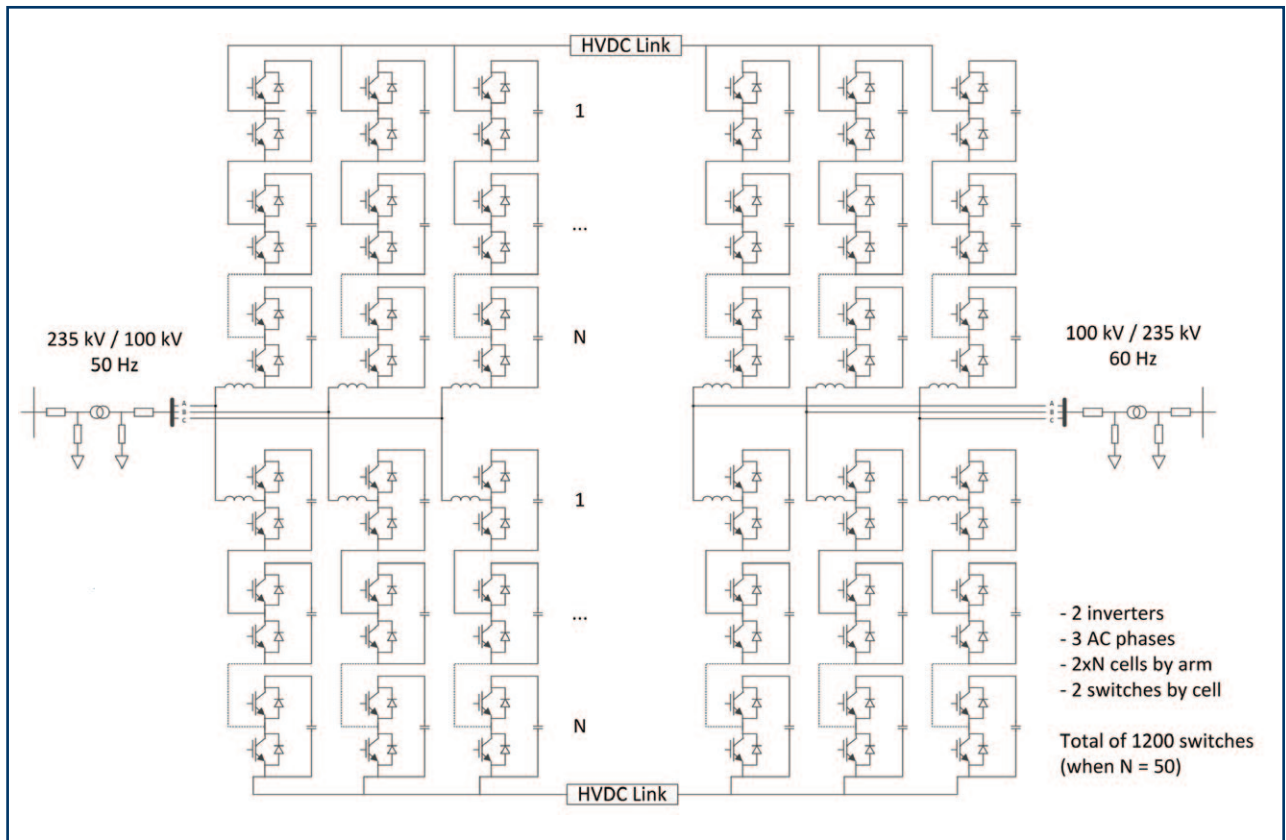
## Solution

MMC converters require more sophisticated controllers than those used in conventional VSC topologies. To fulfill these requirements, OPAL-RT has developed distinctive technologies that address the new challenges of MMC converters and HIL simulation. Its unique solution allows engineers to design and test complex MMC converters with one versatile platform that simulates all converter switches and all other parts of the complete power system, such as protection equipment and FACTS devices.

The e*MEGA*sim simulator has been used in several HVDC and STATCOM applications and has demonstrated its ability to connect real controllers that have thousands of I/O channels while providing the best accuracy, the smallest I/O latency and the best real-time performance.
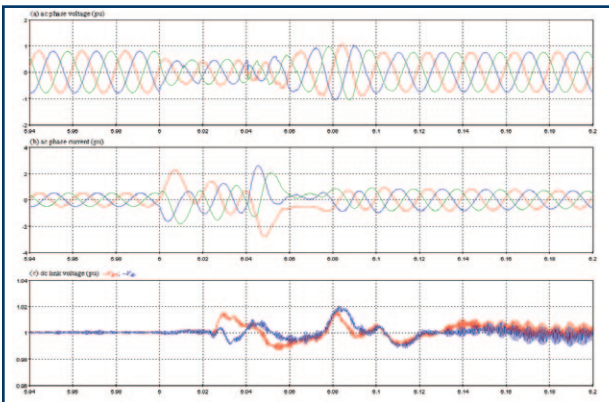


**MMC Response to a Short Circuit Fault at Transformer Primary Side**

## Technology Summary

• Simulate various faults and disturbances on the converter and grid to see the effect on the controller.

• Can include thousands of analog and digital I/O channels, to interface all firing signals and converter measurements, such as cell voltage.

• Simulate different HVDC and FACTS converter topology (series and shunt configuration) such as STATCOM or back-to-back converter without decoupling.

• Simulate various cell topologies (half and full bridge…).

• Study multi-carrier PWM strategy.

• Simulate the entire power system model and converter with a very small time step, such as 25 μs or below.

• Allow the validation of the MMC control scheme and regulation algorithms:
- Active and reactive power control
- DC link and bus voltage balancing
- Arm current regulation
- Zero sequence current elimination
- Overall cell voltage control and individual cell voltage balancing

• Provide the best solver that uses interpolation techniques for highly precise gate firing generation and measurement.

• Can optionally simulate converter model with very stiff equations on FPGA with a time step of 250 nanoseconds and output cell voltages and other signals to the controller at 1 MHz.

## STATCOM and FACTS Systems

### Client Need

STATCOM and FACTS systems with a large number of fast switches are very difficult or impossible to simulate with conventional real-time simulators since designing and testing such systems requires high reliability, high precision and high speed simulators.

Testing a FACTS controller that integrates new control algorithms requires a platform that allows simulating all type of FACTS devices in normal and abnormal conditions, but also the entire power grid and its various distributed energy resources (DER). It also requires a large set of analog and digital I/O modules to easily connect the controller. Such a system can be used to test complex control schemes and study the optimal location of FACTS devices.

### Typical Application
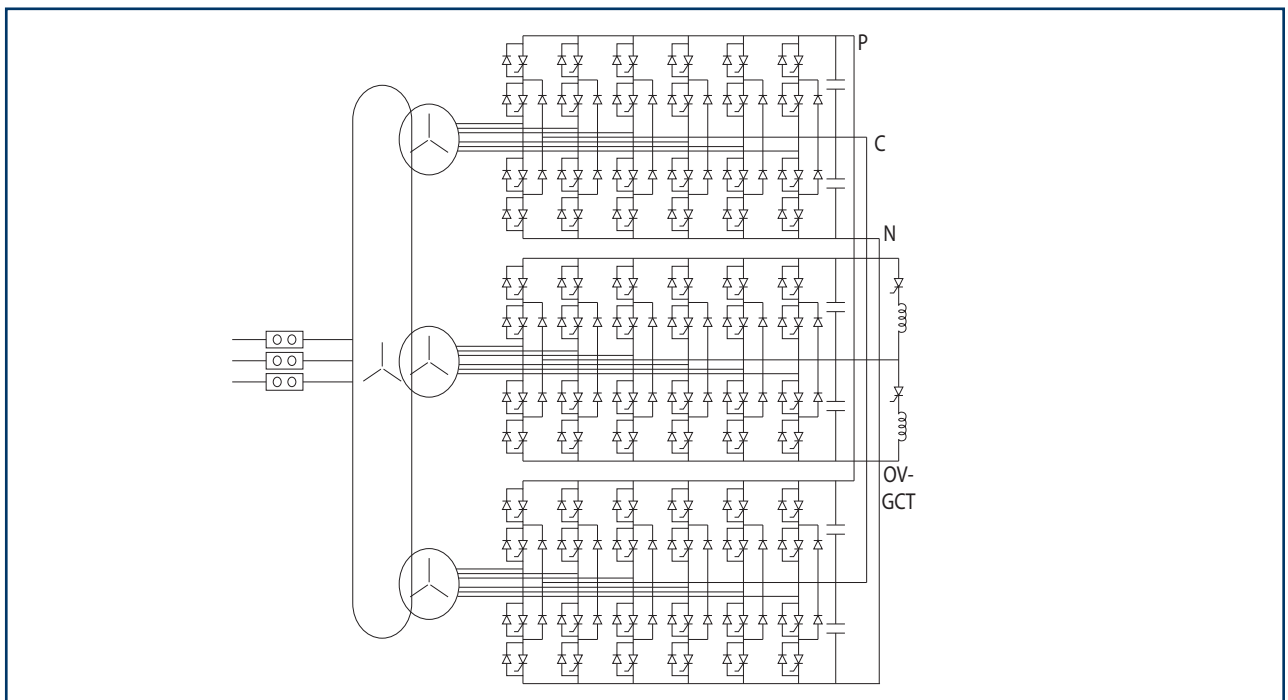


**3-Level STATCOM Converter Circuit**

## Solution

The eMEGAsim simulator includes the best technologies on the market to simulate the entire power system and converter models with very small time step, such as 10 µs or below. It also allows simulating various faults and disturbances on the FACTS and grid to see the effect on the controller.

The eMEGAsim simulator can have thousands of analog and digital I/O channels to interface all firing signals and measurements of complex FACTS topology. For example, the simulator can generate and measure the valves' high-frequency switching (higher than 10 kHz) with great accuracy.

The ultrafast I/O system enables users to measure and analyse power flow, harmonics, control angle, etc.
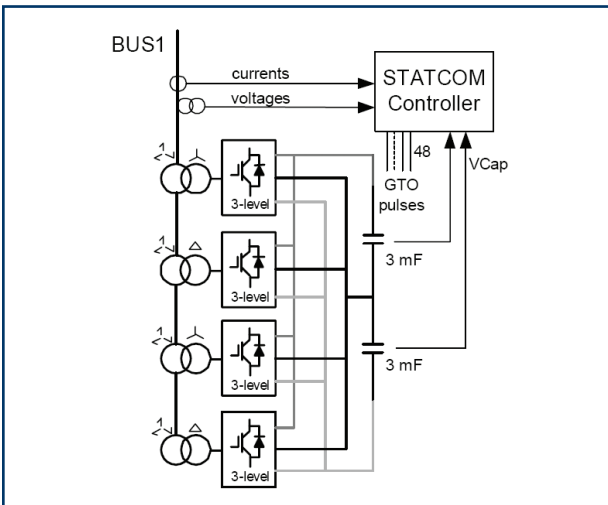


**3 Level STATCOM system**

## Technology Summary

- Simulate different FACTS compensators:
- Series compensator: SSSC, TCSC, TCSR, TSSC, and TSSR,
- Shunt compensator: STATCOM, SVC, TCR, TSR, TSC, and MSC,
- Combined series-series, series-shunt, or shunt-shunt compensators:TCVR, UPFC.

- Validate FACTS device operation and optimize your control algorithms.

- Test power system stability and FACTS controller response to any type of disturbance, such as voltage and current reference change, active and reactive power change, loss of transmission line, outage, islanding, and bus faults (1ph-g, 2ph-g, 2ph, 3ph-g, …).
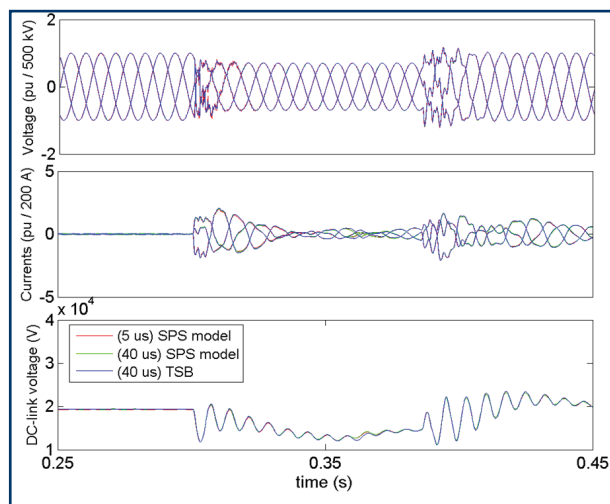


**STATCOM signals (3-phase to ground fault at BUS3)**

# eMEGAsim™ applications

## Microgrid and Smart Grid Simulator and Power Hardware-in-the-Loop Testing

### Client Need

To correctly test and evaluate new physical equipment found in "smarter" grids and microgrids, the need is to simulate and analyse the interaction between the various elements forming the grid. The goal is to ensure the high efficiency and security of electricity services but also to maintain power quality and reliability. Since the grid must support both aging devices, which were not developed for bi-directional power flow, and new innovative technologies for control, protection, and metering devices, a versatile platform is required to test and optimize such a system with its inherent complexity.

It is achieved by simulating or physically connecting parts of the grid, such as distributed energy resources (DER), and any smart equipment to the virtual distribution and transmission power system and then by studying the overall control, protection and monitoring schemes.

### Typical Application
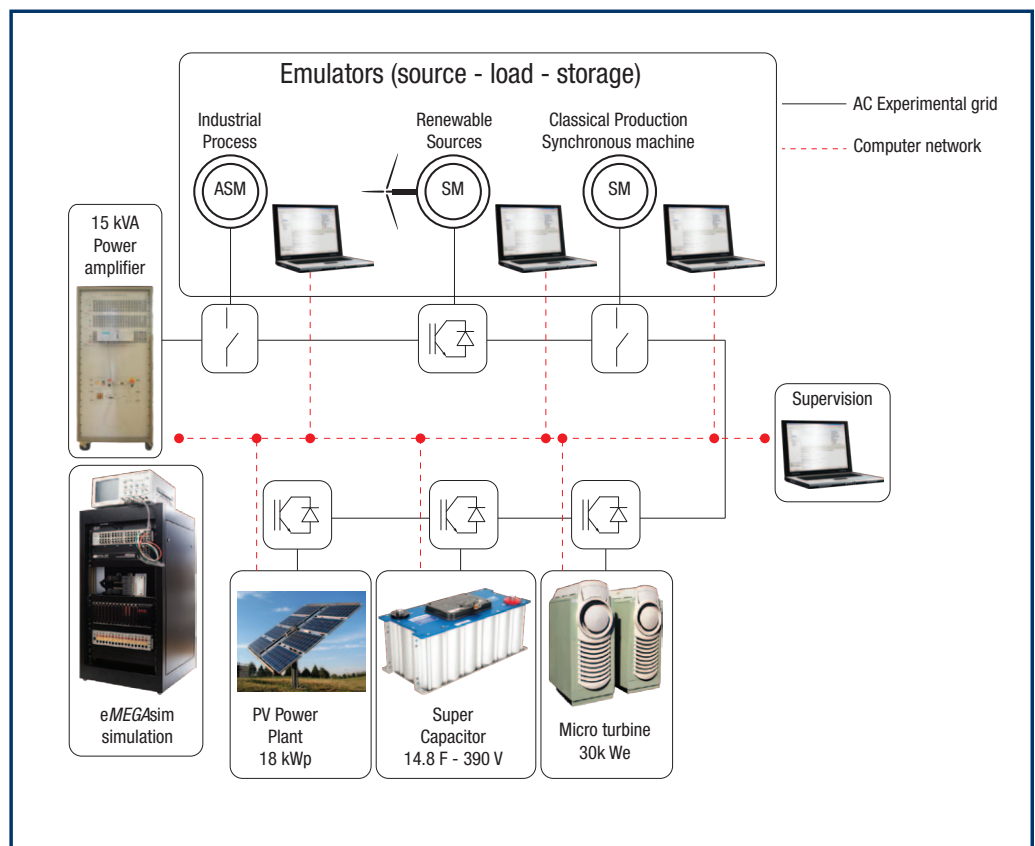


**Real-time Platform for Microgrid PHIL Testing**

## Solution

The *eMEGA*sim simulator is the ideal platform to develop and test smart grid and microgrid equipment. It includes all tools required to interface high power physical DER devices such as PV, fuel cell or synchronous machine with simulated transmission and distribution grids. The interface is achieved using standard communication protocols, custom mapping boxes, and amplifiers delivering four quadrant operation modes. Moreover, the simulator can virtually simulate extra grid elements, not physically available, that allow testing of more complex control, protection and monitoring schemes where much equipment is involved and coordination is required. It also allows testing various scenarios difficult or impossible to achieve with full analog test benches. Weak or islanded networks are typical grid configurations that are tested with the simulator for ensuring reliability, efficiency and security.
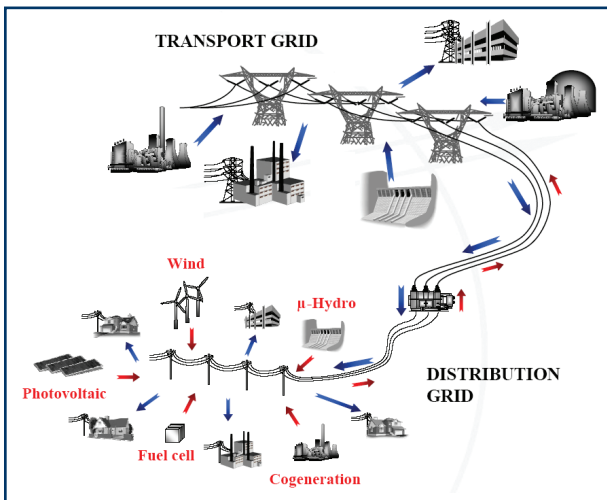


**Interconnection of Microgrid, Transmission System and Distribution System**

## Technology Summary

• Simulate large transmission and distribution networks with SVC, FACTS and HVDC elements with time steps below 50 microseconds.

• Include a large set of fast I/O modules supporting a 250 volt high voltage interface.

• Simulate DER such as micro turbines, photovoltaic arrays (PV), wind turbines, synchronous machines, fuel cells, reciprocating engines and more devices found in a real grid. Users can also develop their own blocks that are not based on standard model equations.

• Simulate power inverters and their filters at the point of common coupling and anywhere in the grid, work on inverter coordinated control strategies to improve microgrid voltage profile and study influences of different types of microgrid units on both islanded and non-islanded mode.

• OPAL-RT can provide standard or custom amplifiers working in four quadrant operation modes (generation and dissipation of power) and that have high accuracy and bandwidth and low distortion.

• The simulator supports standard IEC 61850 with GOOSE messaging and Sampled-Value (SV) and Ethernet based protocols used for communication between grid elements.

• Provides API and gateways to common commercial-off-the-shelf tools and programming languages enabling a variety of third-party software and systems to be used with the RT-LAB environment such as LabVIEW, automation systems, OPC, and openPDC.

# *eMEGAsim*™ applications
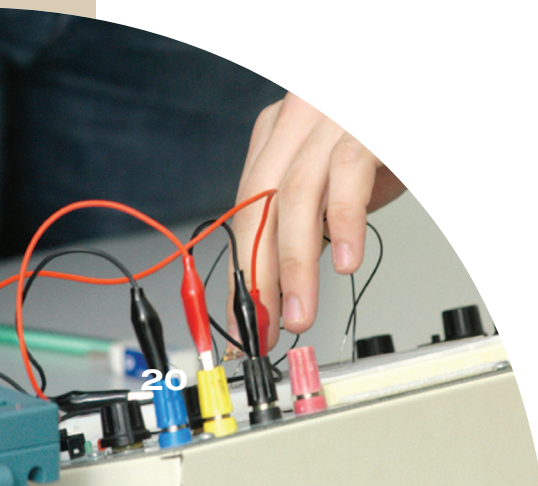
## IEC 61850 Relay and Protection Equipment Testing

### Client Need
Test and certify the relay performance and study the relay interaction and its effect on the power system, in a real-time and closed-loop environment as in the customer's real grid.

### Typical Application
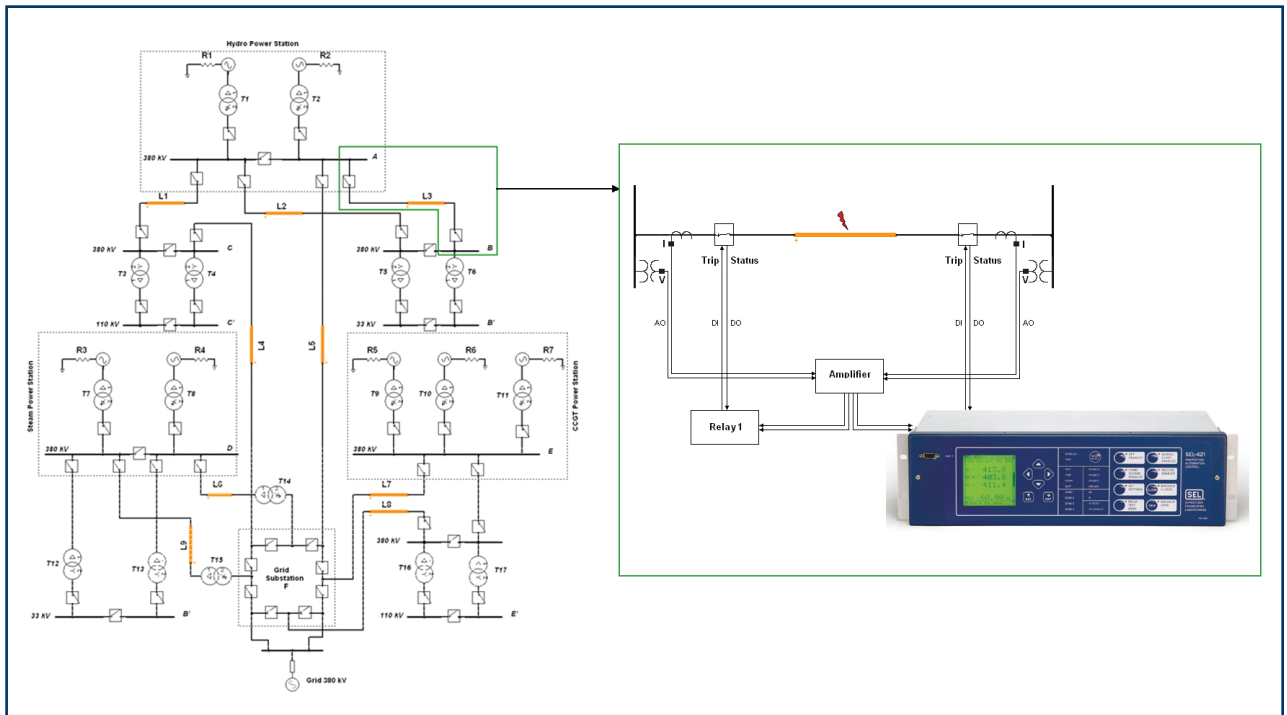


**Relay Under Test Connected to a Simulated Power System Using *eMEGA*sim™ Simulator**

## Solution

The eMEGAsim simulator provides a platform for testing relays and protection schemes used in all recent power system applications. Its functionalities allow users to reduce the time to test relays and increase test reliability and precision. Thus, the performance and the understanding of the protection scheme operation are improved and undesired misoperations prevented.

Moreover, the eMEGAsim simulator helps to determine if simple relays or full modern multi-function digital protection equipment respond correctly to various power system events and disturbances. This is achieved by simulating the electromagnetic transients of the power system in real-time using detailed models of lines, transformers, loads and generators as well as FACTS, HVDC transmission systems and power electronic converters. Note that relays are connected in closed-loop with the power system model using I/O modules and thus the steady-states, dynamic-states and transient characteristics relay can be fully tested. Playback mode can also be used to repeat recorded scenarios and validate relays over time.

Furthermore, the simulator allows validating that all transducer signals are measured correctly and that communication between equipment works properly. The simulator can also be used to calibrate and validate CT and PT transducers and to fine tune and validate relay settings.

## Technology Summary

• Test current, voltage, impendance, distance, and frequency relays that have low to high power level.

• Replay and analyze trip conditions and power disturbances such as transient overvoltage, overcurrent, and voltage sag that has been recorded by high voltage substation equipment and oscilloscopes (COMTRADE file). Replay virtually all waveforms recorded on the simulated power system.

• Automate and conduct statistical Monte Carlo tests to evaluate all aspects of the protection systems under several normal and emergency operating conditions; fault location, fault type and fault interception angle are some common parameters.

• Support IEC 61850 compliant protection equipment that use sampled values (SV) and generic object oriented substation event (GOOSE) messages.

• Complement perfectly conventional relay test set and calibrator equipment such as OMICRON and Dobble relay testers.

• Optionally available with standard or custom power amplifiers to interface high power protection equipment.

## Line Commutated HVDC Transmission System – Controller Development and Testing

### Client Need

These days, testing of complex high voltage direct current (HVDC) system controllers and protection schemes in HIL mode with a real-time simulator is a common and mandatory practice for the development of new controllers and to reduce risks of equipment damage during system commissioning. Several thousand systematic and random tests are often required to evaluate the performance, reliability and stability of the integrated HVDC and AC networks while minimizing power loss and reducing harmonic distortion. Testing also allows detection of instabilities caused by unwanted interactions between control functions and the power system that will usually include FACTS devices and other HVDC systems that may interact with the system under test.

### Typical Application
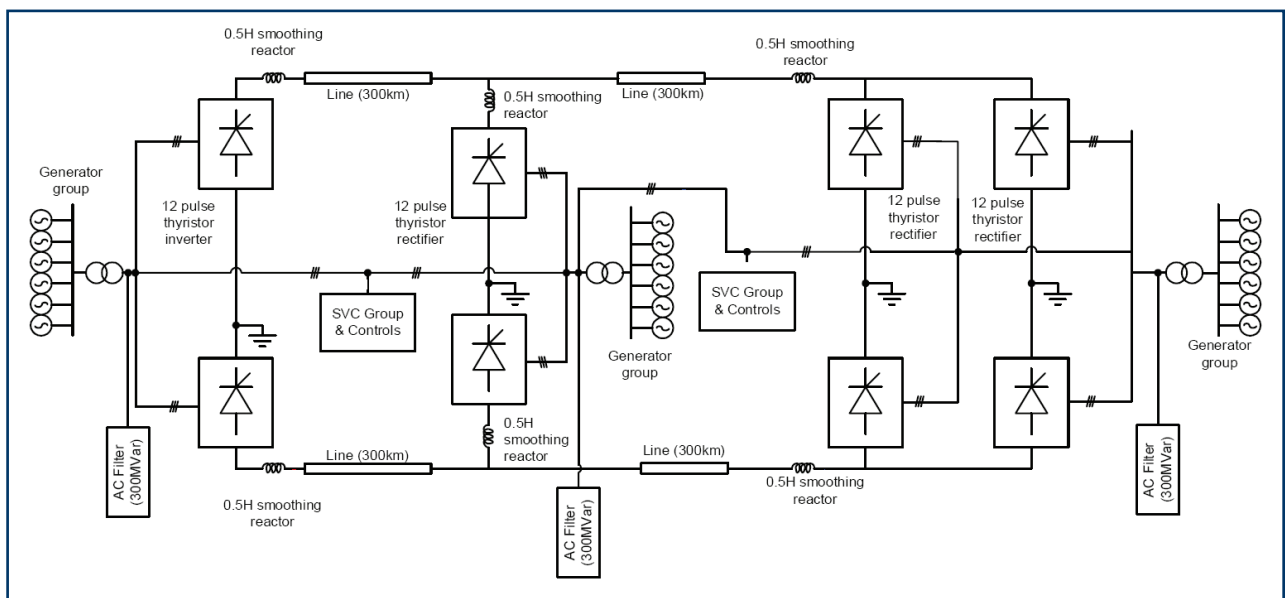


**Multi-Terminal HVDC System**

## Solution

The e*MEGA*sim™ simulator can accurately simulate complex and large power networks with any type of HVDC transmission systems, such as unipolar, bipolar or multi-terminal HVDC, and FACTS systems such as SVC and TCSC that may interact with the system under test. The simulator also allows users to study the effect of switchable power filters that can cause significant overvoltage during fault recovery and affect network performance, especially when the AC network strength is relatively weak.

It also allows developing and validating control algorithms for power flow control and reactive power compensation. Conventional protection and special control schemes can also be developed and tested under various fault conditions, such as single-line-to-ground, phase-to-phase and three-phase faults on the AC system, DC-side fault or any power system disturbance, such as loss of generators or lines.

The simulator comes with flexible and reprogrammable high-performance I/O modules to interface the simulator with modern power electronic controllers and protection systems to perform HIL simulation and factory acceptance tests.

## Technology Summary

- Simulates complex multi-terminal HVDC systems with time steps of 10 to 50 microseconds.

- Integrates powerful modern multi-core INTEL processors and FPGA chips to simultaneously simulate several HVDC systems and FACTS that are connected to very large AC systems including hundreds of three-phase buses, generators, transformers and transmission lines.

- Integrates an unsurpassed interpolation technique that ensures an accurate simulation of thyristor firing effects with equivalent accuracy of 0.1 degree, even if the firing occurs within the simulator time step.

- Integrates an innovative solver, called State-Space Nodal (SSN) method, that enables parallel computation of many FACTS devices and switchable filters without using extra artificial delays often required by traditional solutions for system decoupling.

- Simulates numerous circuit breakers in the same or adjacent HVDC substations without introducing extra delays to perform parallel computation.

- Fully integrates with SIMULINK for the development of advanced control algorithms.

## Modeling and Rapid Control Prototyping of Wind Turbine Controller

### Client Need

The past decade has seen increased interest in wind energy generation as environmental awareness is on the rise. With megawatt-range wind turbines now being manufactured by several companies, the need for rapid control prototyping and HIL testing of such apparatus is also increasing. The integration of large, several hundred megawatt, wind farms on weak networks also requires more sophisticated simulation and control tests that must be executed in laboratories before the turbines are actually built. The traditional way of testing, integrating and validating complex controls consists of the systematic analysis of the individual component's behaviour, mostly by simulation, before complete integration on real apparatus. At this stage, real precautions must be taken because of the power levels: a simple controller malfunction can damage the prototype or the real system and create project delays and increase costs. A more advanced testing/ integration approach is needed to diminish the probability of damage, personal injuries and time-to-market as well as to perform more tests in less time, which is often very difficult or impractical to perform on the real system.

### Typical Application
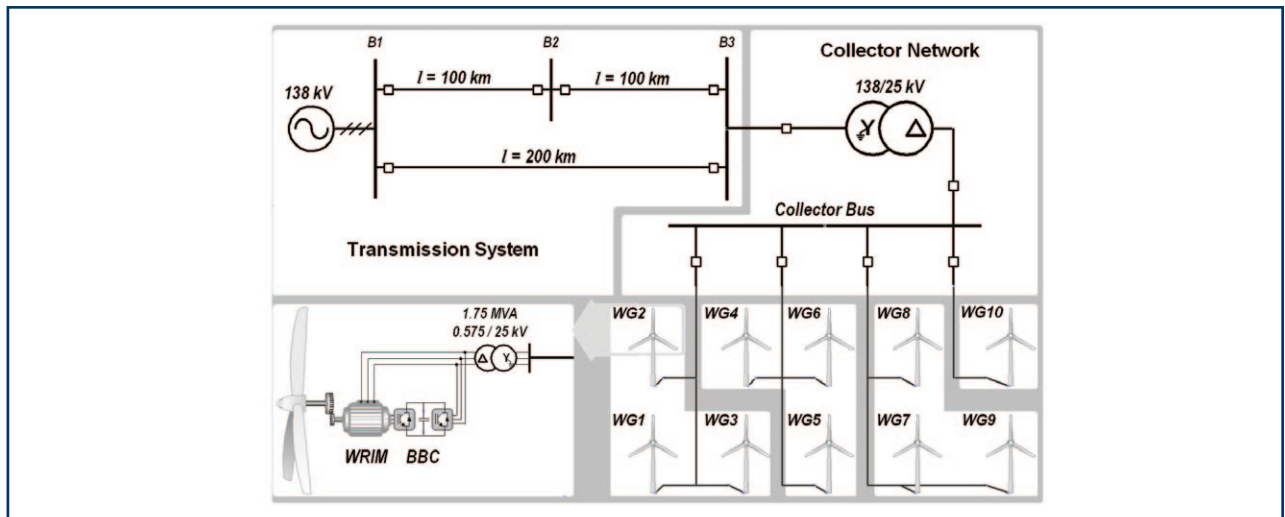


**Wind Farm Network**

## Solution

Ensuring turbine efficiency, maximizing output power, improving disturbance rejection and ultimately minimizing down time of wind turbines and wind farms by performing better tests at the design and system integration stages are some common tasks that are performed on the e*MEGA*sim™ simulator. Its rich set of tools offers a versatile platform based on MATLAB and Simulink that allows users, regardless of experience level, to design and develop control strategies with an intuitive user interface commonly adopted by the main industry players. For engineers who already have models and control algorithms built with this off-line application, the learning curve to make real-time HIL tests with prototype or actual controller equipment is very fast.

Moreover, by simulating the complete wind farm and the power grid with e*MEGA*sim™, users can easily certify that the control strategies provide valid voltage control, do not contribute to grid fault or instability, and that the farms are not damaged by grid faults.
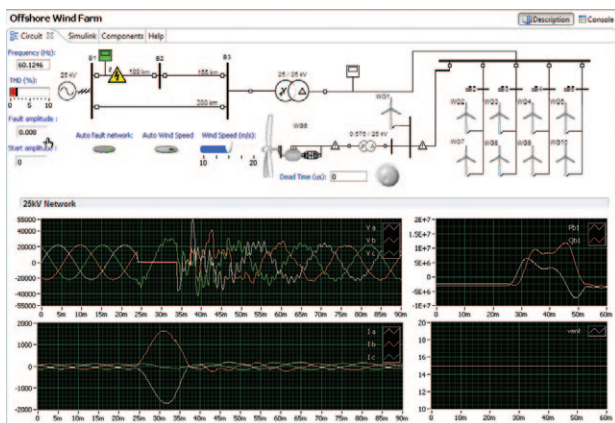


**Custom User Interface for Wind Farm Controls**

## Technology Summary

• Fully integrates with MATLAB, Simulink and SimPowerSystems (SPS) from The MathWorks enabling users to build complex control systems and wind farms by dragging control blocks and power components from the library browser to the developed models.

• Fully integrates with e*MEGA*sim simulator software and hardware, based on modern multi-core INTEL processors and FPGA chips to simulate, in real-time, several wind turbines interfaced to large AC grids either directly or through multi-modular voltage source HVDC converters.

• Comes with automation software to analyse various faults and disturbances on generators, converters and grid. See the effect on the prototype or actual hardware controllers in HIL simulation mode.

• Includes RT-EVENTS control function library for highly precise gate firing generation with a resolution better than 100 nanoseconds and the best and proven solver, ARTEMIS, which uses interpolation and time stamping techniques for precise simulation of IGBT firing effects.

• Simulates steady-state conditions, harmonic and electromagnetic transients expected on the entire power system model and converter in real-time with very small time step of 20 μs or below.

• Integrates with SimMecanic, Dymola and AMEsim to simulate wind and mechanical effects.

# eMEGAsim™

## Why Choose e*MEGA*sim™ Real-Time HIL Digital Simulator?

Because our solutions for hardware-in-the-loop test bench and rapid control prototyping for the electric drive and power electronics industry are simple, unique, very scalable, reliable, and cost effective.

We make no compromises to ensure a successful implementation of your project, minimize risks, and maximize your ROI.

- We provide the highest performance solvers, models, computing platform, and integrate the latest hardware technology to meet the requirements of the most demanding application.
- We provide open solutions based on commercial off-the-shelf (COTS) technology, robust and full-featured RTOS and maximum compatibility with external high fidelity modelling tools already used by customers.
- We provide a complete range of simulation solutions under one roof from 'large-scale turnkey' to stand-alone HIL and RCP components and services.
- We provide solutions that are backed by a competent, responsive, and dedicated technical support team that will ensure the successful deployment of your project.
- We provide a full range of standard and custom training on all the elements of a solution to ensure a seamless integration by your team.
- We provide sales and support offices worldwide, ensuring continuity for global customers.

### Partial List of Satisfied Customers
ABB
AIT-Austrian Institute of Technology
Alstom Grid
CAPS-Center for Advanced Power Systems
École Polytechnique of Montréal
EDF
G2ELAB
Hydro-Québec
Imperial College
ITT Hydrabad
KTH-Royal Institute of Technology
L2EP
McGill University
Mitsubishi Electric Corp.
Nari Relay
North Carolina State University
NREL
Ohio State University
Rockwell
Siemens
Toshiba-Mitsubishi Industrial Systems Corp
University of Alabama
University of Connecticut
University of Michigan
University of North Carolina
University of Sherbrooke
University of South Florida
University of Waterloo

## Typical *eMEGA*sim™ Configurations

The following table presents typical *eMEGA*sim™ configurations. For more information contact your sales representative.

| Description | | Config E1-12 | Config F1-12 | Config F2-24 | Config F4-48 |
|---|---|---|---|---|---|
| **APPLICATIONS** | | | | | |
| Power grid | Transmission and distribution systems | Yes | | | |
| Power electronic | FACTC, Thyristor and VSC MMC converters, wind farms, microcrids, trains, aircrafts, electrical ship … | Optional | Yes | Yes | Yes |
| Capability | Typical number of three-phase busse simulated in 50 us | 150 | 200 | 400 | 800 |
| **MULTICORE PROCESSOR AND OS FOR REAL-TIME SIMULATION** | | | | | |
| Real-time processor | Fast INTEL XEON 2.3 GHz or above | Yes | Optional | Optional | Optional |
| | High-end XEON 3.3 Ghz or above | Optional | Yes | Yes | Yes |
| Number of processor cores | Number of enabled processors that can execute parallel computation | 12 | 12 | 24 | 48 |
| RTOS | Real-time operating system | Linux Redhat | | | |
| Minimum time step on CPU | For subsystems running on multi-core processors | 10 us | | | |
| Minimum time step on FPGA | For subsystems running on FPGA chips | 100 ns | | | |
| **TARGET COMPUTER AND I/O MODULES** | | | | | |
| OP5600 Chassis | 19 inches 4U chassis with real-time processors (up to 12 cores), up to 128 analog and 256 digital I/O channels and monitoring test points | 1 | 1 | 2 | 4 |
| OP7000 MULTI-FPGA Chassis | 19 inches 6U chassis with up to 9 Virtex 6 FPGA boards, analog and digital I/O channels and signal conditioning boards | Optional | | | |
| **FPGA BOARD** | | | | | |
| OP5142 card with Spartan III FPGA | FPGA User programmable models (optional) and  I/O | Yes | | | |
| ML605 card with Virtex 6 FPGA | Ideal for advanced floating-point co-simulation and user programmable I/O | Optional | | | |
| RT-XSG FPGA development tool | Enable users to develop their own FPGA models, controllers and IO signal processing functions | Optional | | | |
| **SOFTWARE TOOLBOXES** | | | | | |
| RT-LAB | Real-time software to run models on distributed processors and FPGAs | Yes | | | |
| RT-EVENTS | Simulink block set to simulate detailed controller with fixed time step and discrete events | Optional | Optional | Yes | Yes |
| RTE-DRIVE | Simulink block set to simulate motor drives and converter in real-time | Optional | Optional | Yes | Yes |
| ARTEMIS | Real-time solver for SimPowerSystems | Yes | | | |
| OPJMAG on CPU or FPGA | Real-time finite element motor model | Optional | | | |
| **ANALOG AND DIGITAL I/O WITH SIGNAL CONDITIONING (ADITIONAL I/O CAN BE ADDED)** | | Channels | Channels | Channels | Channels |
| Static digital inputs (DI) | Opto-isolated (0-30V) | 16 | 16 | 32 | 32 |
| Timed digital inputs (TDI) | Controlled by FPGA with 10 ns resolution | 16 | 16 | 32 | 32 |
| Static digital outputs (DO) | Opto-isolated (0-30V) | 16 | 16 | 32 | 32 |
| Timed digital outputs (TDO) | Controlled by FPGA with 10 ns resolution | 16 | 16 | 32 | 32 |
| Upgrade static to timed DIO | All static DIO can be controlled by FPGA with 10 ns resolution by installing optional FPGA functions | | | | |
| Analog inputs (AI) | Differential ± 16 V 16 Bits @ 2.5 µs (500 ns optional) | 32 | 32 | 64 | 64 |
| Analog outputs (AO) | Differential ± 16 V 16 Bits @ 1 µs | 32 | 32 | 64 | 64 |
| Current and voltage sensors | Up to 50 Amps / 600 Volts | Optional | | | |
| OP8620 signal conditioning box | Remote conditioning box for AD, DA, DI and DO | Optional | | | |

# from imagination to real-time

## About OPAL-RT

Founded in 1997, OPAL-RT Technologies is a world 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's unique technological approach integrates parallel, distributed computing with commercial-off-the shelf technologies.

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

Our customers perform rapid control prototyping, system integration, and hardware-in-the-loop testing of electric drives, electronic controllers and power distribution networks in a variety of industries including automotive, aerospace, electric ships, power generation, rail, and industrial manufacturing.

OPAL-RT helps client's projects to move from imagination to real time.

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