OPAL-RT TECHNOLOGIES

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)

SUCCESS STORY

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.

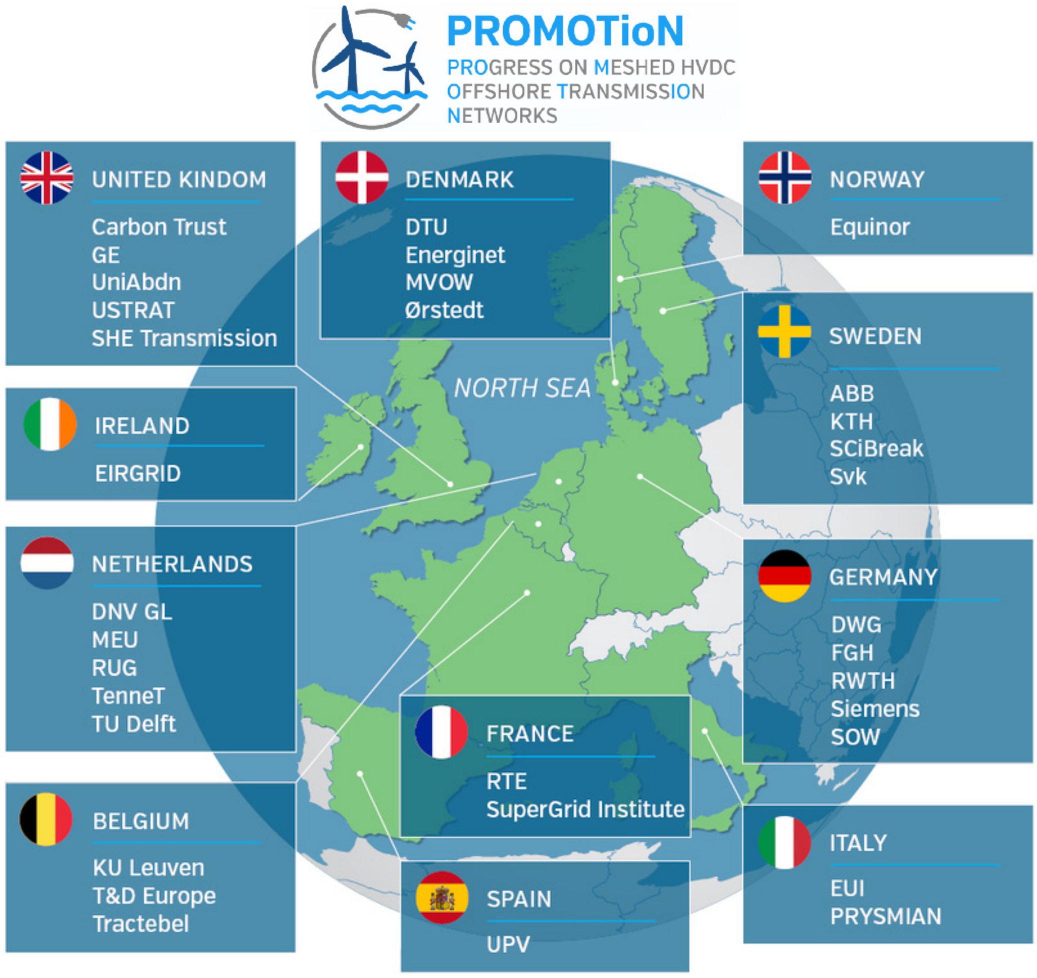
The most common type of VSC-HVDC converter is the Modular Multilevel Converter (MMC). MMC's distinctive topology provides a wide variety of features new to many grids, necessitating the use of increasingly sophisticated controllers.

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.

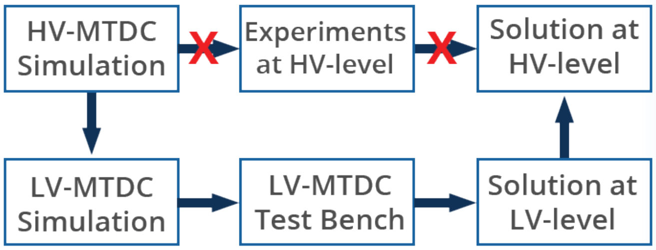
MAJOR OBSTACLE

"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.

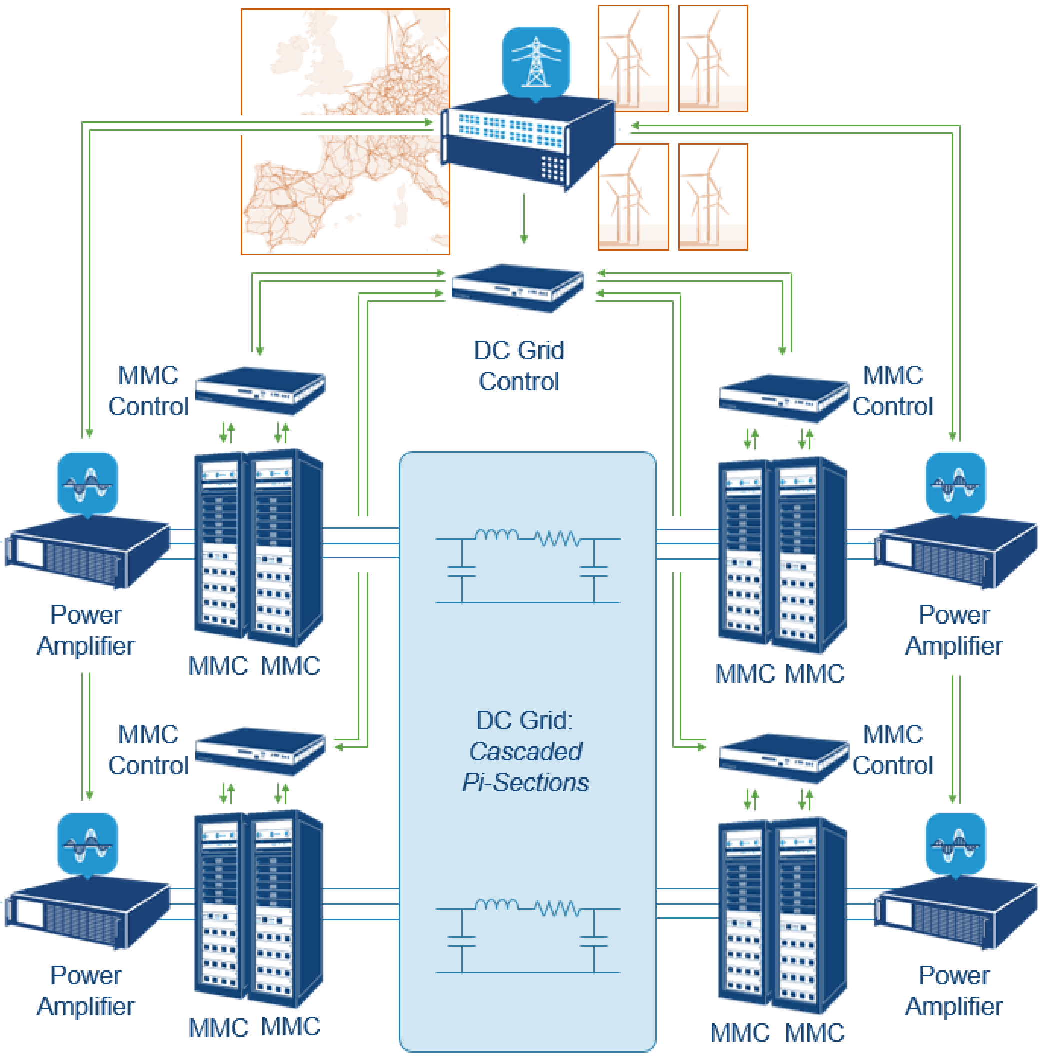
• The laboratory scale MMC converters are coupled with the simulation using four 21kVA linear power amplifiers from *Puissance Plus*.

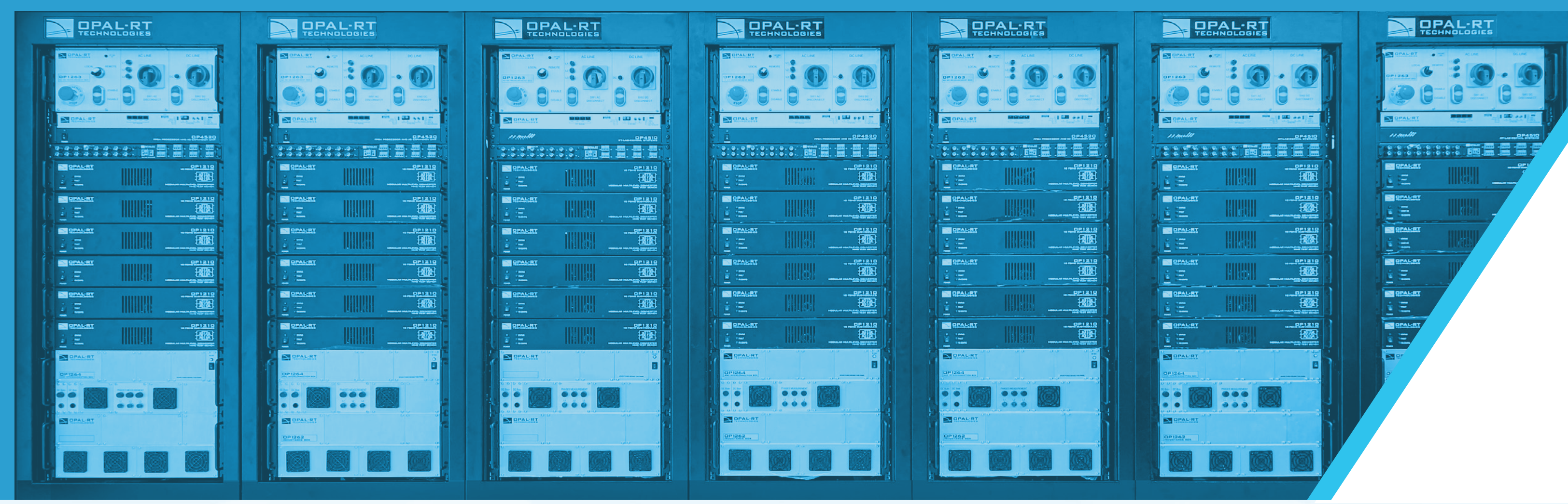
• The DC system has been emulated with PI sections and interconnects the various MMC test benches.

• 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.

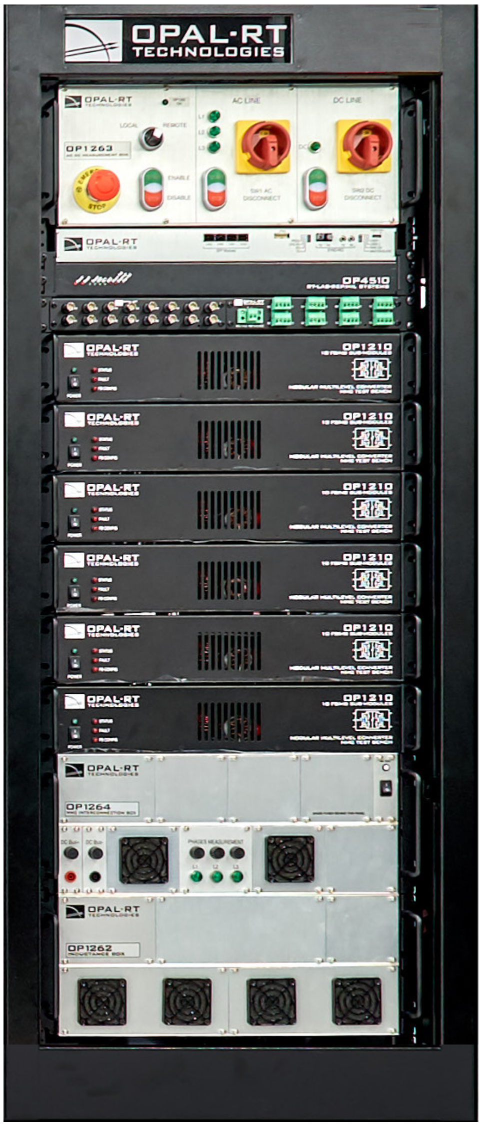
• Eight OPAL-RT Lab-Scaled MMC test benches are in the laboratory. Each of them is composed of an OP4510 for the low-level control and 6 times OP1210 boxes (each of them representing an arm of the MMC converter).

REAL-TIME SIMULATION





THE SOLUTION & IMPLEMENTATION



OP4510

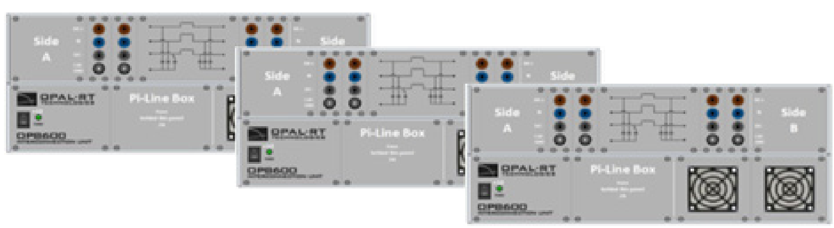
Equipped with the latest generation of Intel Xeon four-core processors and a powerful Xilinx Kintex 7 FPGA, the OP4510 delivers raw simulation power for both CPU-based real-time simulation and sub-microsecond time step power electronic simulation.

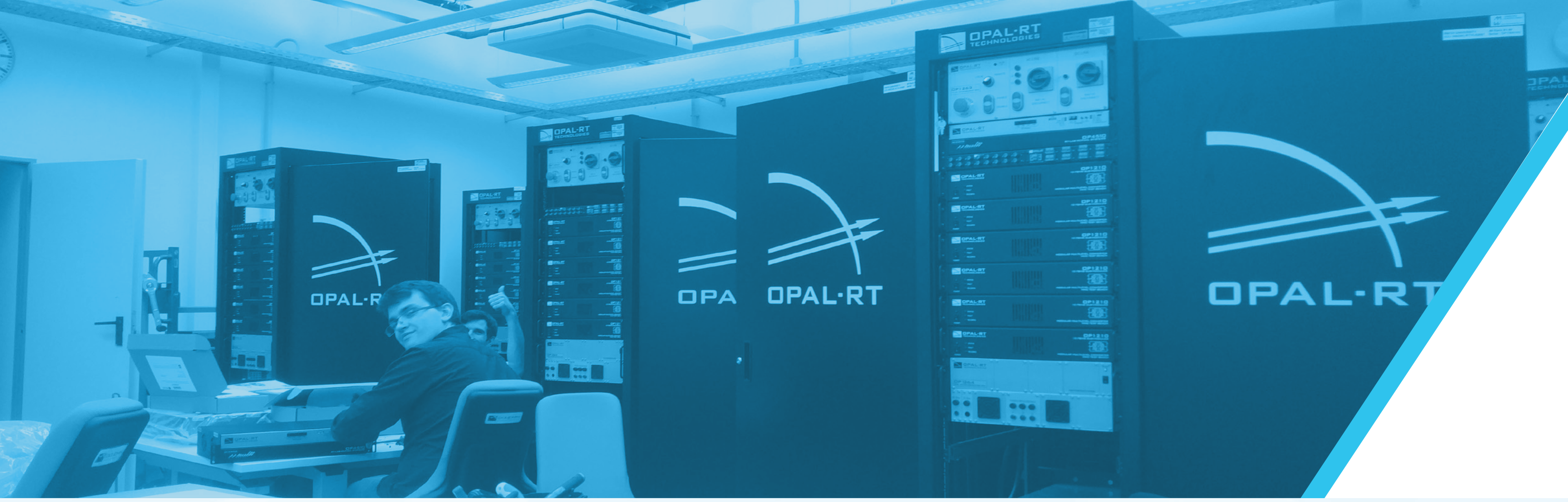
OP1210

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.





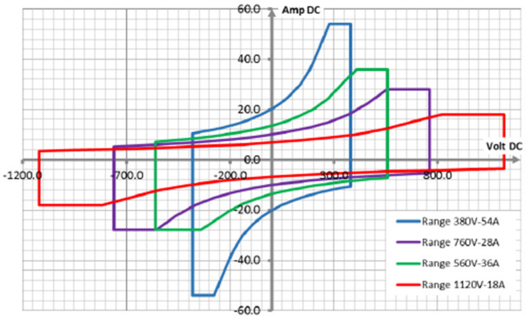
THE SOLUTION & IMPLEMENTATION

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*

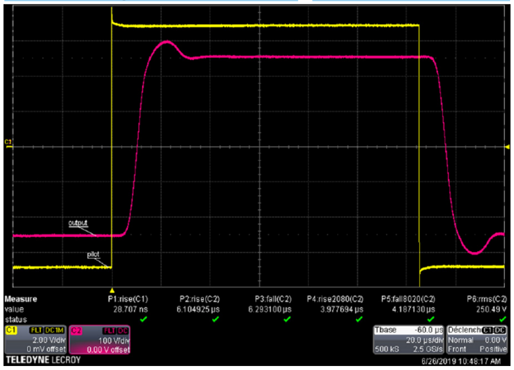
SPHEREA
PUISSANCE PLUS

4 Quadrants | Amplifier in HVDC



Bandwidth

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

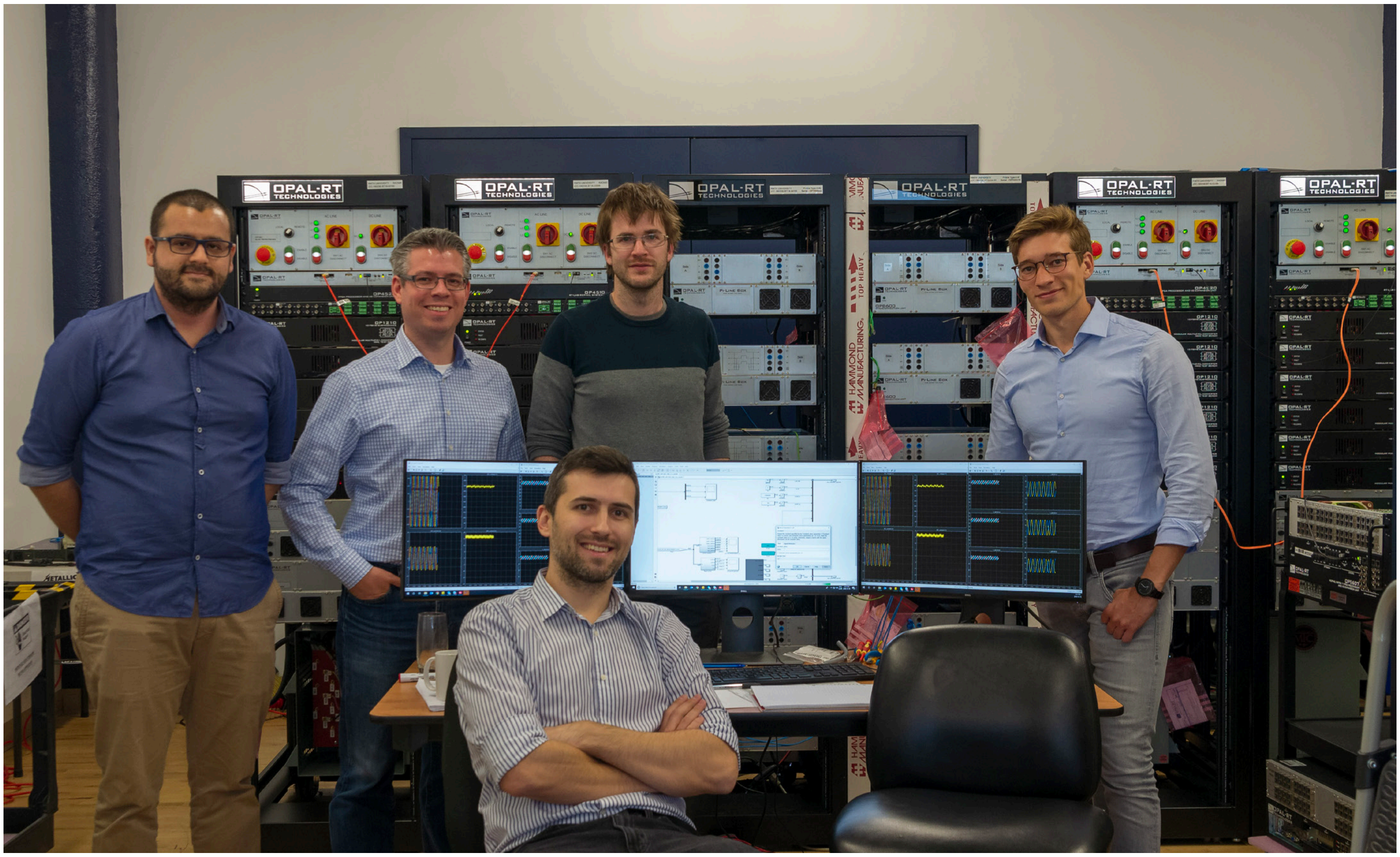


RESULTS

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