A Demonstrator for Experimental Testing Integration of Offshore Wind Farms With HVDC Connection

S.D'Arco, A. Endegnanew, SINTEF Energi

BEST PATHS PROJECT

BEyond State-of-the-art Technologies for re-Powering AC corridors and multi-Terminal HVDC Systems

- Validate the technical feasibility, impacts and benefits of **novel grid technologies**,

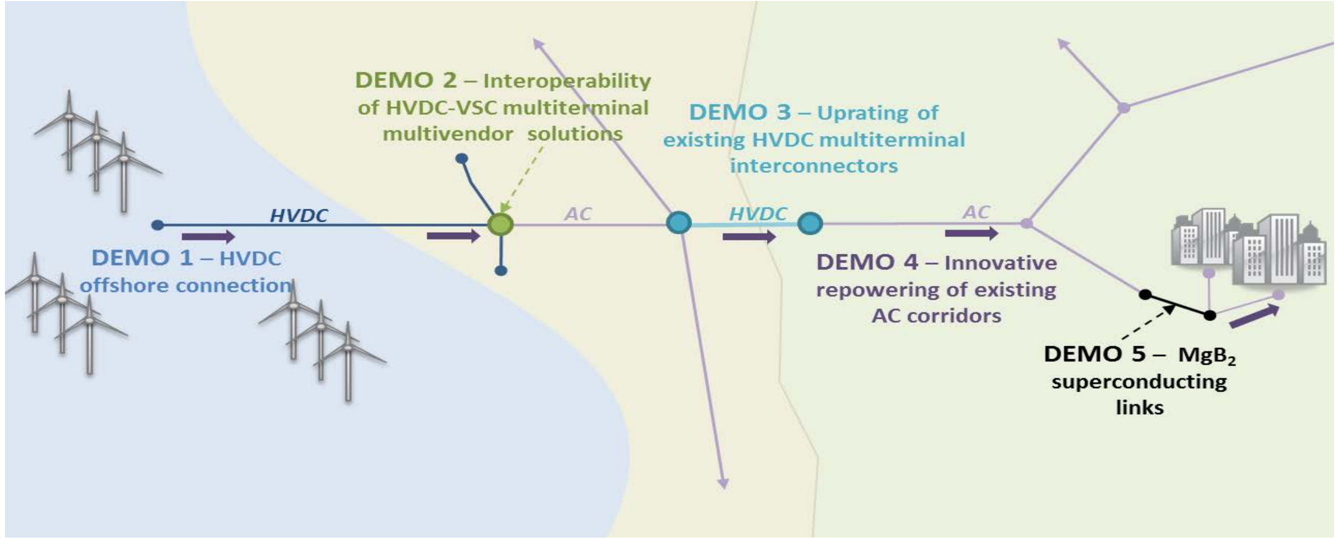
- Five large-scale demonstrations
  - Deliver solutions that allow for transition from **High Voltage Direct Current (HVDC) lines to HVDC grids**;
  - **Upgrade and repower** existing Alternating Current (AC) parts of the network;
  - Integrate **superconducting high power DC links** within AC meshed network

LARGE SCALE DEMONSTRATIONS

1. **HVDC in offshore wind farms and offshore interconnections**
2. **HVDC-VSC multivendor interoperability**
3. **Upgrading multiterminal HVDC links**
4. **Innovative repowering of AC corridors**
5. **DC Superconducting cable**

From HVDC lines to HVDC grid

Upgrading of existing AC grids

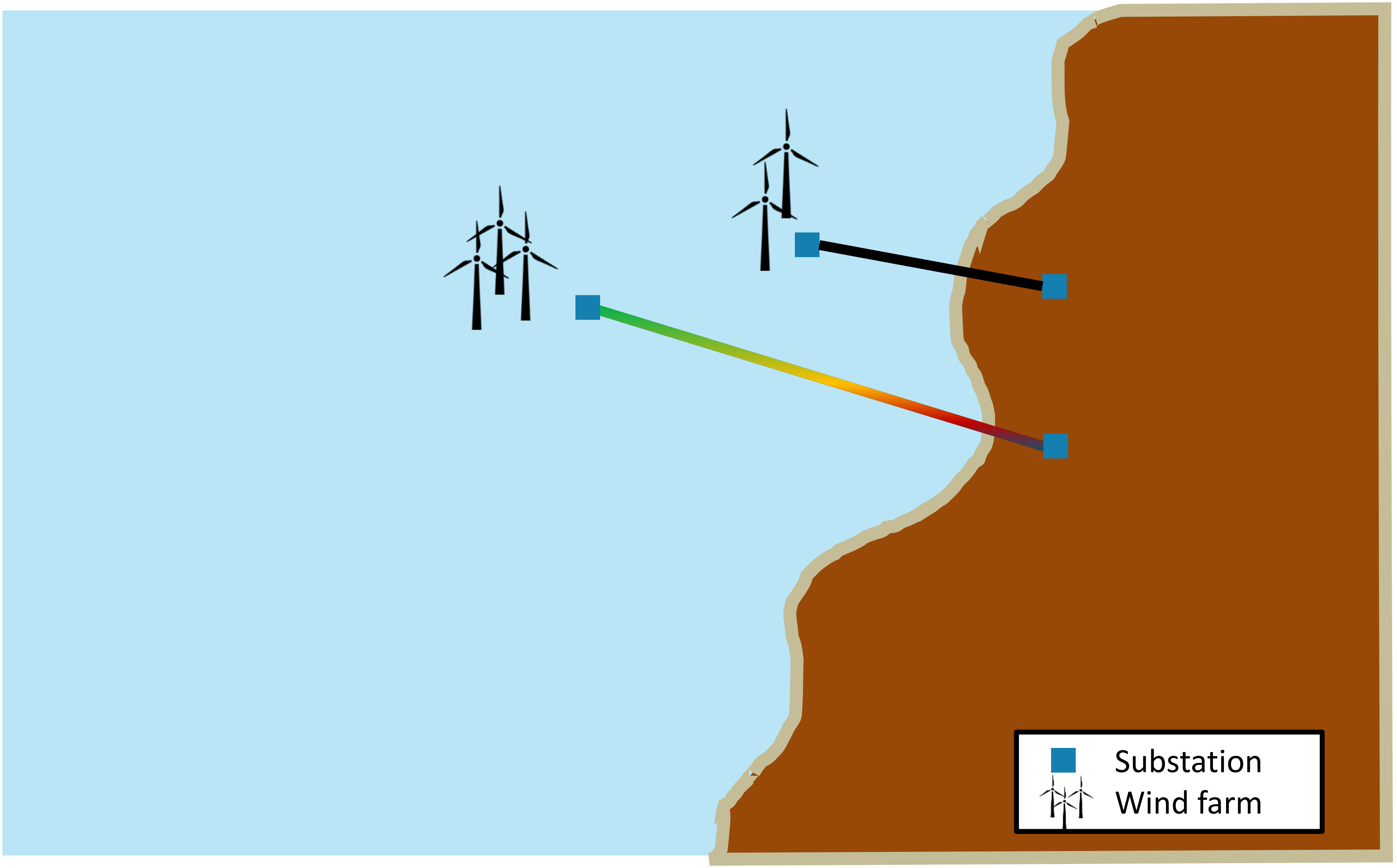


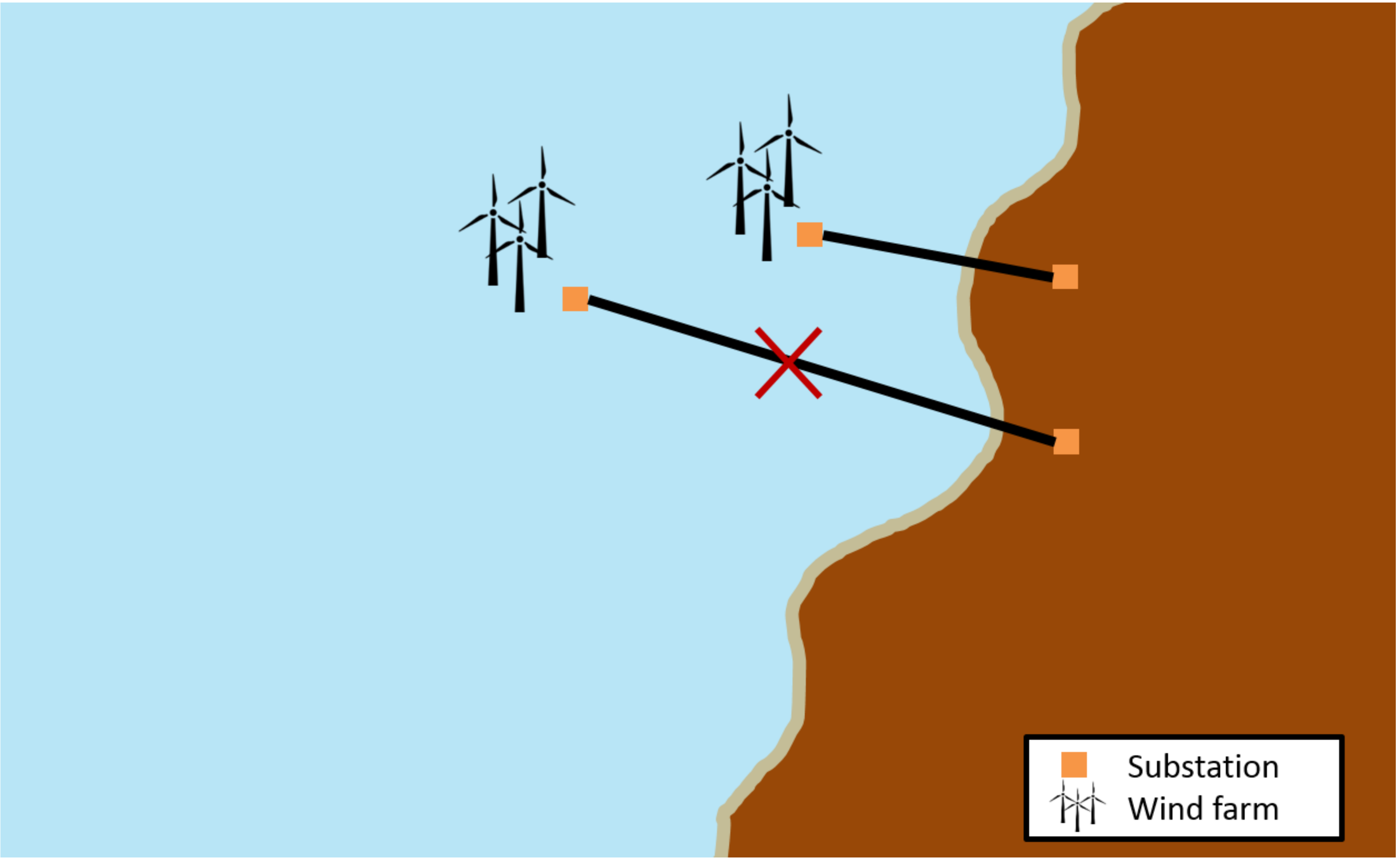
SINTEF

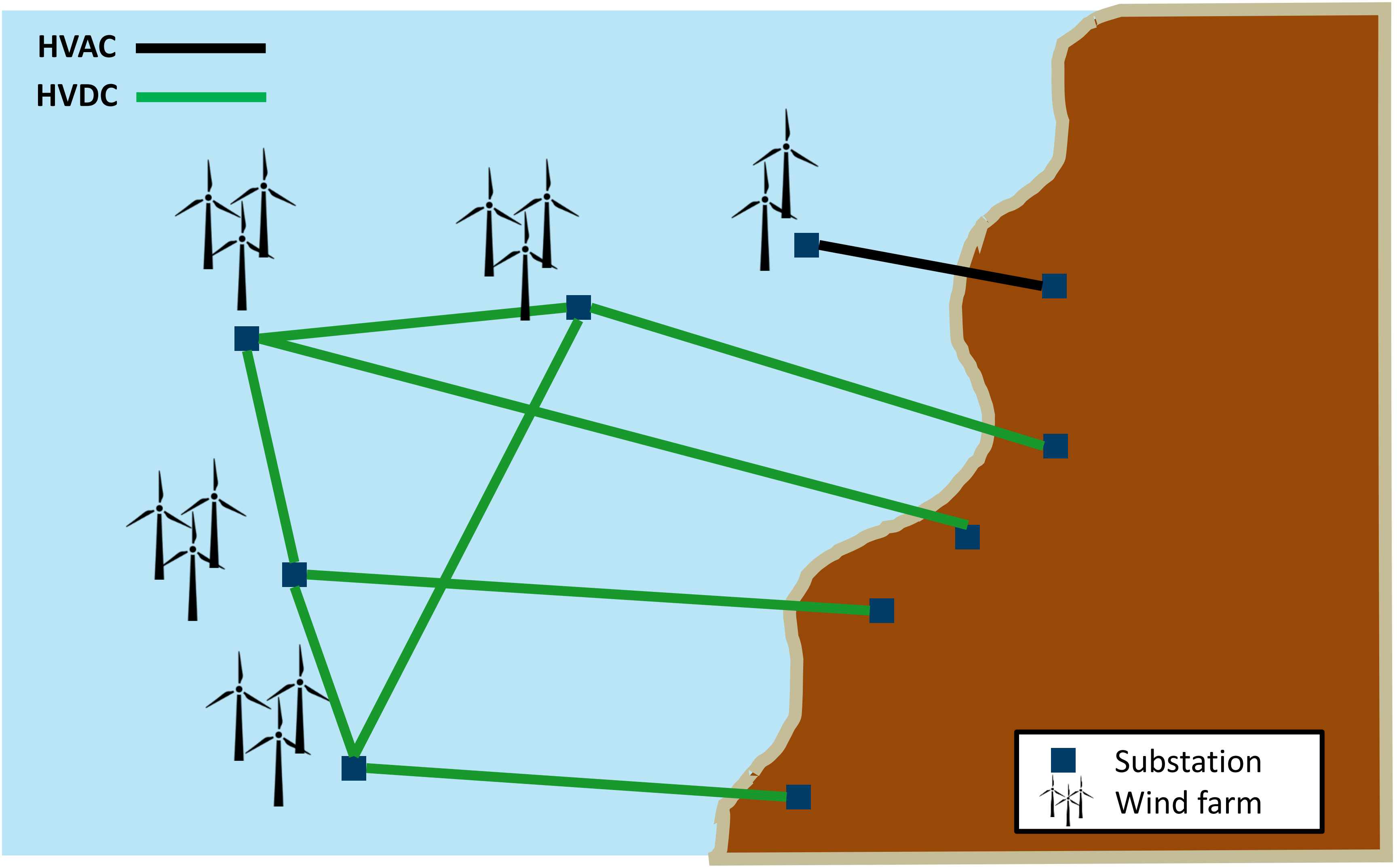
DEMO 1 Objectives

- To investigate the **electrical interactions** between **HVDC link converters and wind turbine converters in offshore wind farms**.
- To **de-risk** the **multivendor and multiterminal schemes**: resonances, power flow and control.
- To **demonstrate** the results in a **laboratory environment** using scaled models (4-terminal DC grid with MMC VSC prototypes and a Real Time Digital Simulator system to emulate the AC grid).
- To use the validated use the validated models to simulate a **real grid with offshore wind farms connected in HVDC**.

IBERDROLA — **Demo leader** Utility & RES operator knowledge	
Definition of models and simulation of scenarios CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD; University of Strathclyde Glasgow; RSE; SINTEF; tecnalia Inspiring Business	Knowledge on WTG & Power Electronics models Gamesa System operation knowledge ENERGINET


Substation
Wind farm


Substation
Wind farm

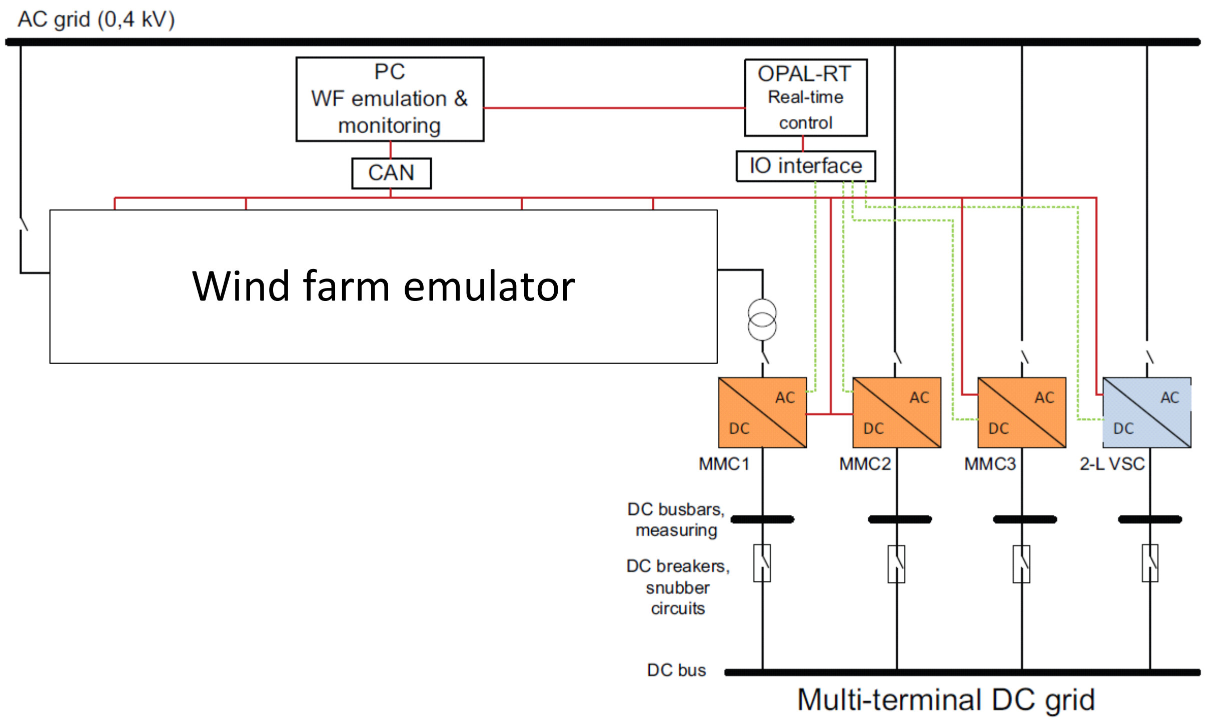

HVAC
HVDC
Substation
Wind farm

Demonstrator overview

- Three-terminal scheme MMC with
  - MMC with HB cells, 18 cells and 6 cells per arm,
  - MMC with FB cells, 12 cells per arm

- Wind farm emulator

- National smart grid laboratory



SINTEF

National Smart Grid Laboratory

- Laboratory formally opened in September 2016 after a major upgrade
- Jointly operated by NTNU and SINTEF
- Reconfigurable layout with multiple ac and dc bus
- Power electronics converters
  - 2 level VSC 60 kVA, MMC 60 kVA
- Electrical machines
  - Synchronous generators, Induction machines
- Real-time simulator

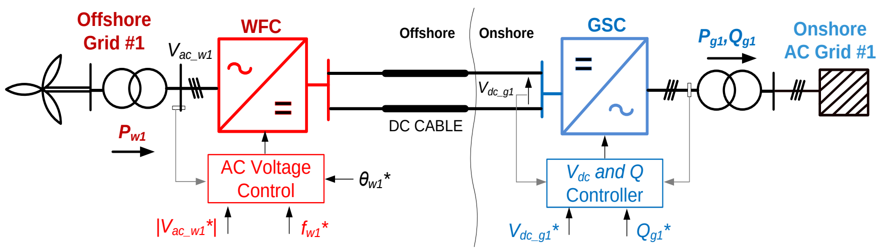
Real-time simulation and PHIL capabilities

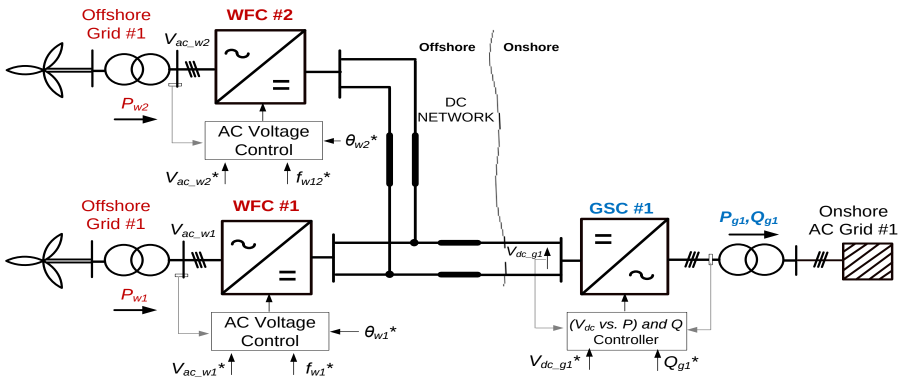
- OPAL-RT based real time simulator platform
  - 5 parallel cores,
  - 2 FPGAs for IO and small time step simulation,
  - Fiber optic communication
- Egston Compiso Grid emulator
  - 200 kVA rated power
  - 6 individual outputs
  - > 10 kHz bandwidth
  - Connected to the OPAL-RT system via fiber optics with 4 μs update rate for measurements and references

SINTEF

Demonstration of HVDC transmission systems connected to offshore wind farms

- Designed and built 3 MMC prototypes
- Tested the converters in point to point and multiterminal configurations
- Planned PHIL experiements with real time model of a wind farm

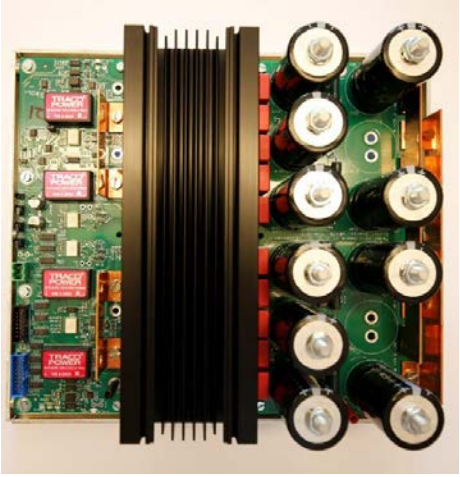




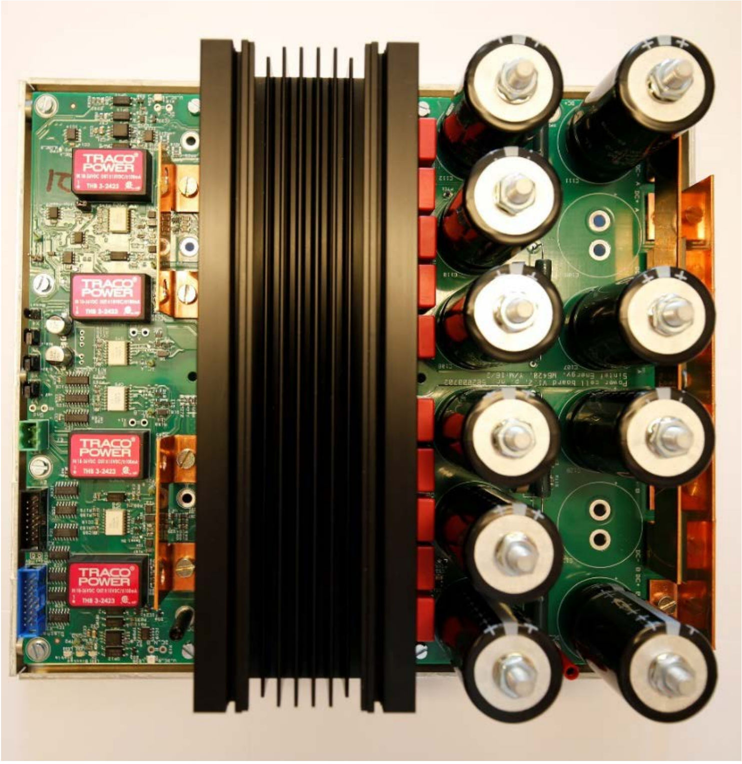
MMC Converters

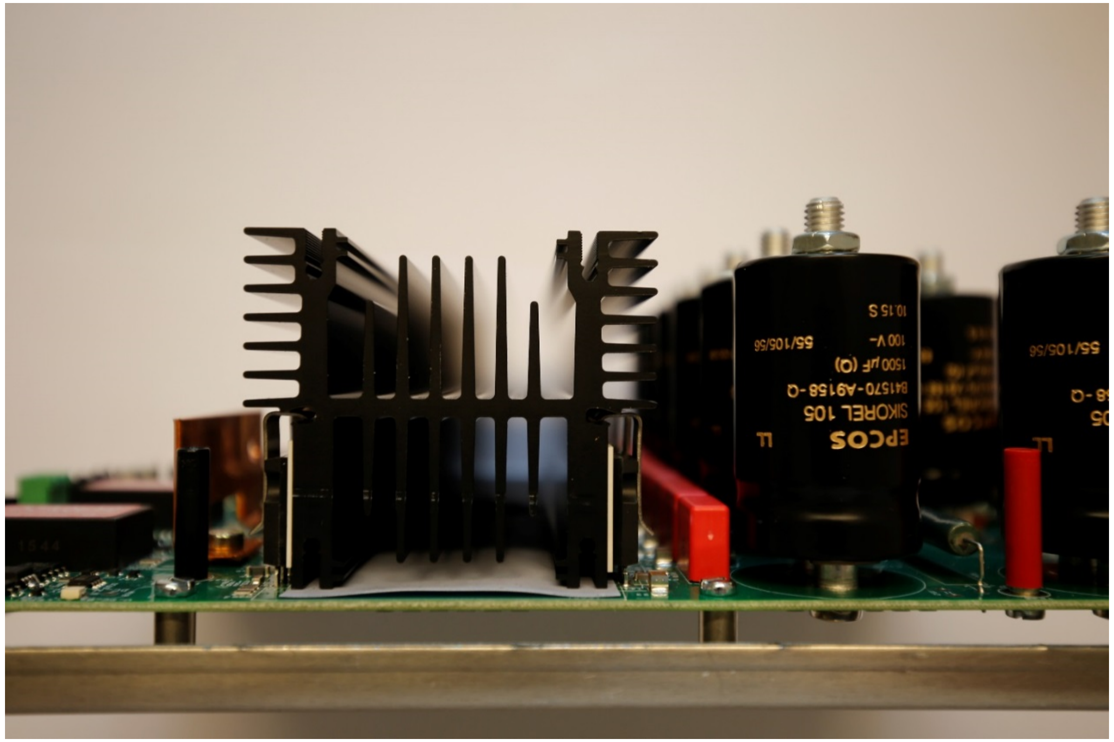
- Three MMC converters were designed from scratch
  - MMC with HB cells, 18 cells per arm
  - MMC with FB cells, 12 cells per arm
  - MMC with HB cells, 6 cells per arm

- Built and successfully tested at full rating
  - 42 modules
  - 144 power cell boards
  - 1764 capacitors

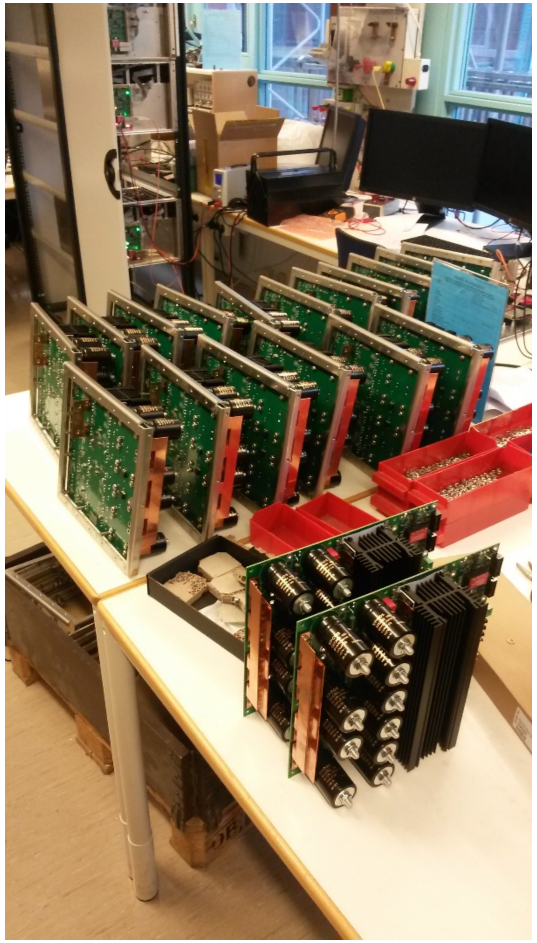


Power cell boards



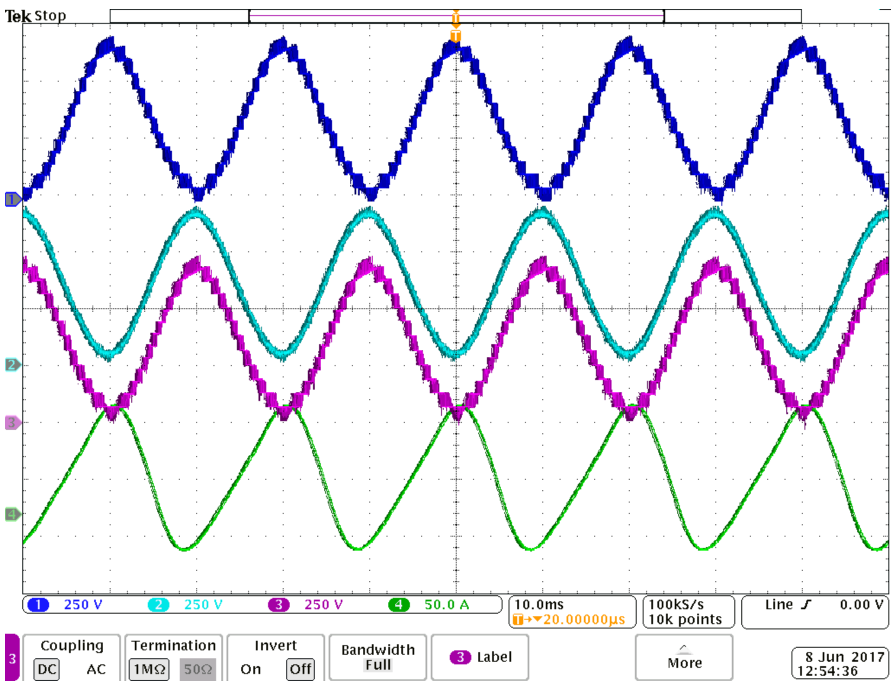


Assembling stages



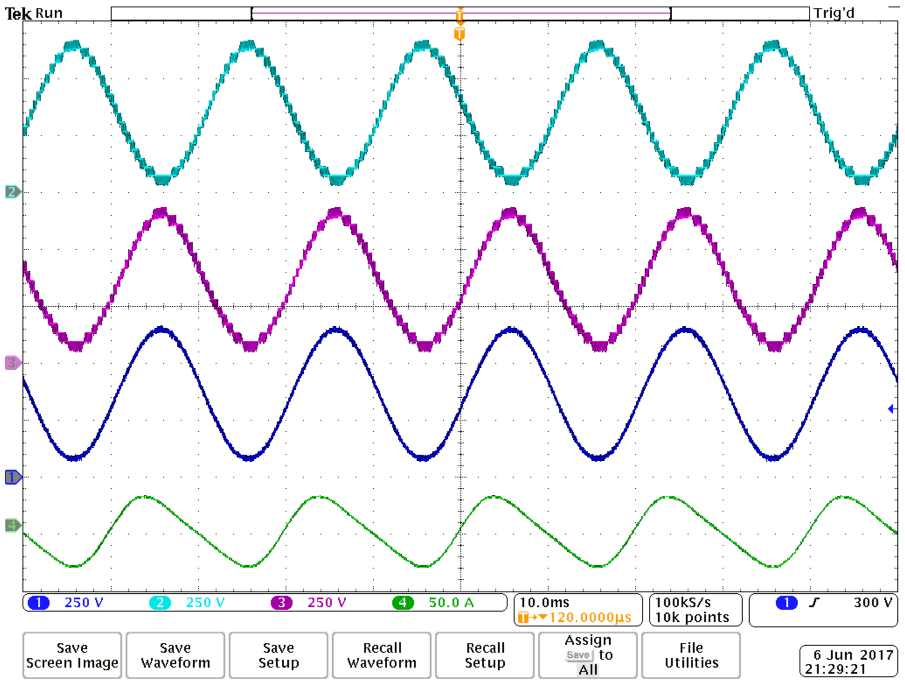
SINTEF

Converter performance test



Conv12 700UDC, 100% active current I_d (-81.2A)

● Phase C upper arm voltage, ● Phase C Lower arm voltage, ● Phase C output voltage, ● Phase C arm current

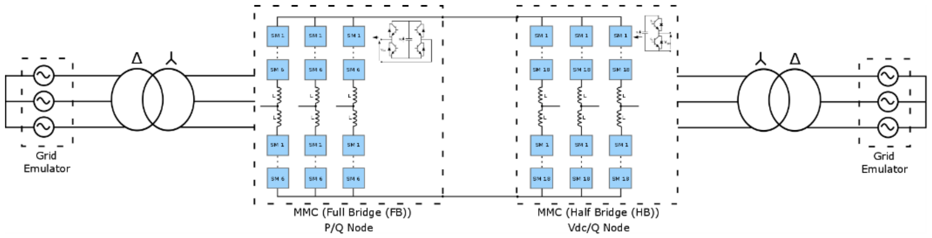


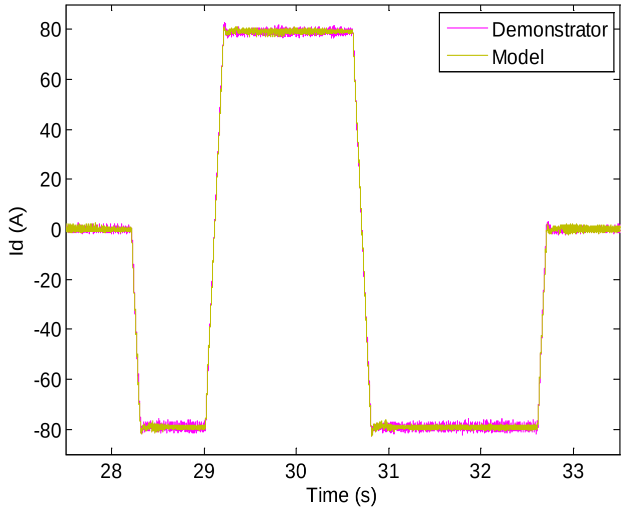
Conv18 700UDC, 24.3kW,7.8kVar

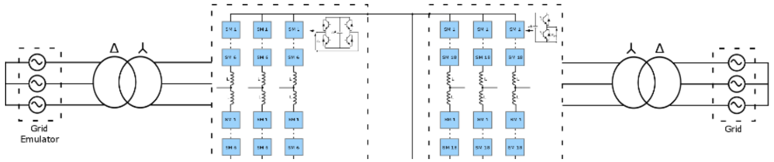
● Phase C upper arm voltage, ● Phase C Lower arm voltage, ● Phase C output voltage, ● Phase C arm current

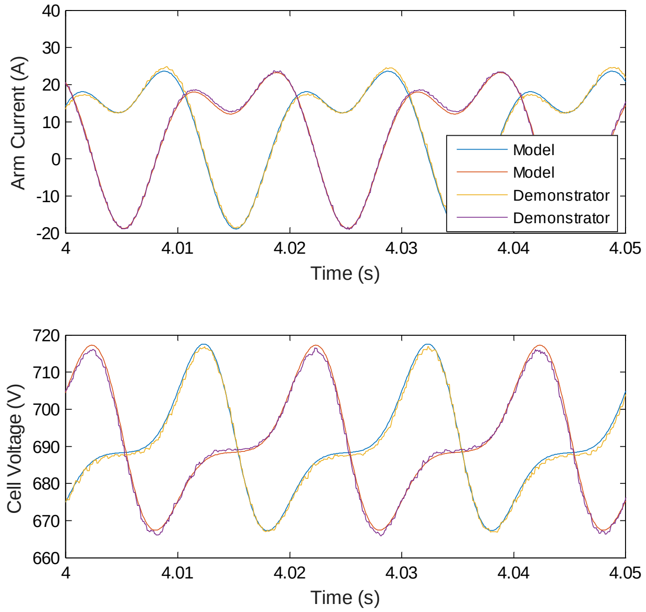
Point-to-point and multiterminal configurations

- Tests to **evaluate the accuracy of the models to represent the demonstrator**



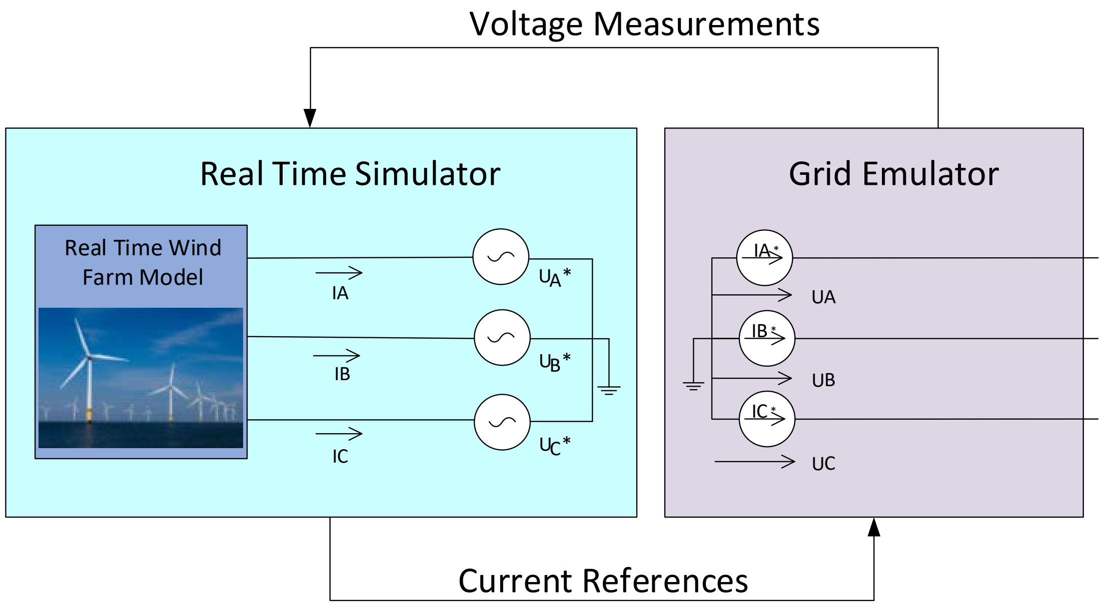






Wind farm emulator

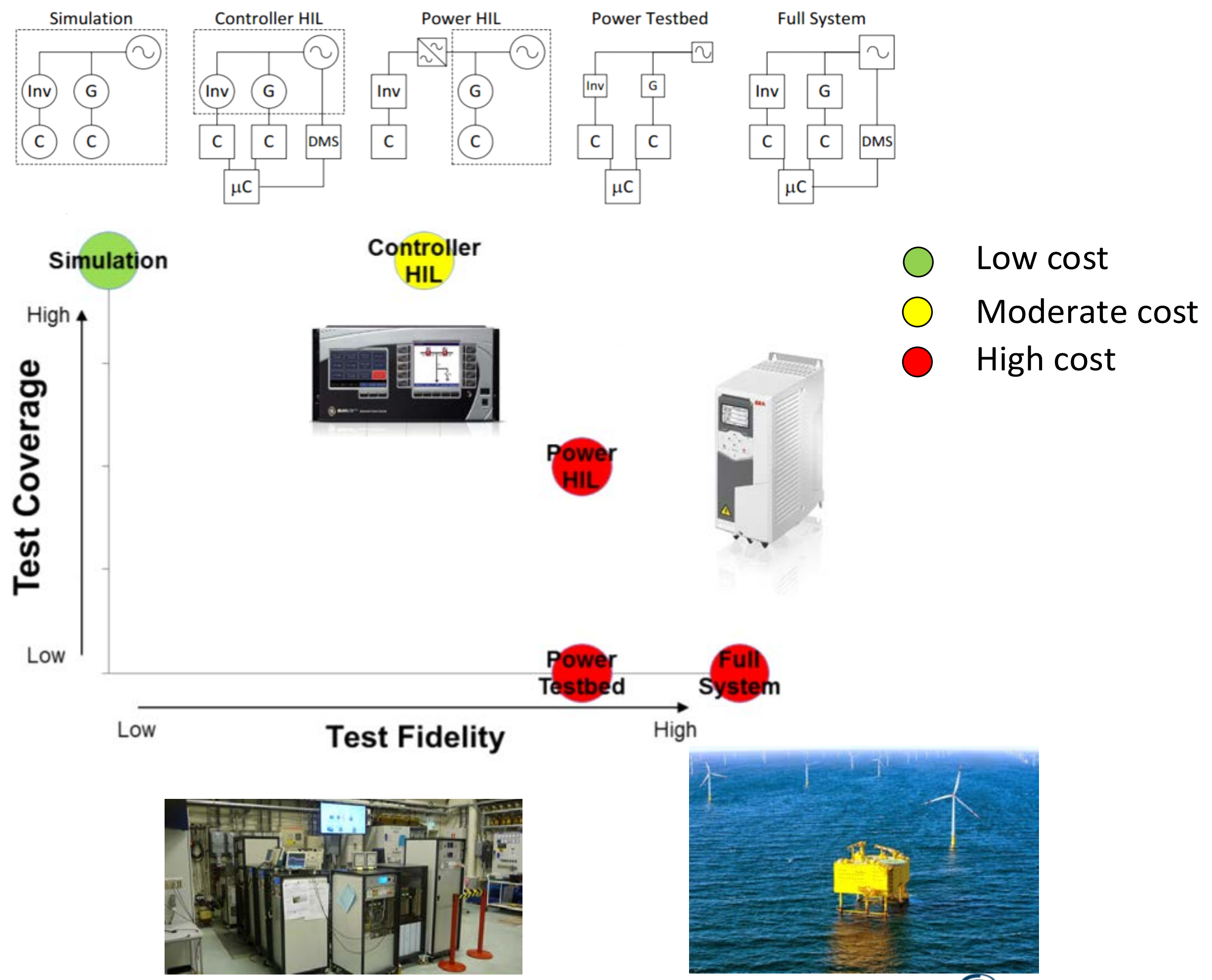
- Wind farm model is adapted to run in the 200 kVA high-bandwidth grid emulator
- PHIL implementation combining the real time simulator and the grid emulator
  - Flexibility in the model simulated
  - Possibility to reproduce faster dynamics



SINTEF

Interaction of an offshore wind farm with an HVDC

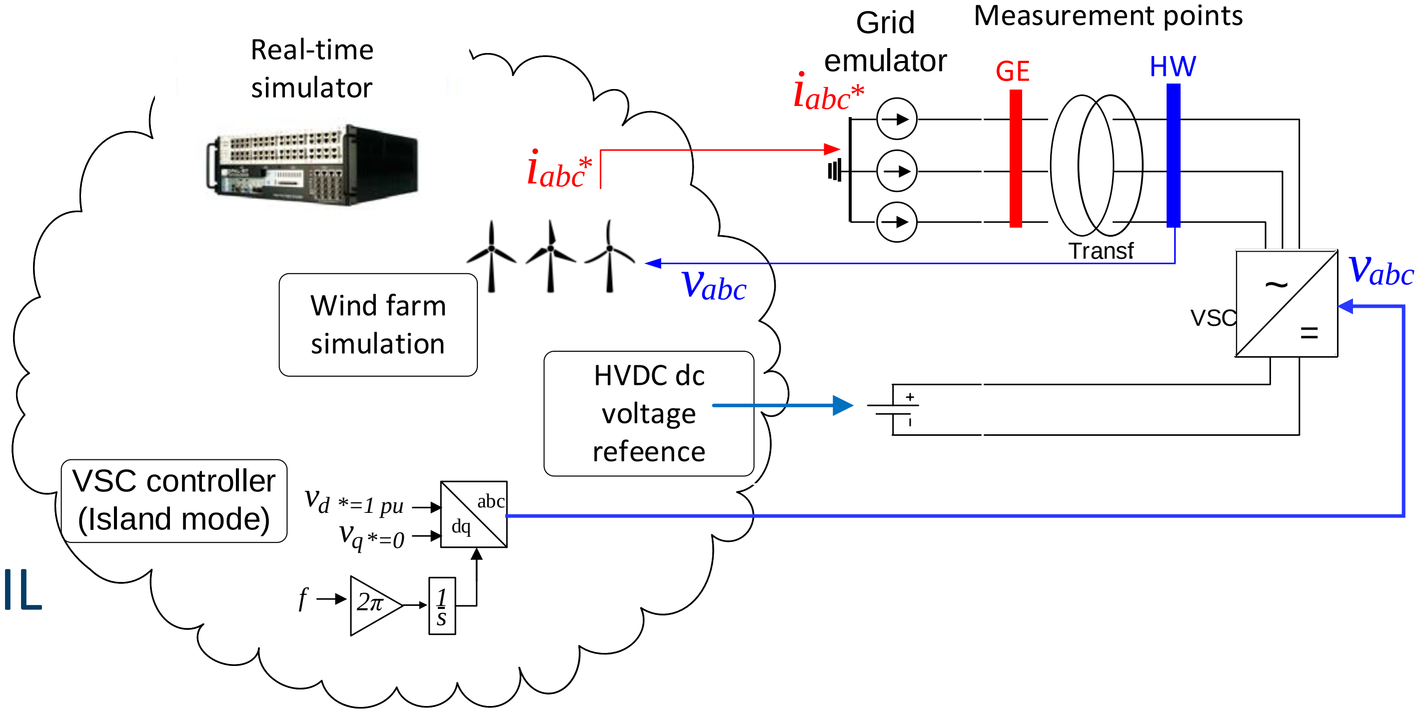
- Complex issues
  - Noise, randomness of event timings, and hardware design
- Numerical simulations are widely accepted and cost effective
  - Test a wide variety of different cases, however, the fidelity of the results is difficult to assess.
- Hardware power-in-the-loop (HIL) simulation offers a good balance between test coverage and fidelity.



SINTEF

PHIL experiment: Wind farm connected to VSC-based HVDC

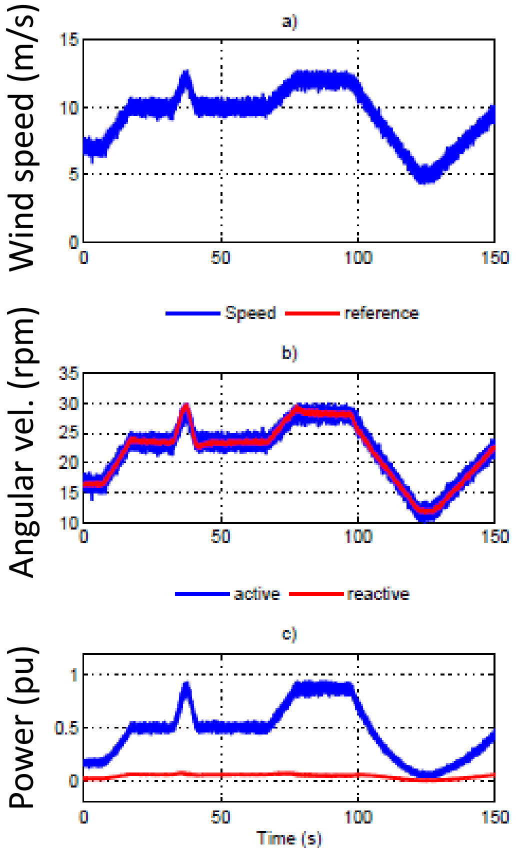
- Simulated wind farm
  - Input: Wind speed and measured voltage
  - Output: Grid emulator reference current
- Hardware
  - Two-level VSC generates a three-phase ac voltage with a fixed frequency
- The close-loop behaviour of the PHIL setup was stable



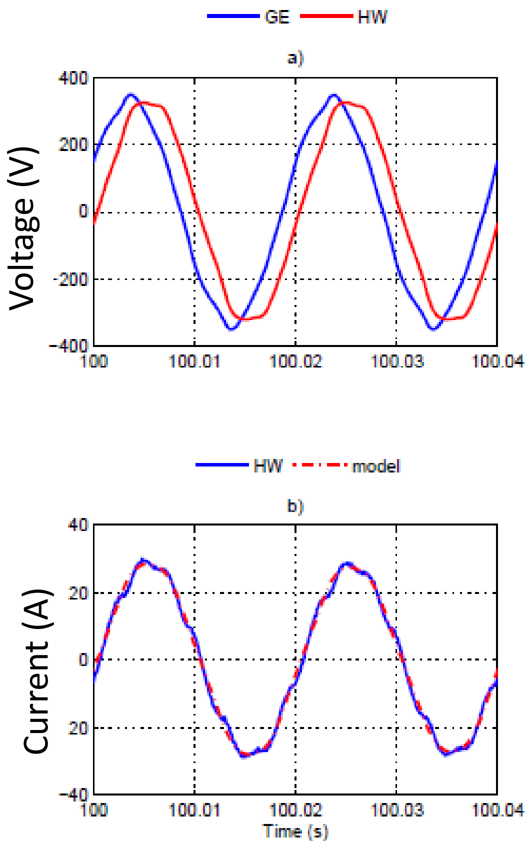
SINTEF

Results

Simulation



Hardware



Conclusions

- Power hardware-in-the-loop (PHIL) approach combines hardware devices with software simulation.
- The hardware part allows a high fidelity of the results whereas, the software simulation part allows an extensive study of different cases at a reasonable cost
- Grid integration of wind farm using VSC-based HVDC system was evaluated in PHIL experiment as a proof of concept.
- In the future work ,PHIL implementation using modular multilevel concepts will be studied

SINTEF

Teknologi for et bedre samfunn