PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Black-start by off-shore wind turbines

Wind Turbine – Converter Interaction
PROMOTioN WP3

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28 February 2019, PROMOTioN MIGRATE Joint Workshop, Berlin

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

WP3 Partners

DTU
Technical University of Denmark

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

University of Strathclyde

RWTH AACHEN UNIVERSITY

ENERGINET

ABB

SIEMENS

MHI VESTAS OFFSHORE WIND

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equinor

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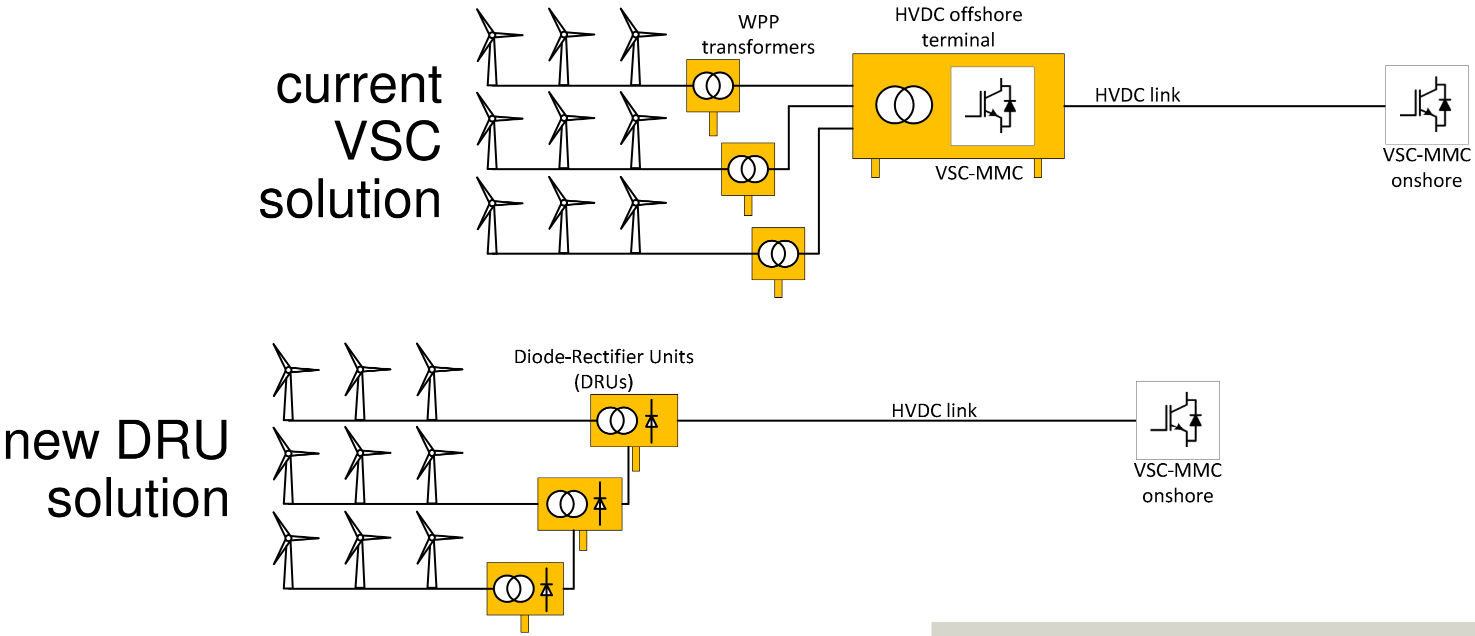
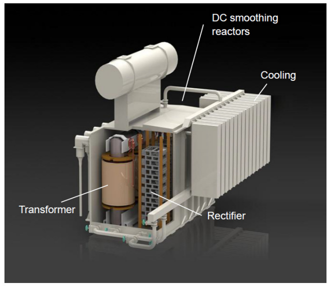
- Diode Rectifier as offshore HVDC
- Grid Forming Wind Turbines
- Offshore AC Grid Start-up
- Black Start by Offshore Wind Turbines
- Conclussions

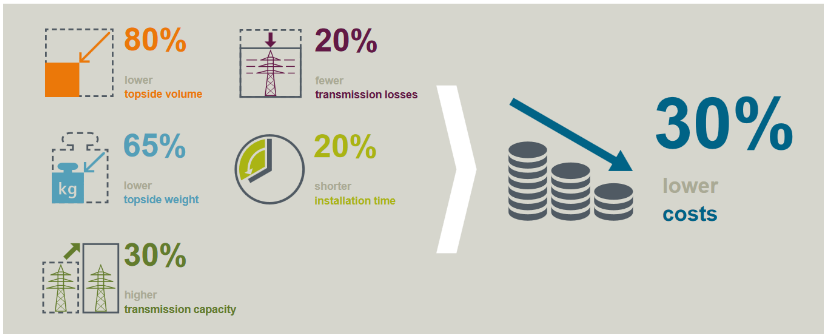
Diode Rectifier Units as offshore HVDC



Key features of the Modular Diode Rectifier Unit

- Encapsulated, rugged equipment
- Bio degradable and flame retardant insulation
- Simple and robust power electronics
- Small platform with easy transport and installation
- High reliability, minimal maintenance
- No offshore DC converter as single point of failure
- Flexible offshore installation options due to modular rectifier concept





Source: Siemens AG

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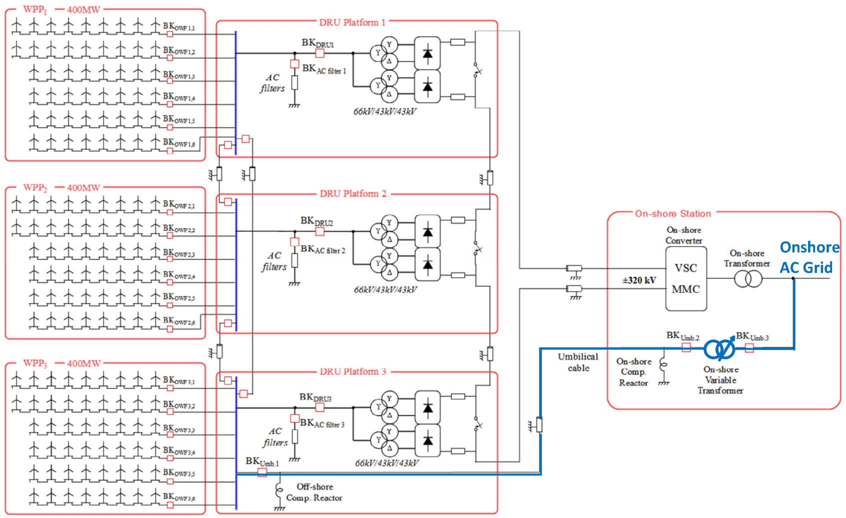
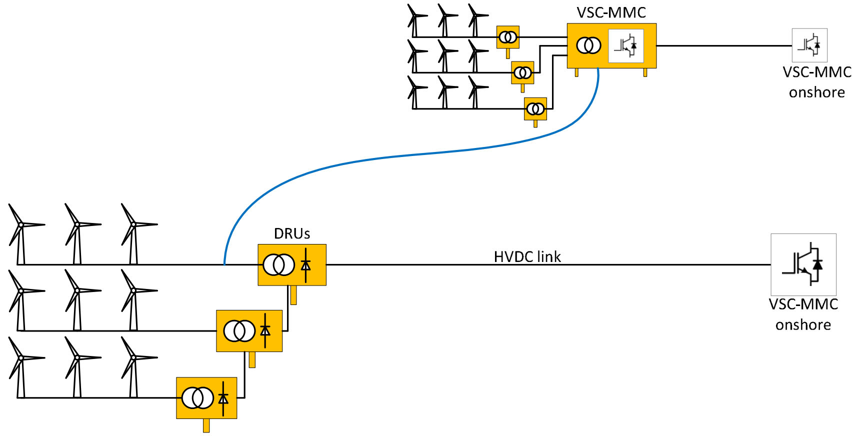
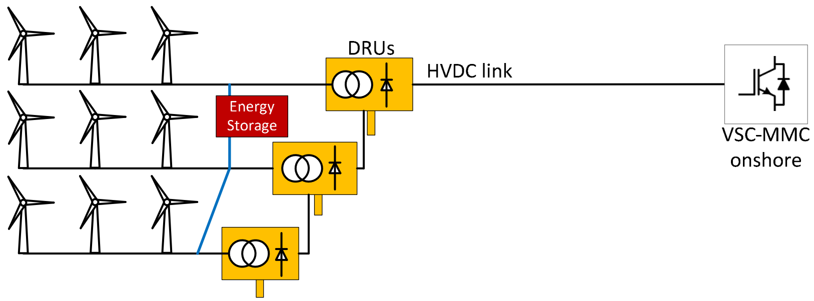
Offshore AC Grid Start-up Options



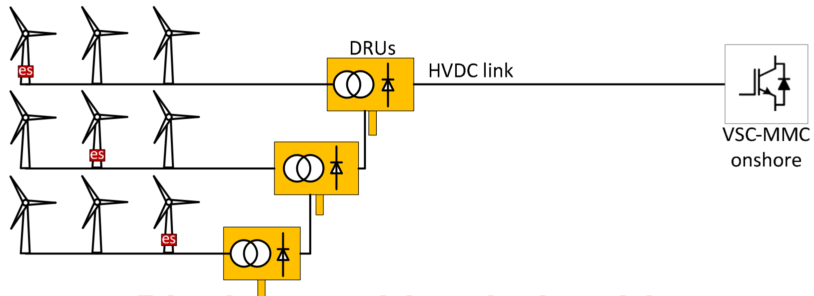
Umbilical AC Cable



Nearby VSC-HVDC (or AC)



Local Energy Storage (e.g. battery, diesel)



Black-startable wind turbines

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Black Start by Offshore Wind Turbines

Step 1: Self-start of Wind Turbine	Step 2: Self-Energization of Wind Power Plant	Step 3: Contribution to Grid Restoration
Objective: To avoid issues of non-operating wind turbines; - Moisture - Icing - Vibrations - Deformation	Objective: To energize WPP and substations' auxilary w/o any external supply	Objective: To provide black start for the onshore power system
- Wind turbines will start w/o grid voltage - Wind turbines will supply themselves using wind (houseload operation)	WPP will energize up to the onshore PoC	WPP will operate similar to the conventional black start units

Control capability evolution

Grid Following	Grid Supporting	Grid Forming
P Control	ω Support	ω Control
Q Control	V Support	V Control
Require powered grid	Require powered grid	Islanded operation SCR=0
High SCR	Low SCR	Zero Inertia
High Inertia	Low Inertia	Shared control effort

Increasing percentage of PE based renewable energy

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Grid Forming WPP applications

- Wind Turbine self-start
- Wind Power Plant Islanded Operation
- Black/brown start (HVAC and/or HVDC)
- Improvement of system stability in large systems with reduced or zero synchronous generation
- Improved HVDC integration
  - HVDC diode rectifier
  - LCC-HVDC rectifier stations
  - VSC-HVDC rectifier stations

INCREASED CONTROL FUNCTIONALITY

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Motivation

the japan times

NEWS

北海道

Hokkaido industries still struggling following quake-triggered blackout

JIJI

OCT 6, 2018

ARTICLE HISTORY

PRINT SHARE

PHOTOS

CLICK TO ENLARGE

KEYWORDS

EARTHQUAKE, TOYOTA

HOKKAIDO, ELECTRICIT

Key industries in Hokkaido are still struggling with secondary damage from the massive blackout triggered by the powerful earthquake a month ago.

The power outage even forced factories far away from the seismic center of the 6.7 magnitude earthquake to suspend operations.

Food and beverage factories and retailers had to dispose of products as refrigerators stopped working, suffering larger damage from the secondary effects than the direct impact of the earthquake.

Dairy and livestock farmers have yet to see production return to predisaster levels due to severe aftereffects of the blackout.

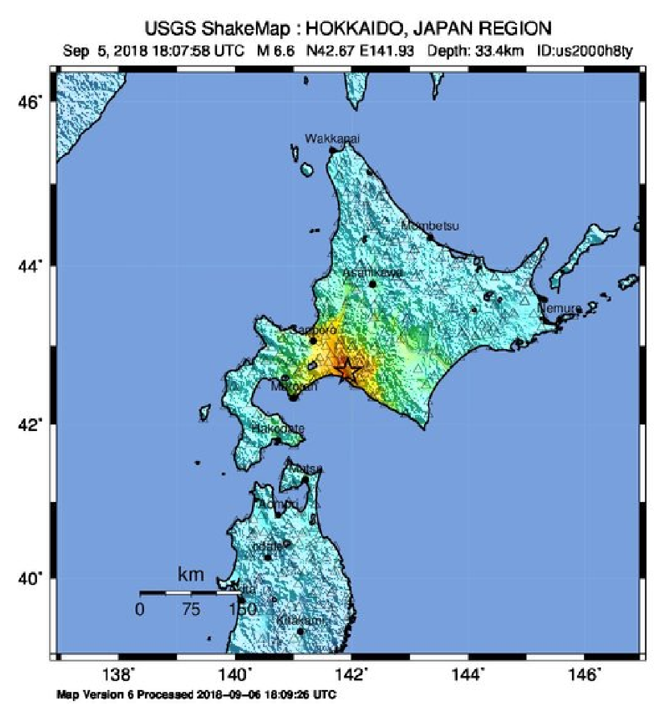
“It will take time to restore production to levels before the disaster,” an official of the Hokuren Federation of Agricultural Cooperatives in Hokkaido said.

According to the federation, the amount of raw milk it collected from group farmers in early September fell 16 percent from a year earlier. Although raw milk production started recovering in mid-September, many farmers are still suffering from the impact of the blackout, which made them unable to use milk pumps and caused their cows to develop mastitis.

Furthermore, farmers had no choice but to dispose of produced raw milk because they were unable to cool it for storage.

The Hokkaido Prefectural Government estimated damage from the earthquake on its dairy and livestock industry at some ¥2.4 billion as of Friday.

A Toyota Motor Corp. subsidiary was forced to suspend transmission

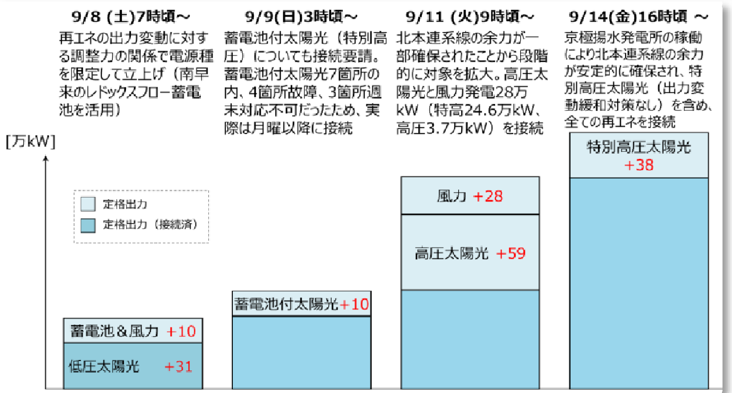


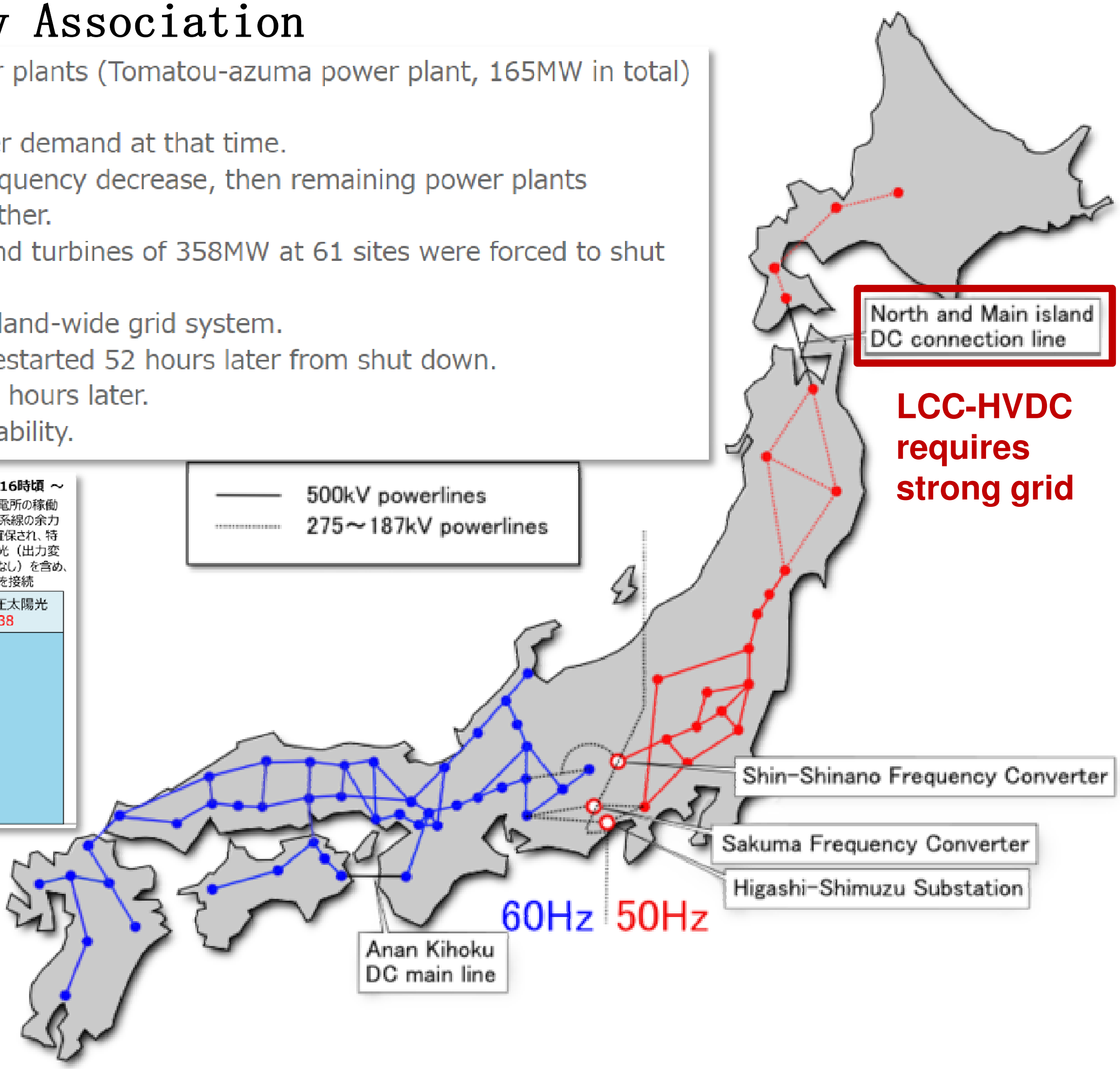
programme under grant agreement No 691714.

Motivation

Japan Wind Energy Association

Huge earthquake damaged 3 coal fired power plants (Tomatou-azuma power plant, 165MW in total) at about 3am on 6 Sep..
They produced about half of Hokkaido's power demand at that time.
Sudden loss of huge power supply caused frequency decrease, then remaining power plants (including wind farms) stopped one after another.
Hokkaido island has gone "black out". 303 wind turbines of 358MW at 61 sites were forced to shut down.
It needed about 40 hours to re-start whole island-wide grid system.
100MW of wind turbines & battery systems restarted 52 hours later from shut down.
The rest of wind turbines restarted 126 - 130 hours later.
Some delay was needed to secure the grid stability.





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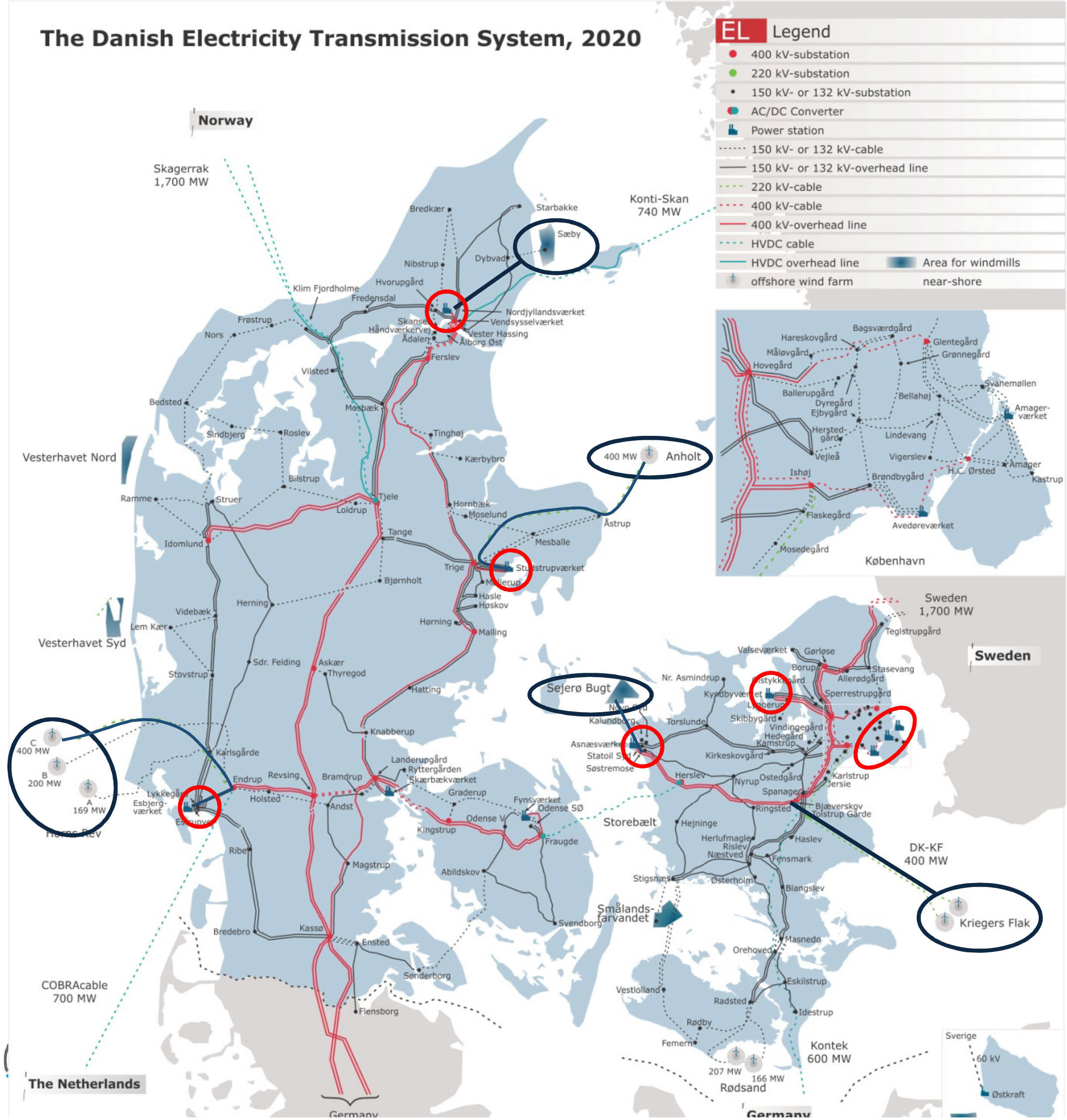
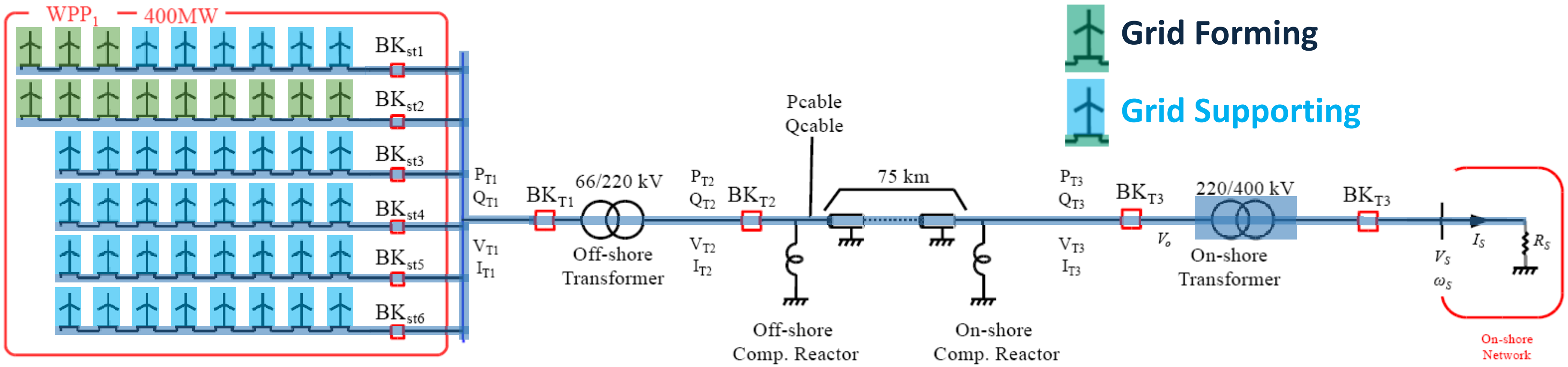
Black start operation (HVAC)



Source: energinet.dk

Black start operation (HVAC)



400 MW WPP
50 x 8 MW
66kV

460MVA Trafo

75km 220kV cable

460MVA Trafo

Thermal Station Auxiliaries 40MW

Realistic transformer + cable models + no POW, no PIR

GOAL: Evaluate how much grid forming power is required. Interaction between grid forming and grid following WTGs

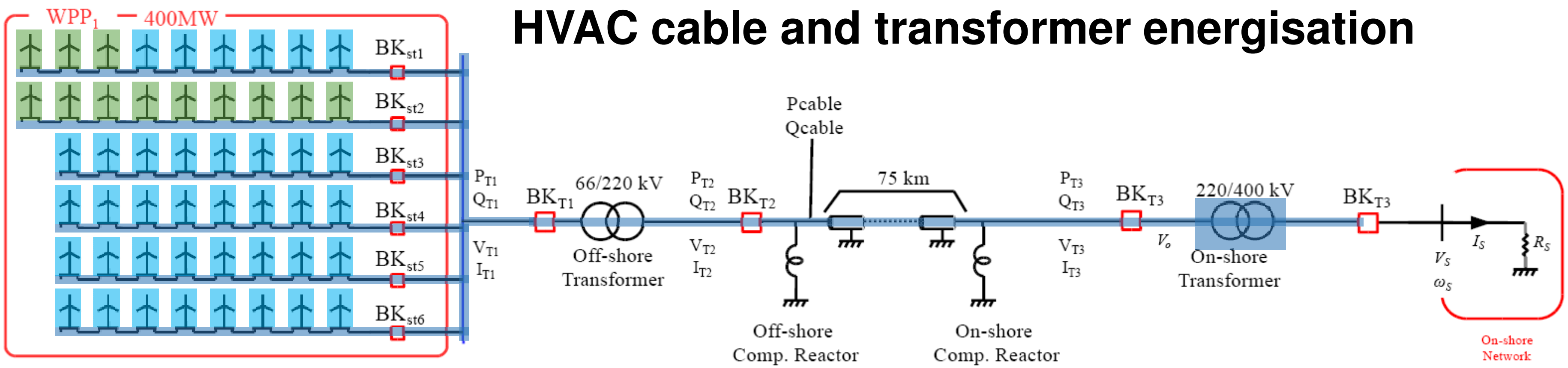
Issues:

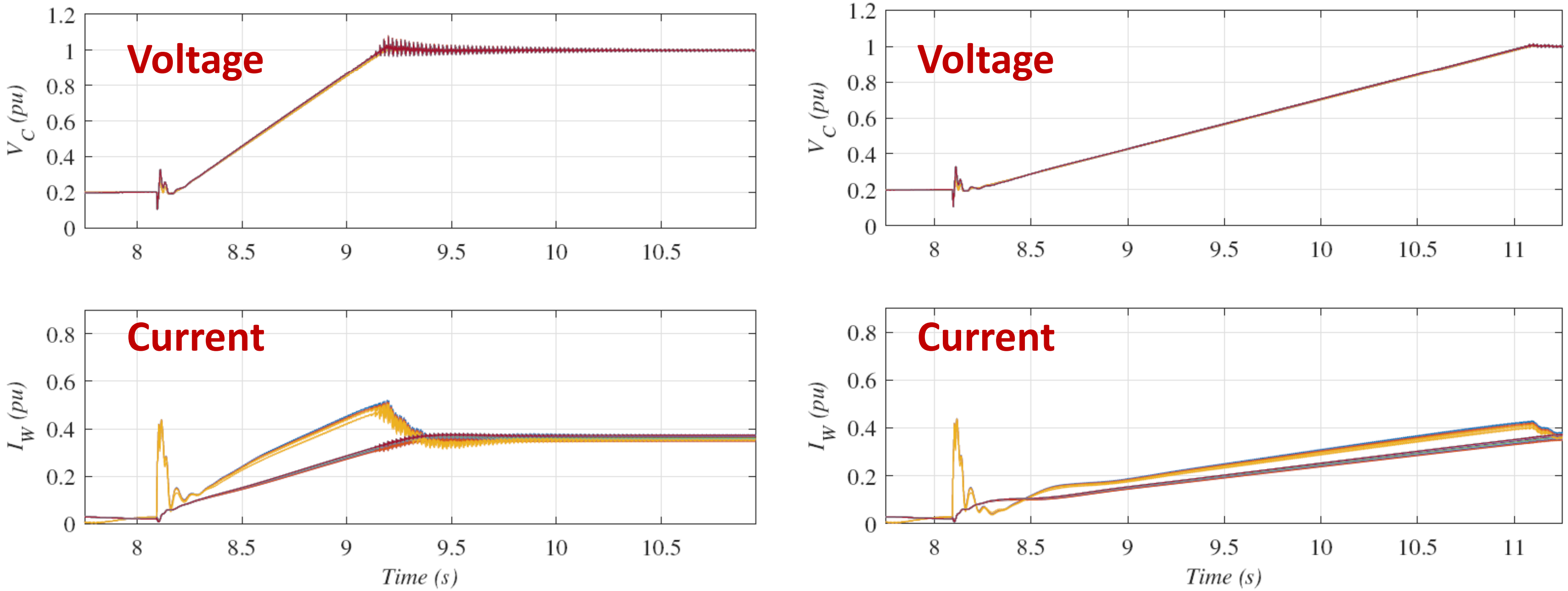
- **Long HVAC cable and transformer energisation**
- **Response to load transients (electrical, mechanical)**
- **Fault response and recovery with and without grid supporting WTGs**

J. Martinez-Turegano, S. Añó-Villalba, S. Bernal-Pérez, R. S. Pena, and R. Blasco-Gimenez, “Mixed Grid-Forming and Grid-Following Wind Power Plants for Black Start Operation,” presented at the 17th Wind Integration Workshop, Stockholm, 2018.

Results

HVAC cable and transformer energisation





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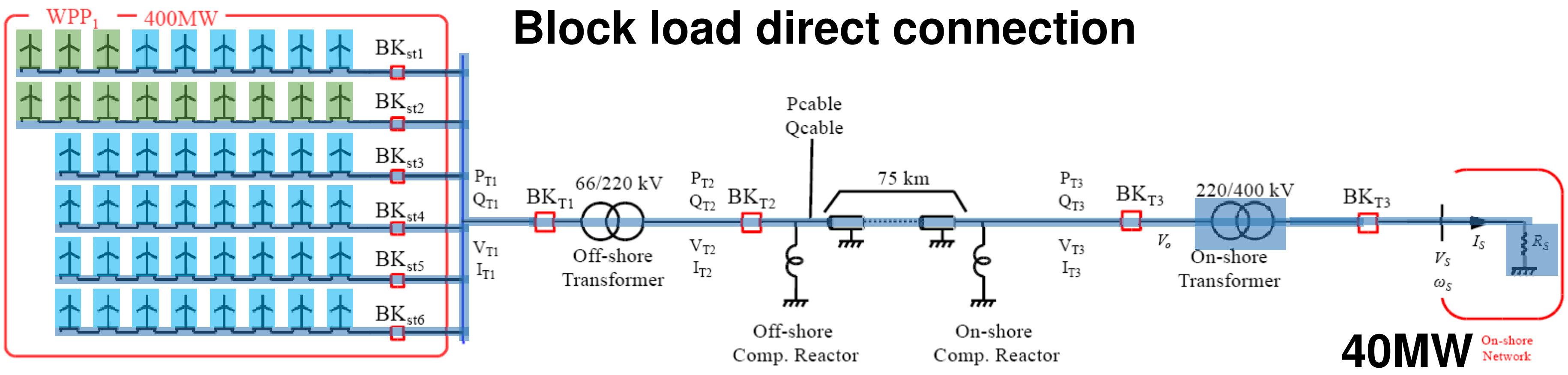
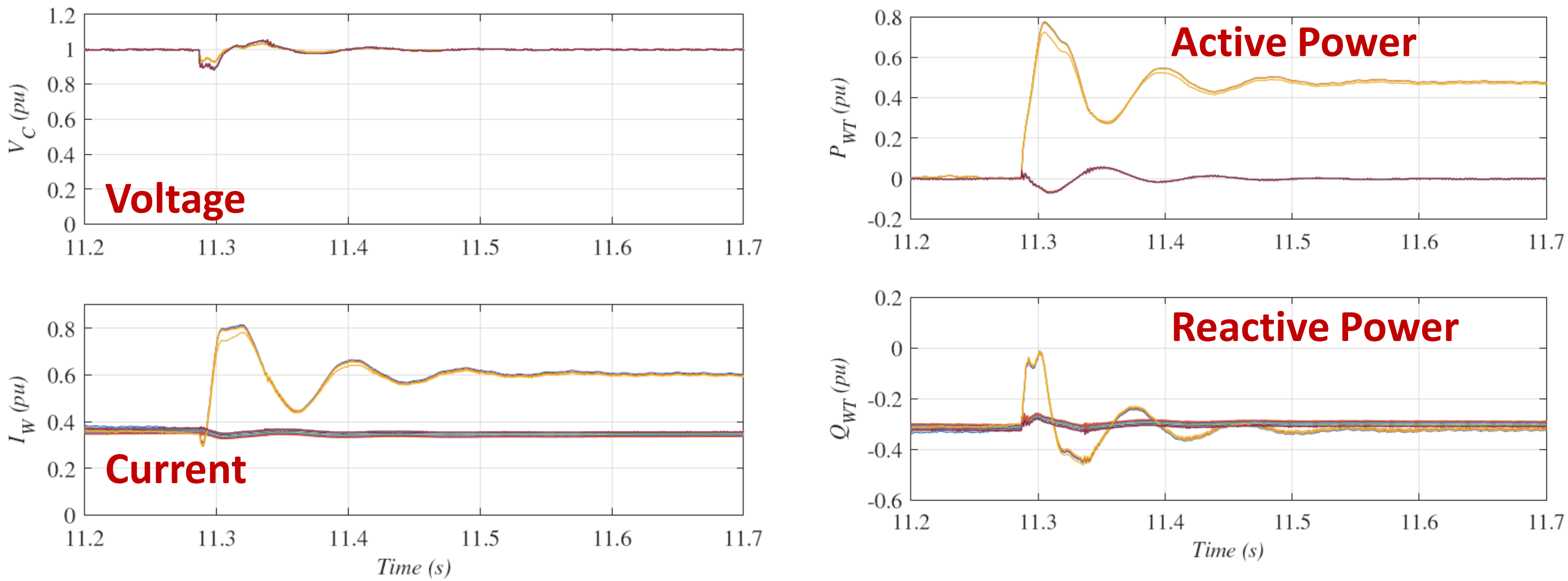
Results

Block load direct connection





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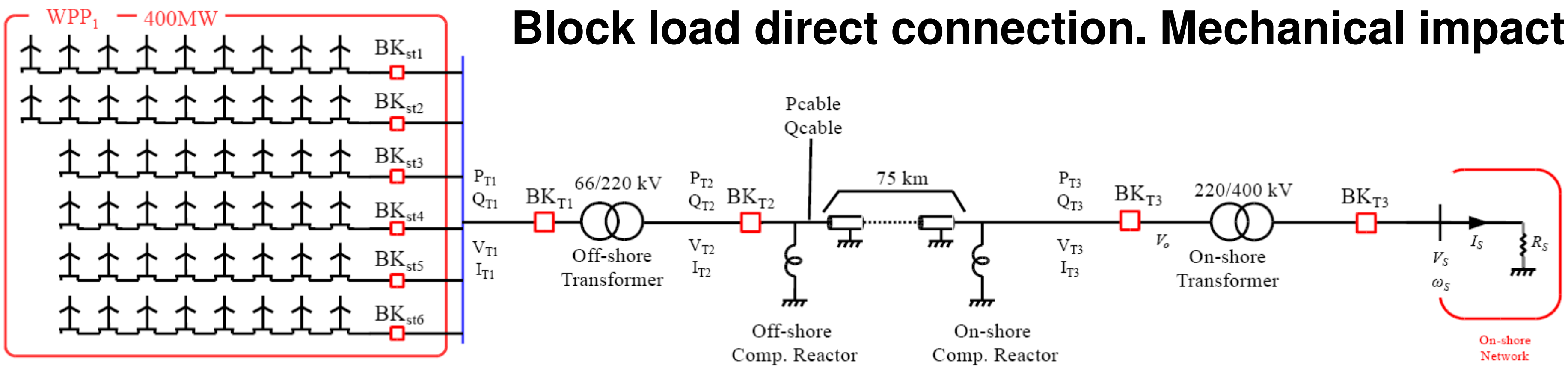
Load Sharing Between WTGs



Block load direct connection. Mechanical impact

Aeroelastic-EMT co-simulation

40 MW block load

Grid forming power	48MW	**96MW**	192MW
Gearbox extreme load	0.6 pu	**0.25 pu**	0.125 pu
Minimum wind speed	10.6 m/s	**8.7 m/s**	6.9 m/s

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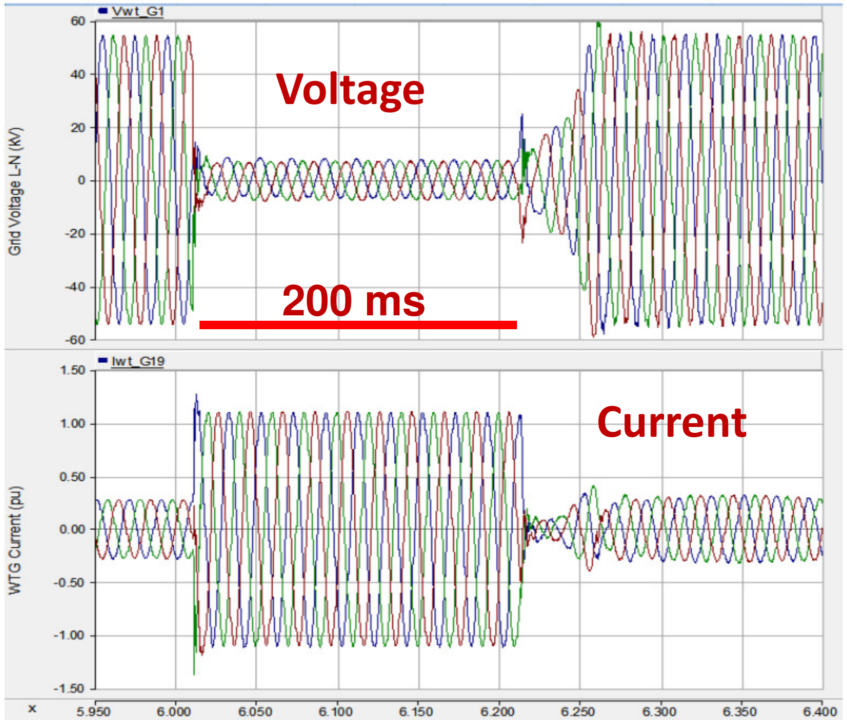
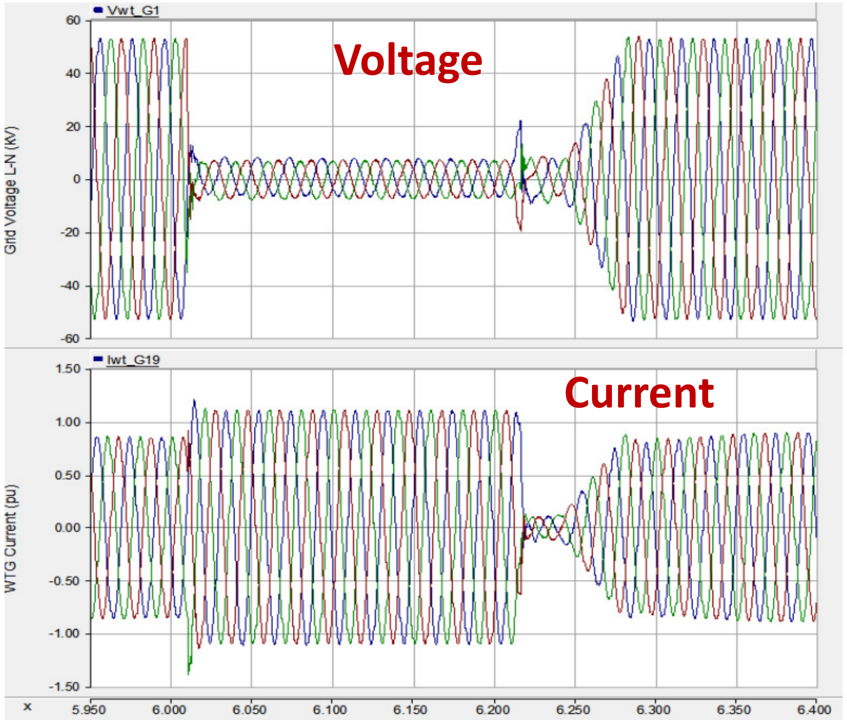
Fault Recovery
HVAC connection

50 x 8MW islanded Wind Power Plant

100% Grid Forming Converters



20% load



80% load

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Discussion

- Grid Forming Wind Power Plants allow for additional applications and functionality.
  - Improved HVDC Integration (DRU, MMC-HVDC)
  - Islanded operation
  - Black start / service restoration operation
- Different technical solutions are available and not all functionality requires grid forming capability
- Adequate control coordination can help to reduce the amount of grid forming power required for a particular application
- Fault recovery is very important with a large number of grid forming WTGs/WPPs, particularly if both grid forming and grid following WTGs/WPPs are considered

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Next steps

- Requirements for HVAC/HVDC black/brown start operation
- Specification of benchmark scenarios and test cases
- Specification of controller validation by simulation
- Validation of controllers
- Validation in a realistic scenario (North Jutland, replicate black start from Skagerrak HVDC)
- D3.7 : Report with the compliance evaluation results using simulations (late 2019)
- D3.8 : List of requirement recommendations to adapt and extent existing grid codes (late 2019)

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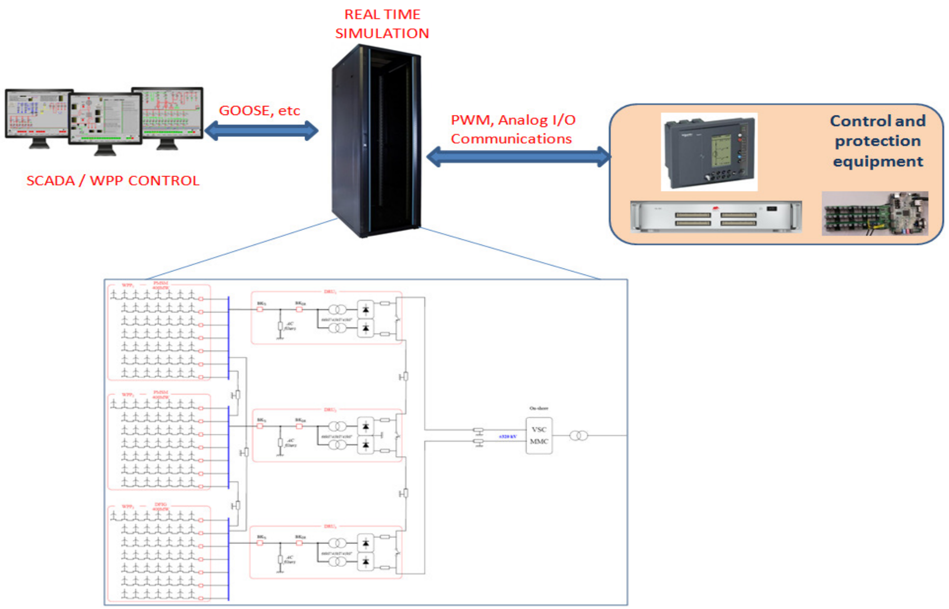
Next Steps

- **CHIL validation** (WP16 demonstrators - DNV-GL, RWTH Aachen, UPV)
  - **DRU connected grid forming wind power plants**
  - **Black start for HVAC connected wind power plants**
  - **Black start for HVDC connected wind power plants**
  - **HVDC grid connected WPPs**



APPENDIX

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