De-risking multi-vendor, multi-terminal HVDC with real-time simulation

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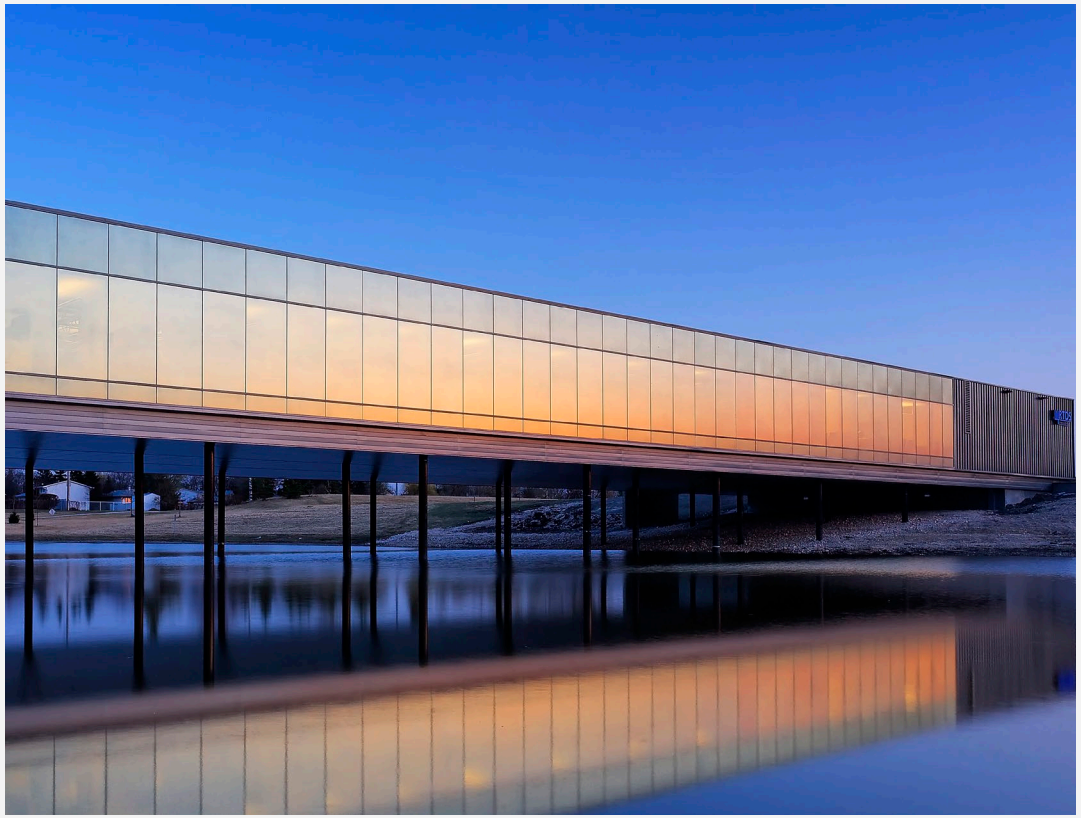
AMETEK

AGENDA

- Real-time simulation and HIL fundamentals
- HVDC applications and case studies

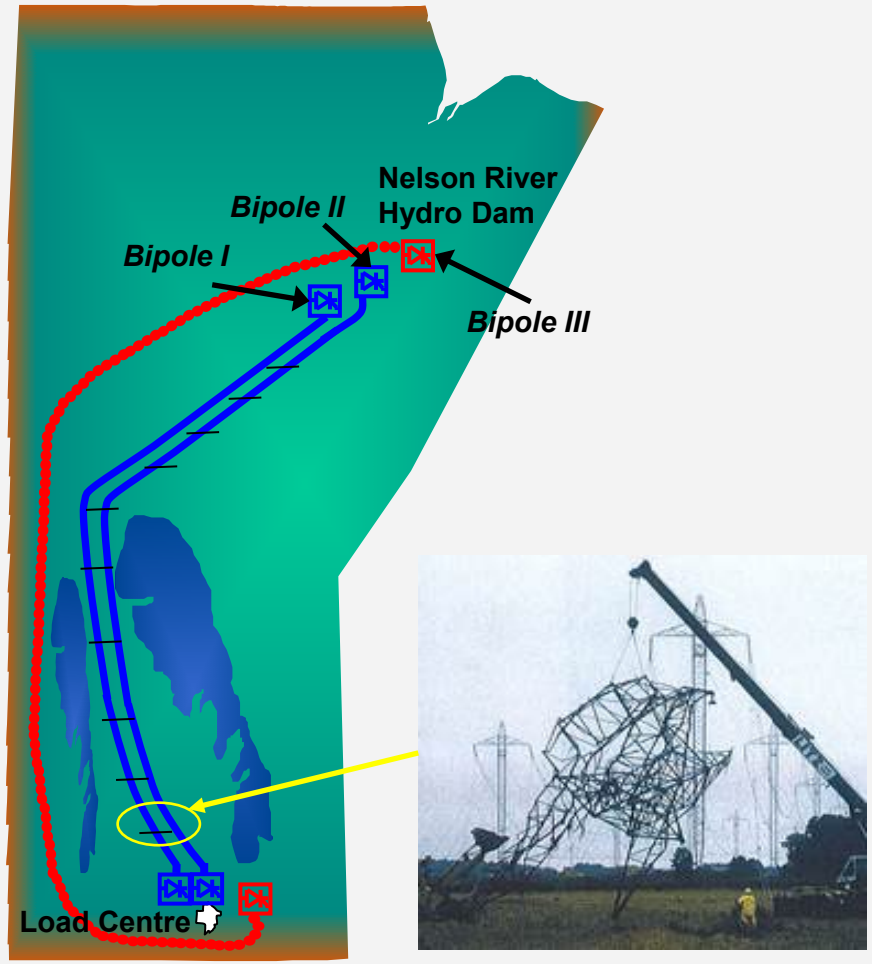
- Find me afterward (or at Stand 215C) if you have questions!

About RTDS Technologies



- Pioneers of real-time digital simulation: world's first real-time digital HVDC simulation in 1989
- Serving the power industry for over 30 years
- Based in Winnipeg, Canada with customers in over 57 countries around the world
- Our main users are utilities, manufacturers, research and educational institutions, and consultants

Our roots in HVDC

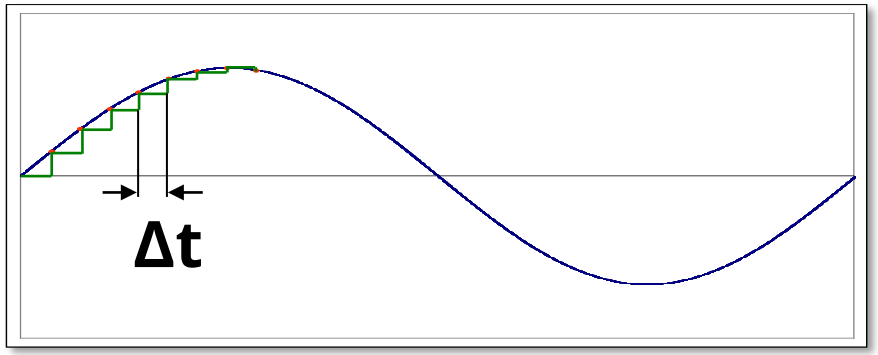


Manitoba, Canada

- Development for Nelson River hydroelectric project started in the 1950s
- Today, Manitoba is home to three HVDC bipoles ranging from 900-1300 km, and is a hub for HVDC knowledge/research
- Careful testing was key for Bipole III – three inverters feeding into tightly-coupled AC system with low short circuit capacity and system inertia
- **“Transient stability & EMT study tools valuable but testing of physical controls irreplaceable & imperative” – Manitoba Hydro**

Electromagnetic transient (EMT) simulation

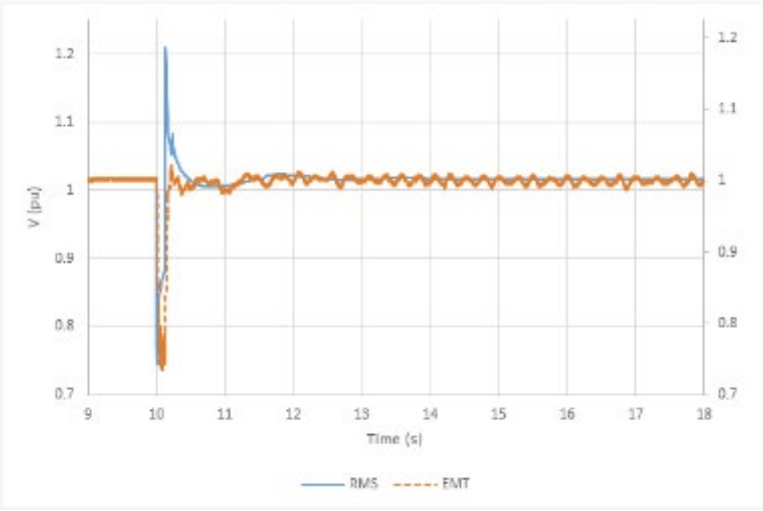
Type of Simulation	Load Flow	Transient Stability Analysis (TSA)	Electromagnetic Transient (EMT)
Typical timestep	Single solution	~ 8 ms	~ 2 - 50 µs
Output	Magnitude and angle	Magnitude and angle	Instantaneous values
Frequency range	Nominal frequency	Nominal and off-nominal frequency	0 – 3 kHz (<15 kHz)



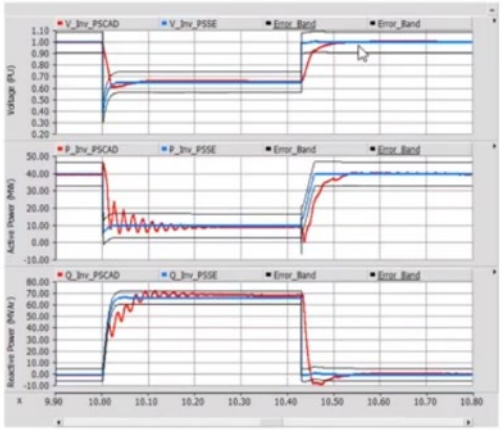
Dommel algorithm of nodal analysis used in RTDS, PSCAD, EMTP, etc.

Increasing adoption of EMT simulation

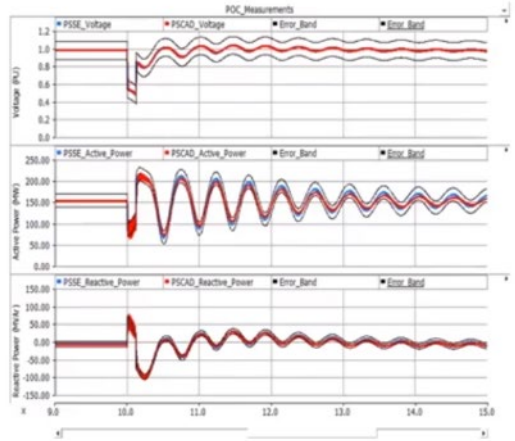
- Allows for a greater depth of analysis than phasor domain (RMS) representations
- RMS models lack the ability to capture fast network dynamics during transient conditions and may provide optimistic results
- Important for modern systems with many power electronic converters (more likely to predict control instability)



Wind farm fault ride through

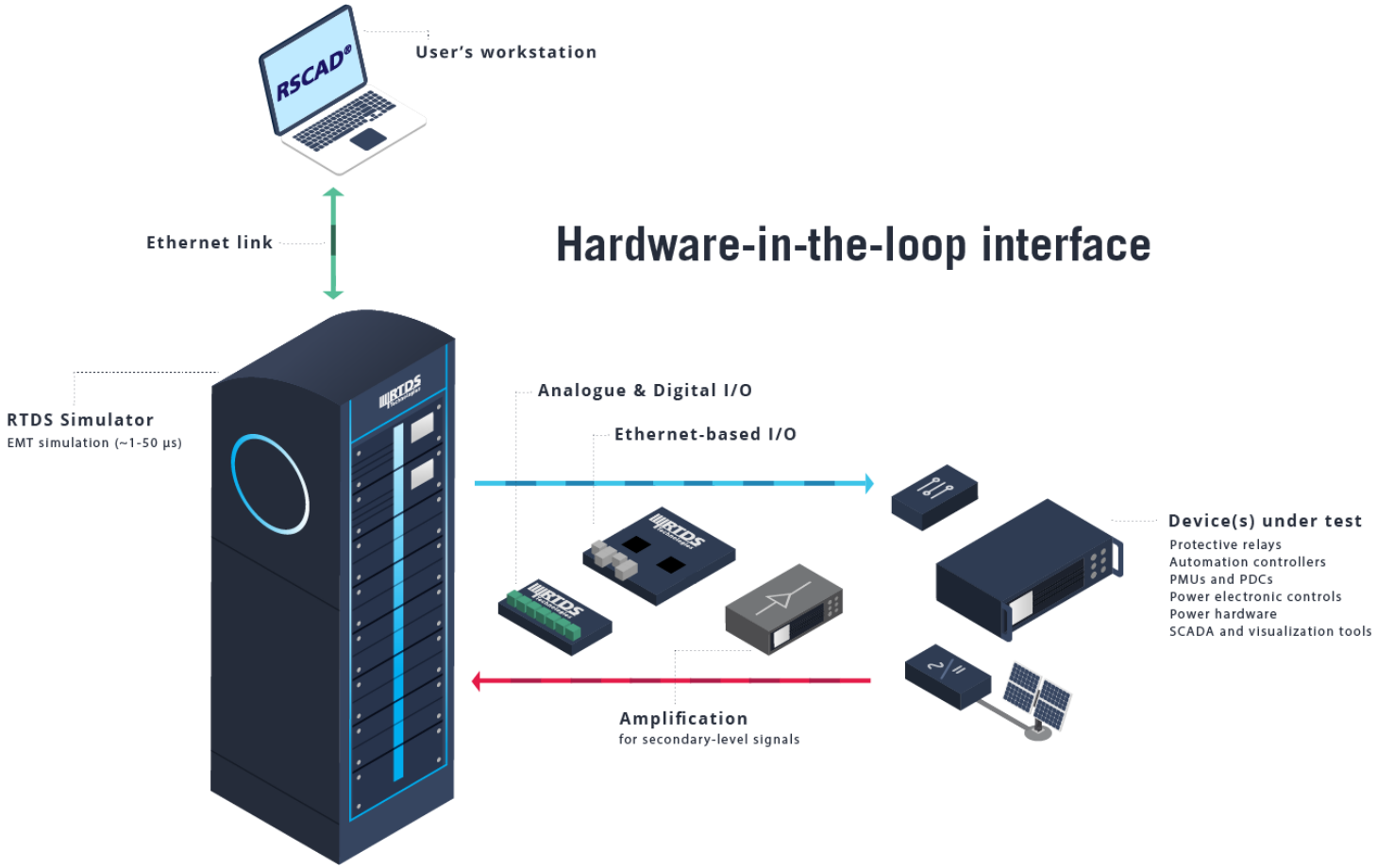


Synchronous generator fault ride through



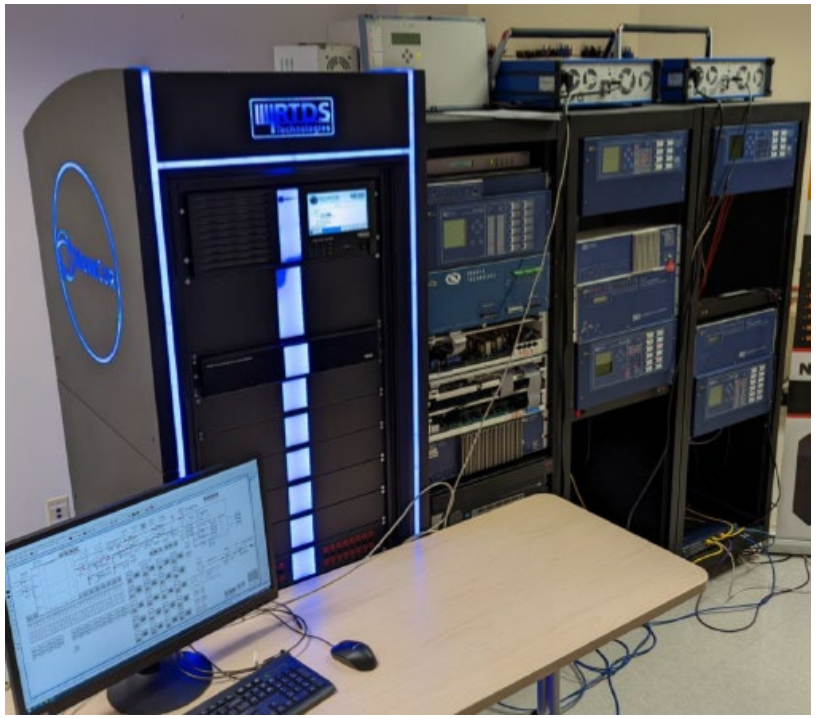
Hardware-in-the-loop testing

- **Real time operation** is what allows us to connect physical devices in a **closed loop** with the simulated environment (hardware-in-the-loop or HIL testing)
- **True closed-loop testing** is only possible with a real time simulator



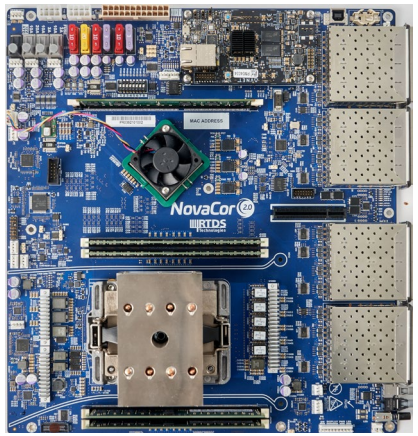
Advantages of HIL testing

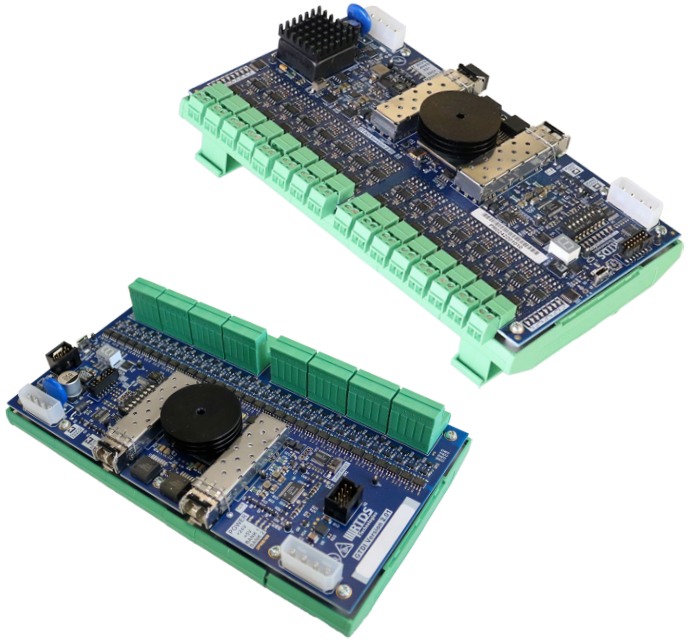
- Test continues after the action of the protection/control device, showing dynamic response of the system
- Test multiple devices, entire schemes at once – gain a holistic understanding of the potential for negative interaction between different devices and systems (HVDC converters and other devices)
- Much more detailed system representation than open-loop test systems provide (e.g. modelling power electronics and detailed fast-acting controls)

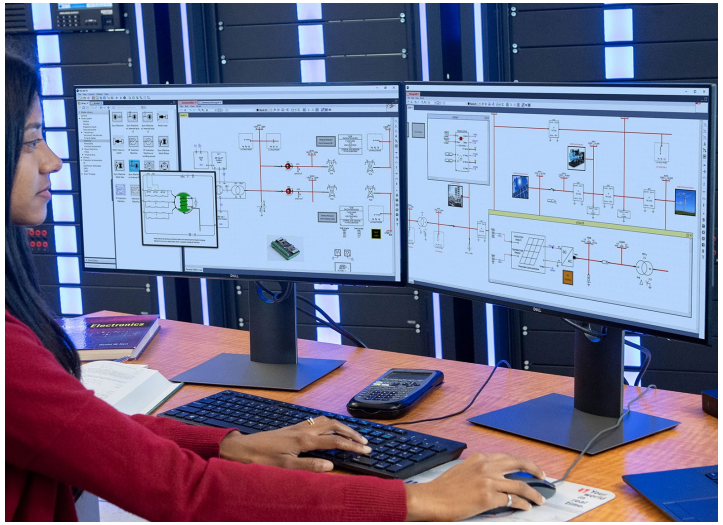


Source: Quanta Technology

Components of a HIL testbed







- **Simulation hardware** – based on a custom-integrated multi-core processor (IBM POWER9); modular and scalable
- **I/O hardware** – analogue, digital, and communication-based connection to external equipment; modular and scalable
- **Simulation software** – user-friendly GUI on your workstation

Applications

Distribution

- Microgrid testing.
- Renewables/DERs.
- Distribution automation.
- Inverter testing.

Power Electronics

- **HVDC and FACTS.**
- Energy conversion.
- Drives.

Smart Grid

- WAMPAC testing.
- PMU studies.
- Cyber security.

Protection

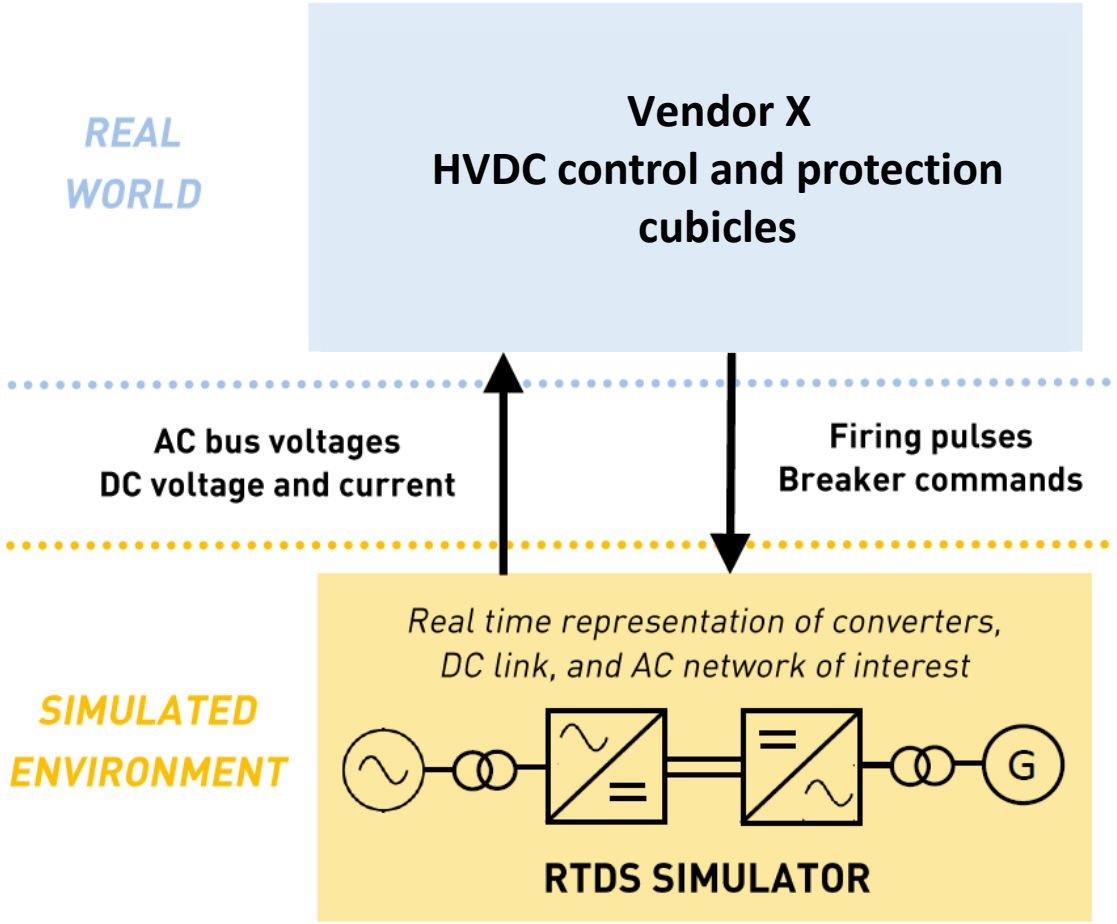
- Digital substations.
- Travelling wave testing.

HVDC/FACTS modelling with the RTDS Simulator

- Many different options for modelling LCC, VSC, and MMC-based schemes (as well as the AC network, nearby IBRs, etc.)
- Detailed MMC-HVDC models allow thousands of submodules per valve, internal faults, damping submodules, batteries
- **New embedded MMC-HVDC models have no interface transmission line and can run in the Mainstep environment**
- Many sample cases including CIGRE benchmarks, new offshore wind example

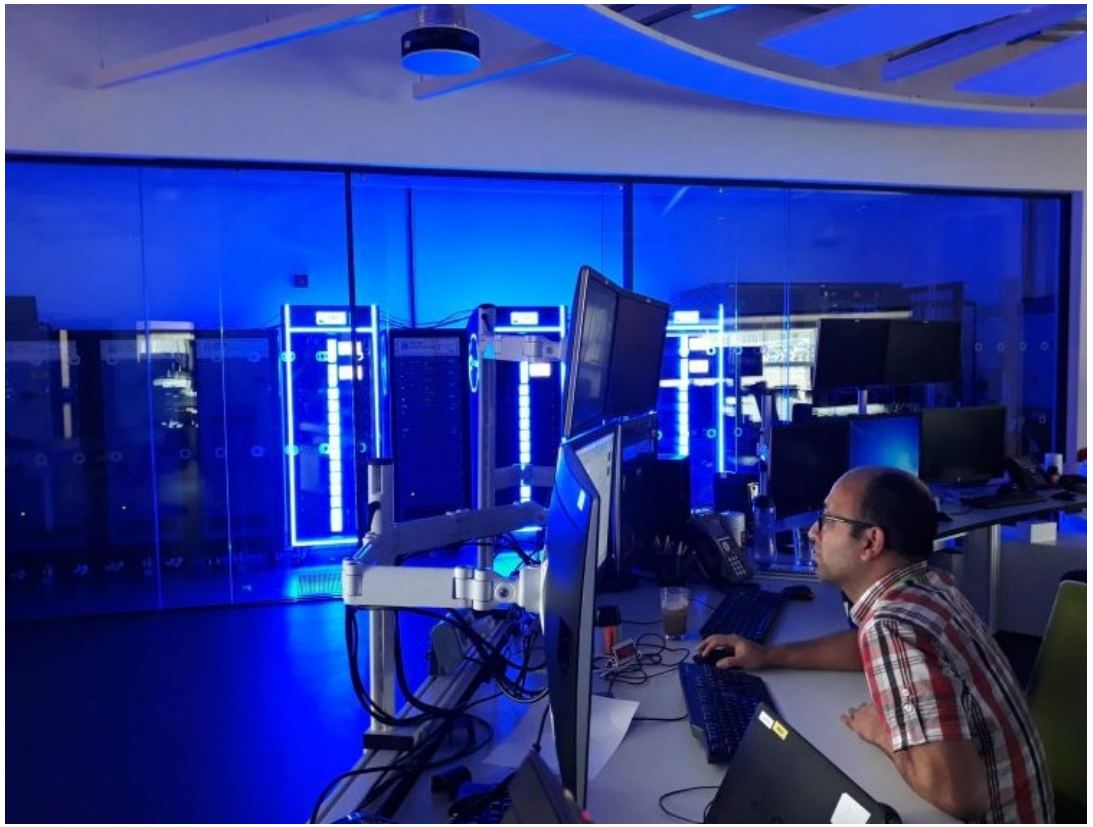
HVDC FACTORY ACCEPTANCE TESTING (FAT)

- Used by all manufacturers of HVDC for FAT
- Vendor builds up a model of their scheme and equivalent of the network where the scheme will be installed
- Hundreds of functional and dynamic performance tests (FPT/DPT)
- Simulations run for hours or days for comprehensive testing



REPLICA SIMULATORS

- Replica controls provided to operator along with RTDS Simulator for testing
- Reduce commissioning schedules
- Investigate proposed network changes or control modifications
- Train personnel on scheme theory and operation
- Important to include in project specification
- Dozens of replica simulators now in operation in utility/TSO labs around the world



Source: National HVDC Centre (UK)

HVDC Testing and Commissioning Process

Operation Readiness

Off-Site Activities (OEM)

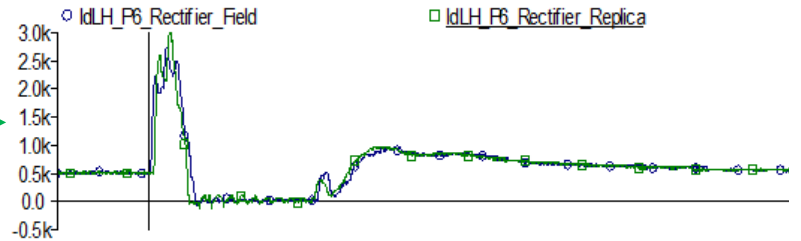
- Functional / Dynamic Performance Test (FPT/DPT)

More than 500 factory tests involving the RTDS Simulator

On-Site Activities (Operator)

- Control & Protection (C&P) Replica Test (CTS)
- Pre-Commissioning (Pre-EF3) Test using System Forecast Condition
- Staged Faults Risk Assessments
- Test Review / Acceptance / Model Validation
- Trial Operation

3 month schedule reduction due to replica/pre-commissioning testing

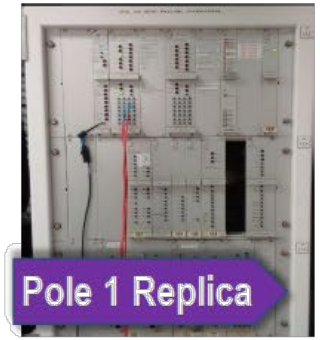


Source: Manitoba Hydro

Manitoba Hydro Real-time Simulation Centre

RTDS Fleet (2 Fully Licensed NovaCor & 14 PB5 Racks)

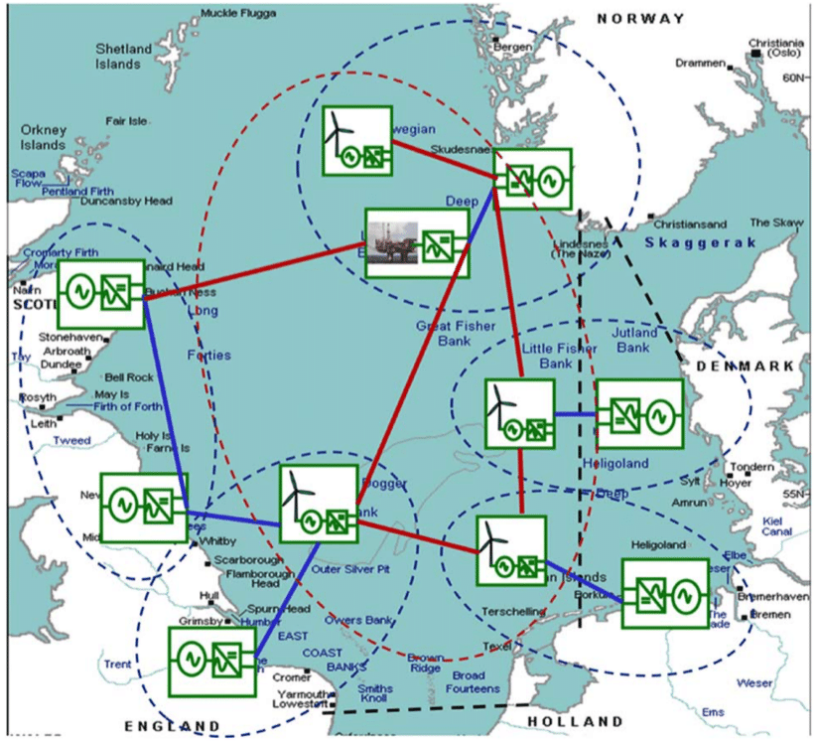
HVDC Control & Protection (C&P) & Auxiliary Equipment Replicas



Source: Manitoba Hydro

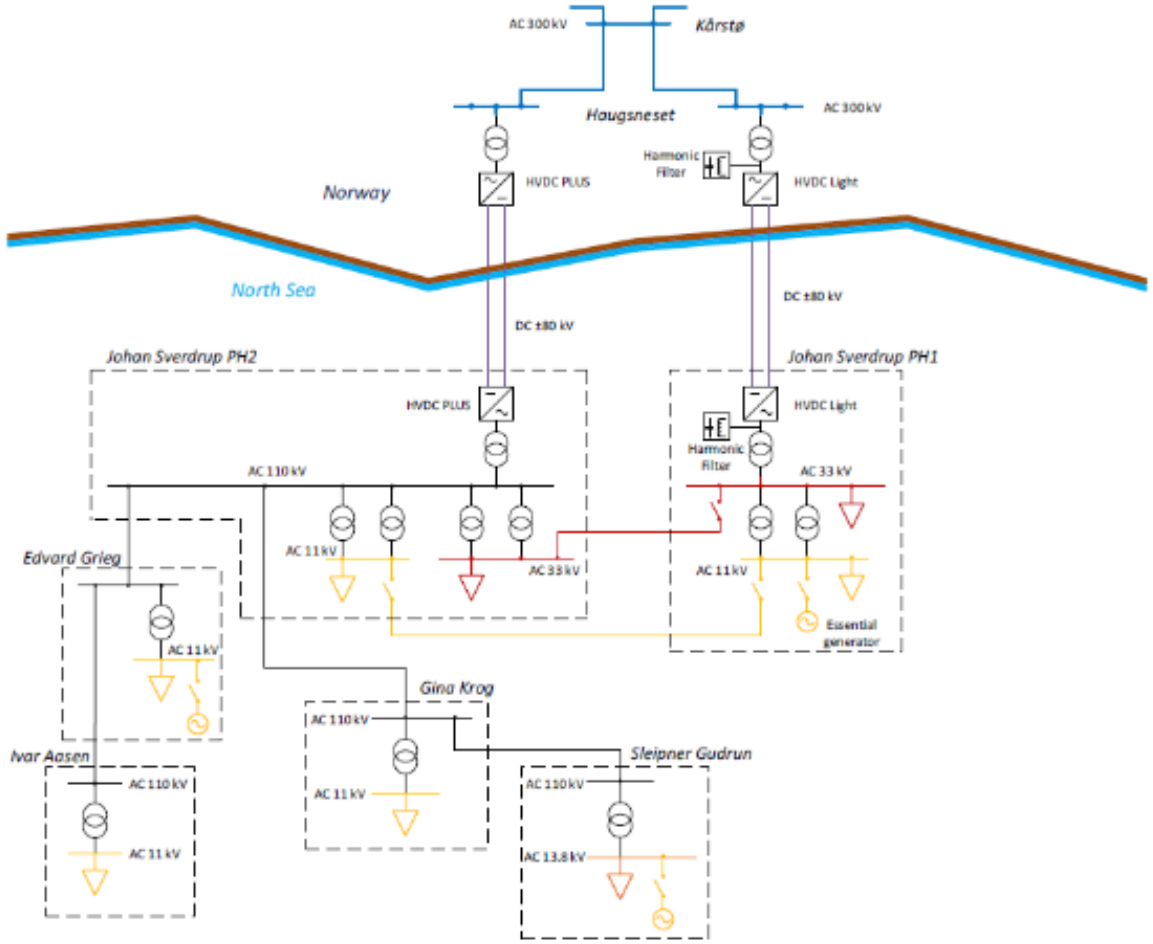
MULTI-VENDOR HVDC GRIDS

- Massive activity in UK and Europe (~450 GW offshore wind by 2050 in Europe)
- Multi-terminal, multi-vendor HVDC grids are the future – will require huge amount of research, collaboration, and standardization
- Not practical for large-scale HVDC grids to be turnkey solutions
- Multi-vendor interoperability is a key challenge, not only technically – need consensus on performance expectations, system structure



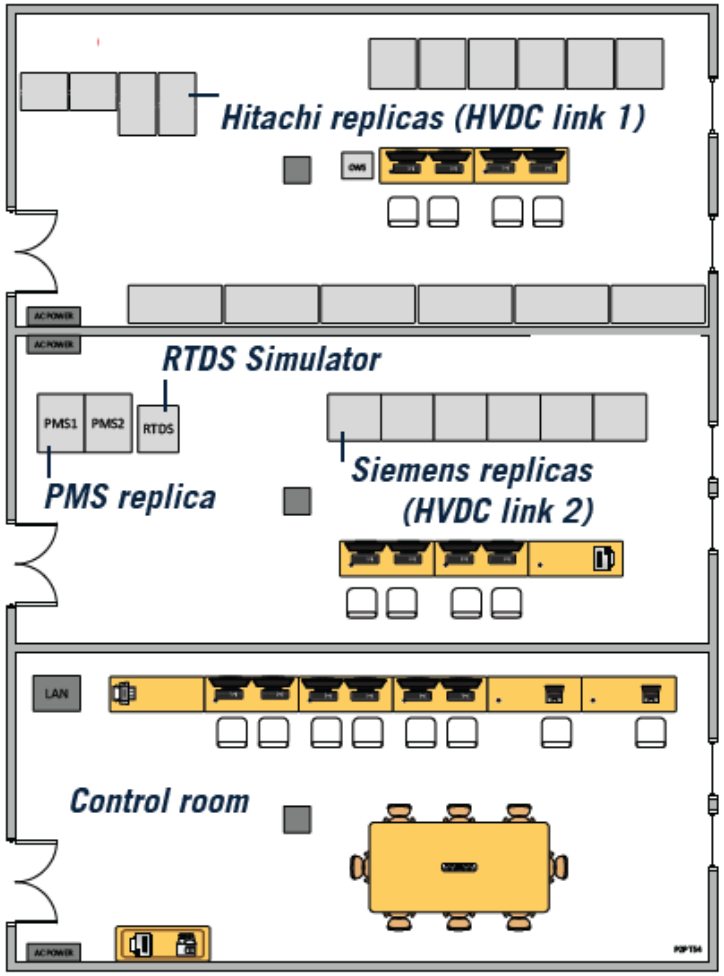
Johan Sverdrup HVDC Project

- Offshore platform connected to Norwegian onshore grid via two parallel HVDC links
- 2-level VSC link supplied by Hitachi Energy and MMC-VDC link by Siemens
- HIL testing of replica control & protection cubicles identified as necessary
  - IP issues – not possible to use open offline models
  - Slower-acting C&P are not included in offline models due to time restrictions
  - Global controller to coordinate two links not available for inclusion in offline model



Source: RTE International

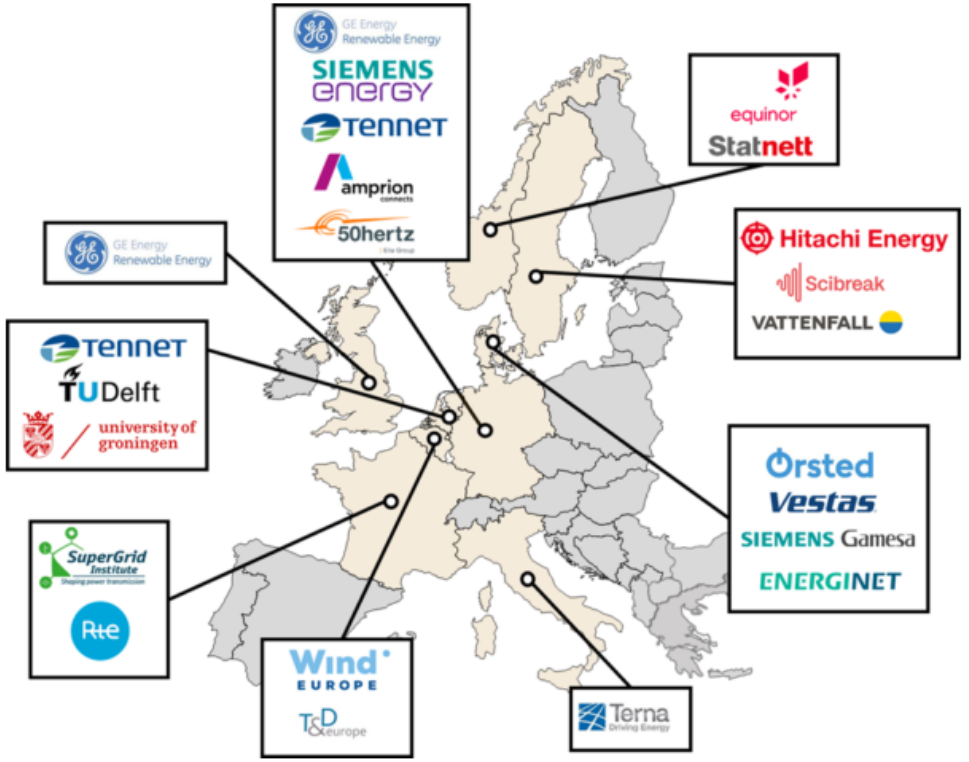
Johan Sverdrup HVDC Project



Source: RTE International

HVDC – InterOPERA project

- InterOPERA research/demonstration project is aimed at enabling interoperability of multi-vendor HVDC grids in Europe
- Funding from Horizon Europe program
- Joint initiative of TSOs, wind developers and manufacturers, HVDC manufacturers, and universities (including TU Delft)
- Real-time physical demonstrator will involve HVDC replicas connected to the RTDS Simulator



HVDC – Project Aquila

- 32 GW of new HVDC in Great Britain between now and 2031
- National HVDC Centre a leader in HVDC simulation, HVDC control replica testing, knowledge sharing
- Project Aquila – multi-vendor interoperability demonstration project

Black box control simulation

- Generic models do not always suit the purpose
- Vendors need a way to provide models that accurately reflect their control/protection to customers while protecting IP
- FPGA- and SoC-based auxiliary hardware allows black-boxed vendor-specific controls to be securely integrated into the real-time simulation environment
- Applications in DERs/IBRs, HVDC, etc.

Software-in-the-loop simulation of HVDC

- GE Vernova has implemented their MMC-HVDC control and protection solution (eLumina) using our black box platform
- SIL testing allows for detailed testing earlier on in project timelines (before control hardware may be available)

Poster session today
4-6 PM in Hall Ternes (Level 1)
"Software-in-the-Loop Real Time Simulation of a HVDC terminal"
with GE Vernova

Thank you!

Find us at Stand 215C

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