Research challenges for offshore HVDC grids and its components

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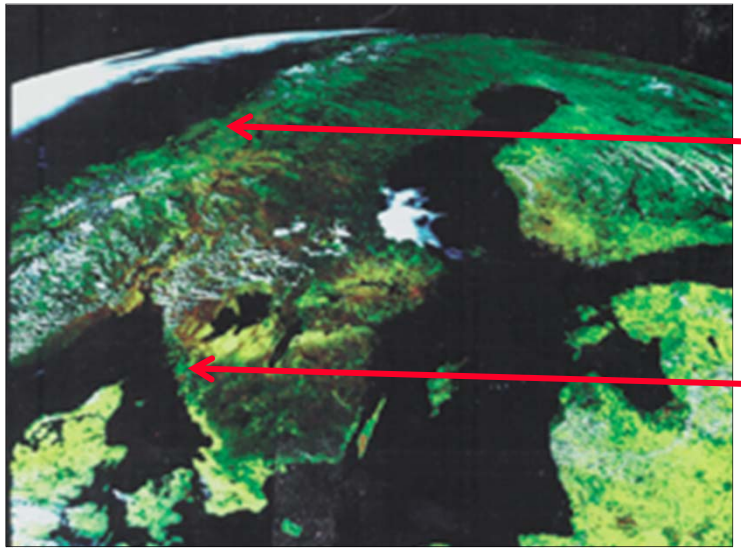


NTNU, SINTEF, Trondheim

Chalmers, Göteborg

Why offshore HVDC grid (in the North Sea) ?

Economical benefit to make power transfer and to balance power variations in different parts of Europe with the Baltic and North Sea in-between

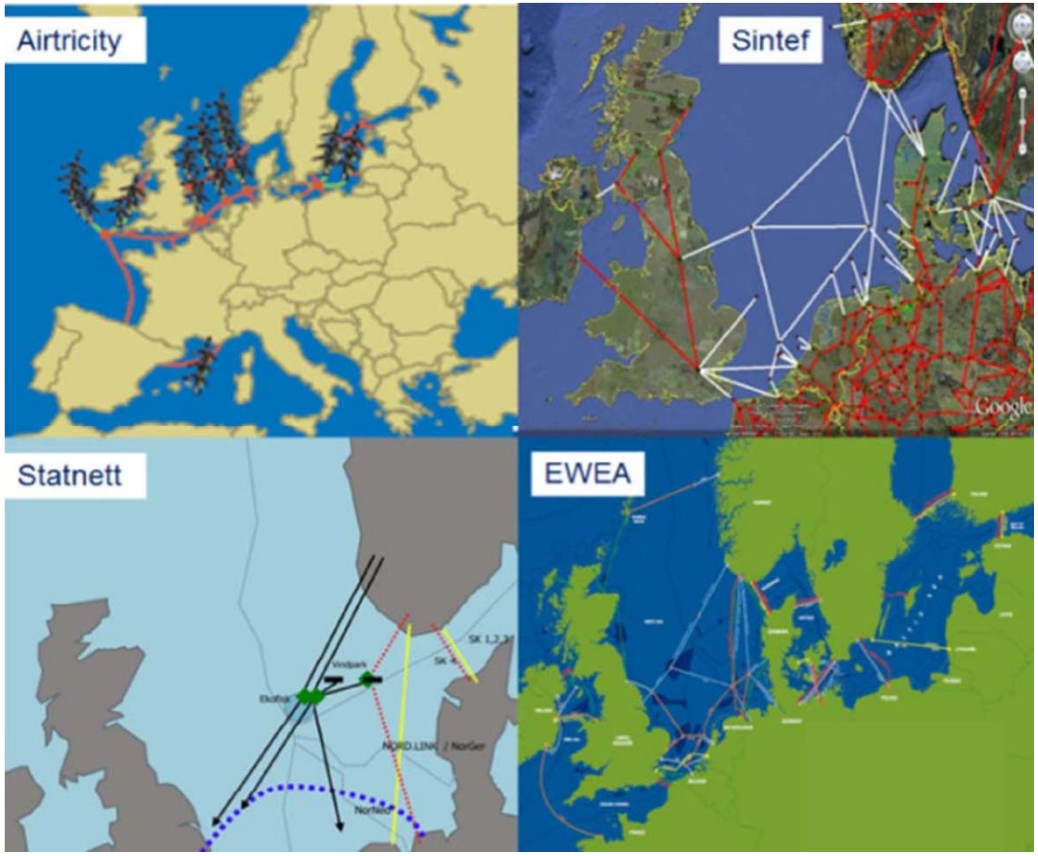
To long distances for AC (could perhaps work with 15 Hz AC)

Why offshore HVDC grid with wind turbines ?

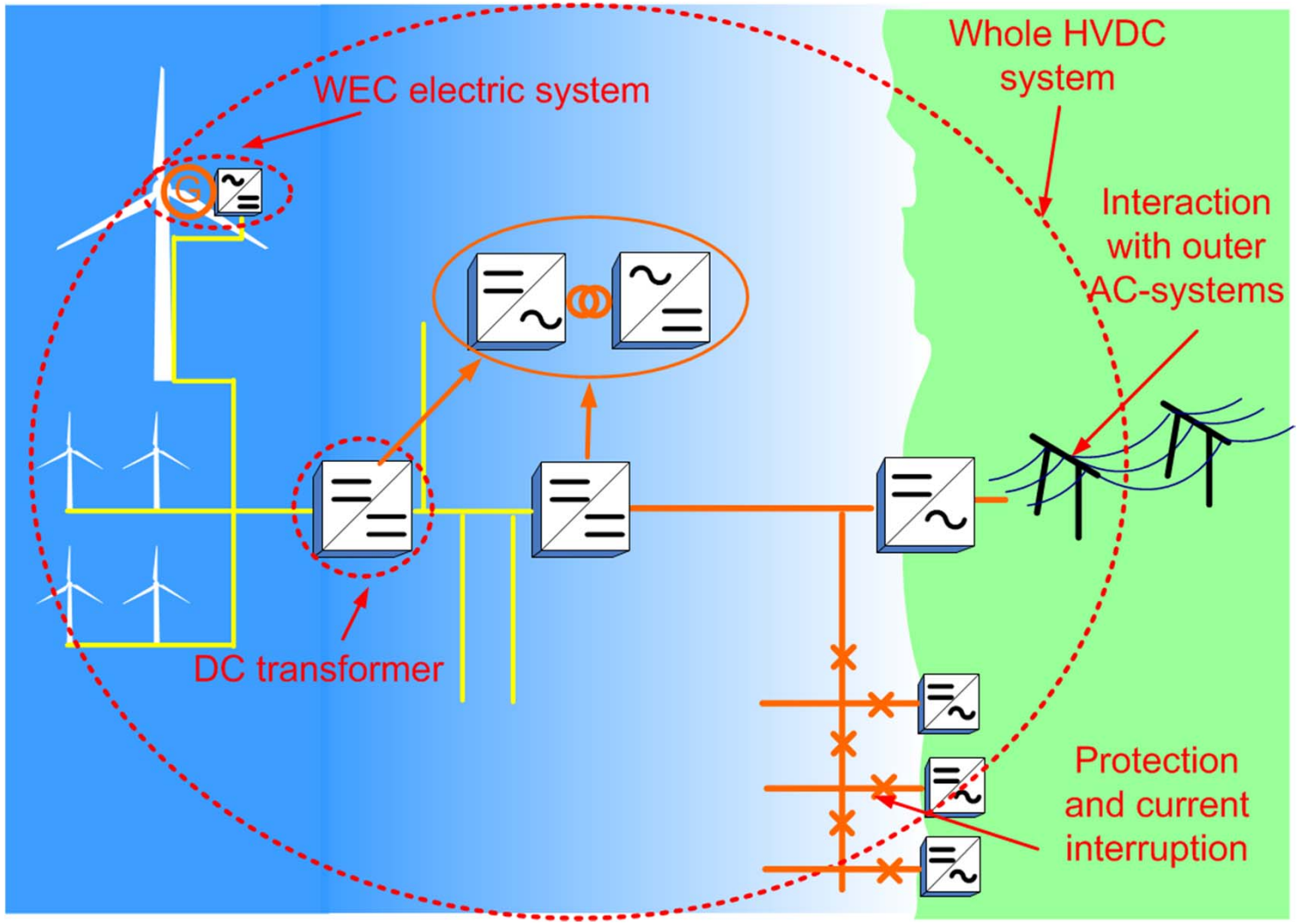
- Interest for installing wind energy in Sea areas – space and wind speed issues
- 20-20-20
- Kyoto protocol
- Peak Oil

SW corner of North Sea

The supergrid



HVDC system with offshore wind farm



Research challenges

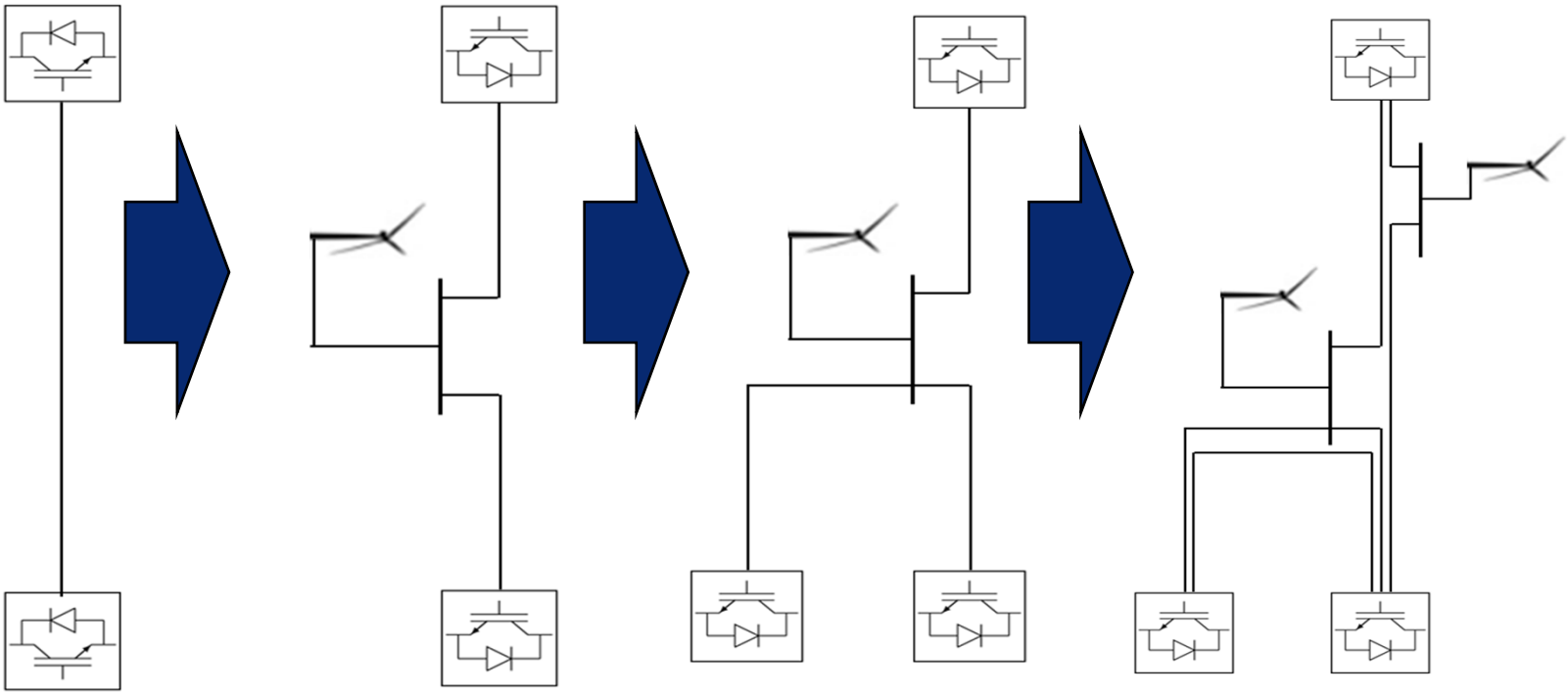
System: overall operation – stability - connection to external ac-grids - cable and grid component dimensioning - grid code – insulation level – protection – current interuption – meshed vs non-meshed – sequential building strategy – dc switchgear station

DC-transformer – design – operation – extra functionality

WEC system – high efficiency – robust – direct drive? –converter-voltage levels- HVDC out

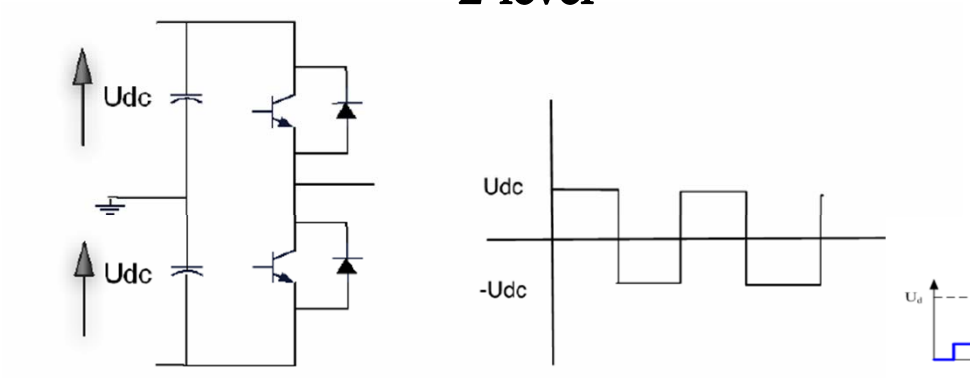
Some thoughts/ideas/aspects

Step-wise building

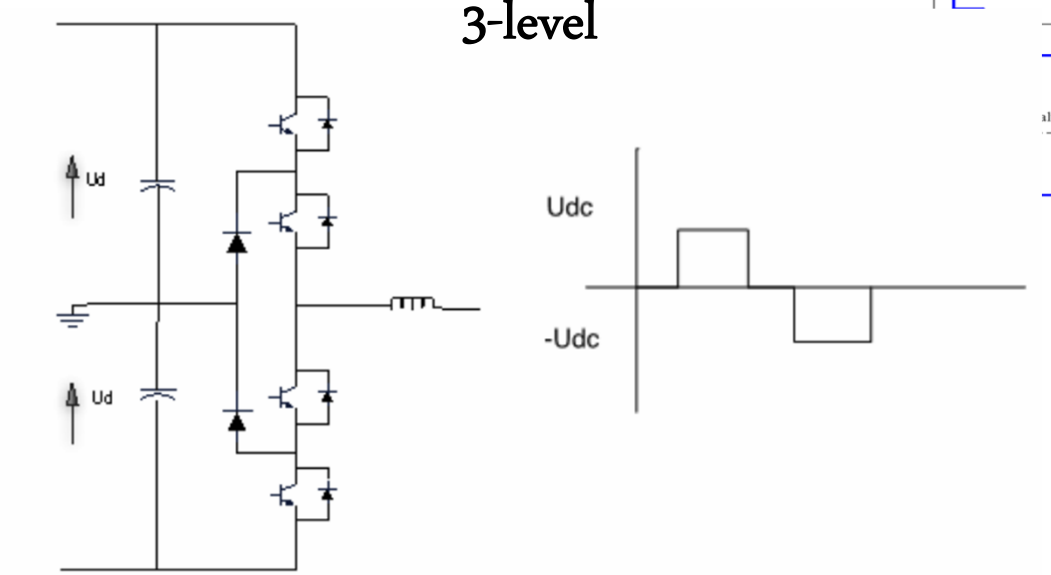


Converter topologies

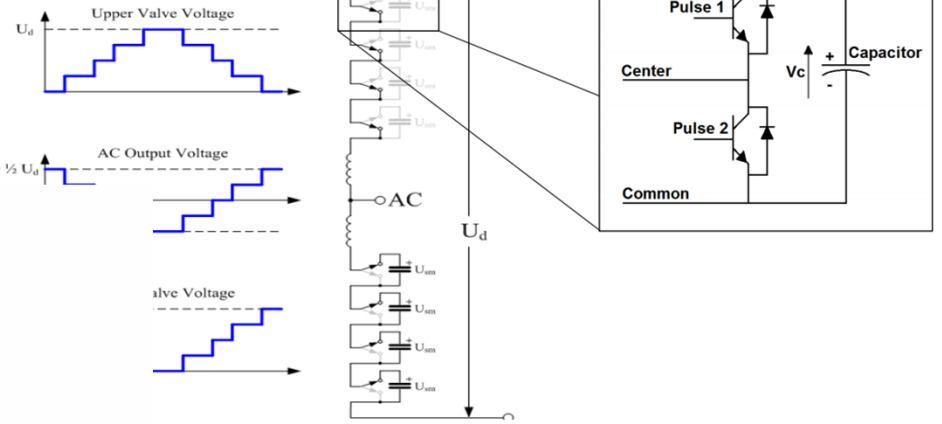
2-level



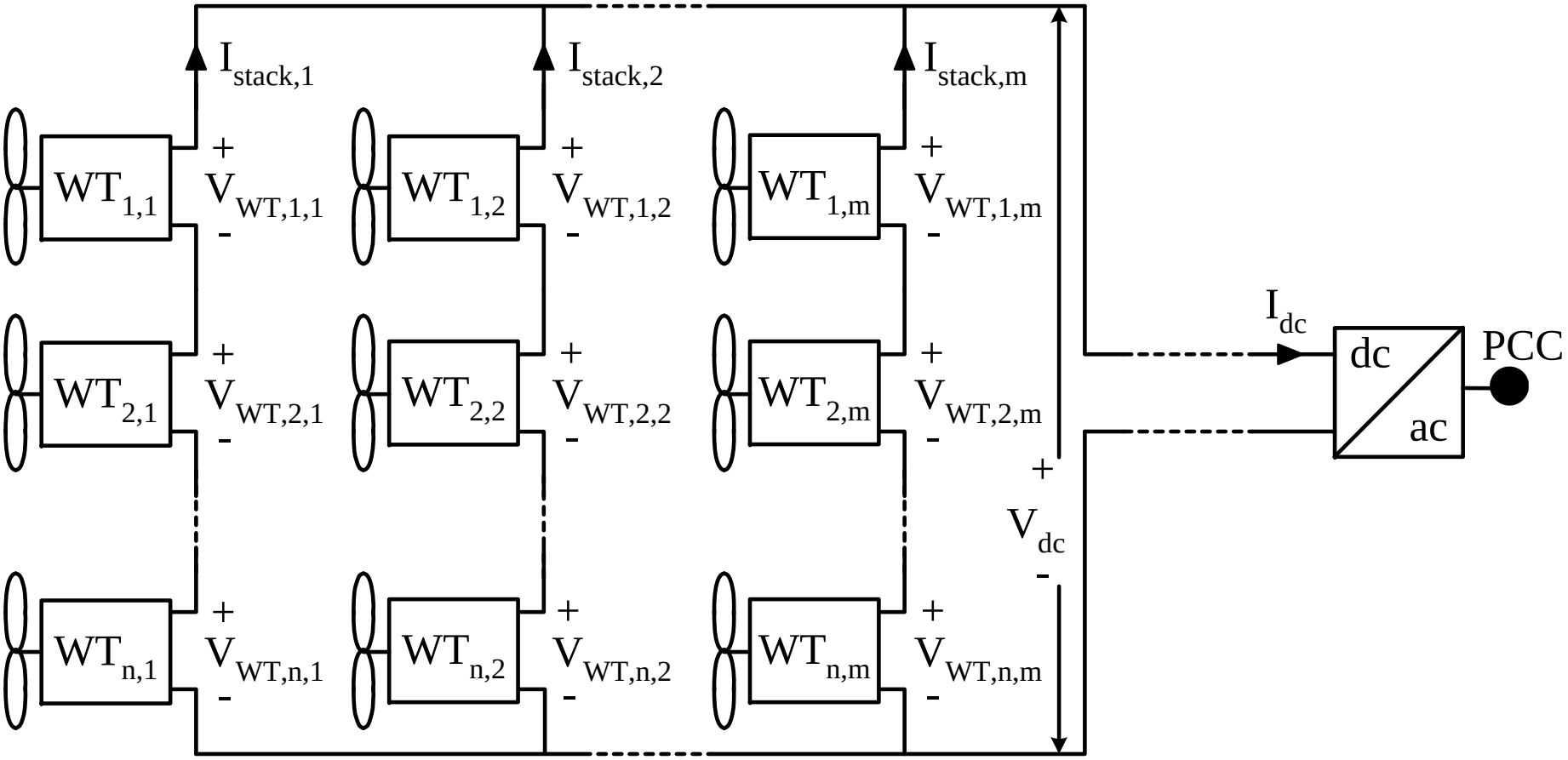
3-level



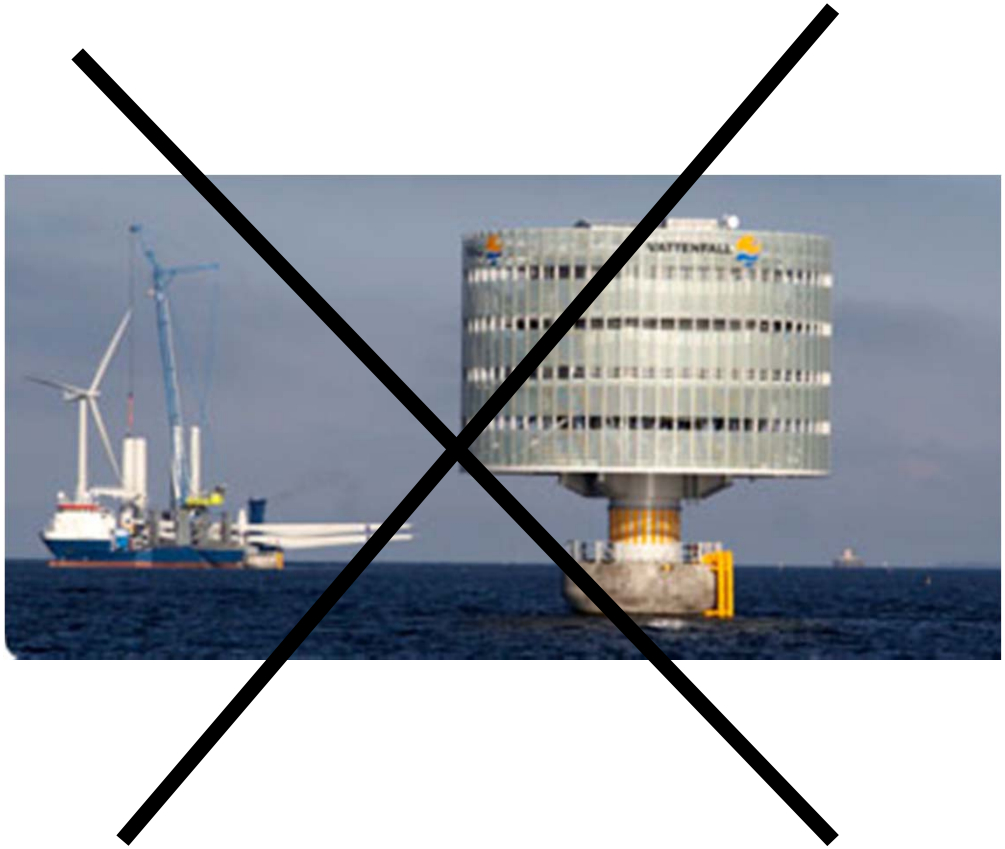
n-level



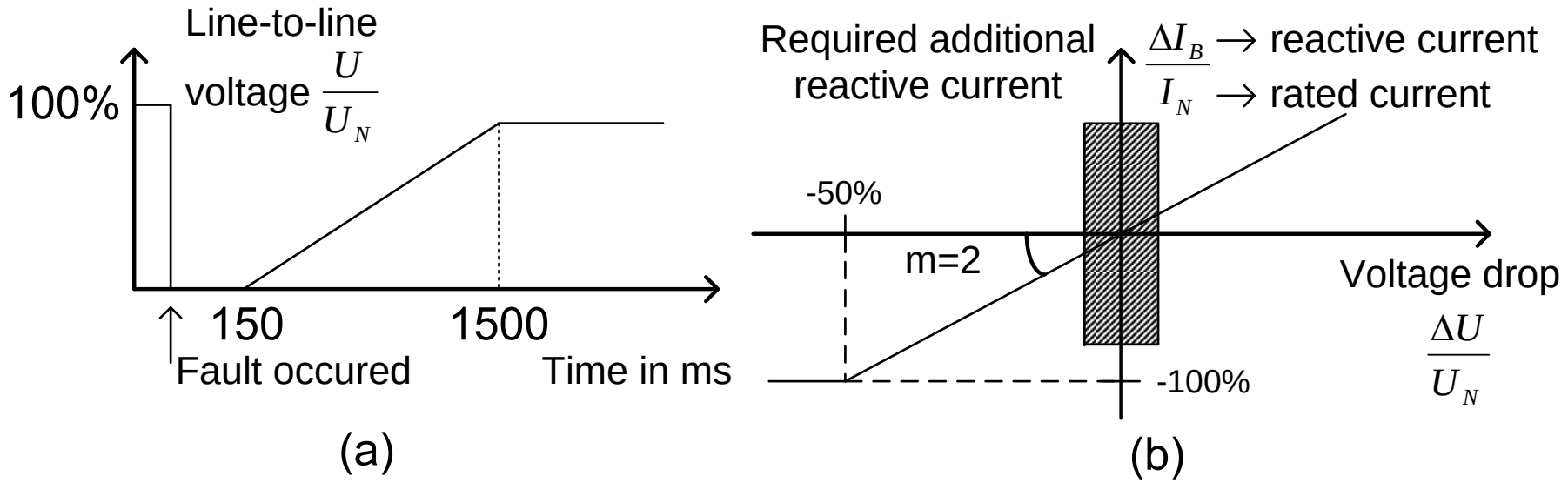
Series connected dc wind farm



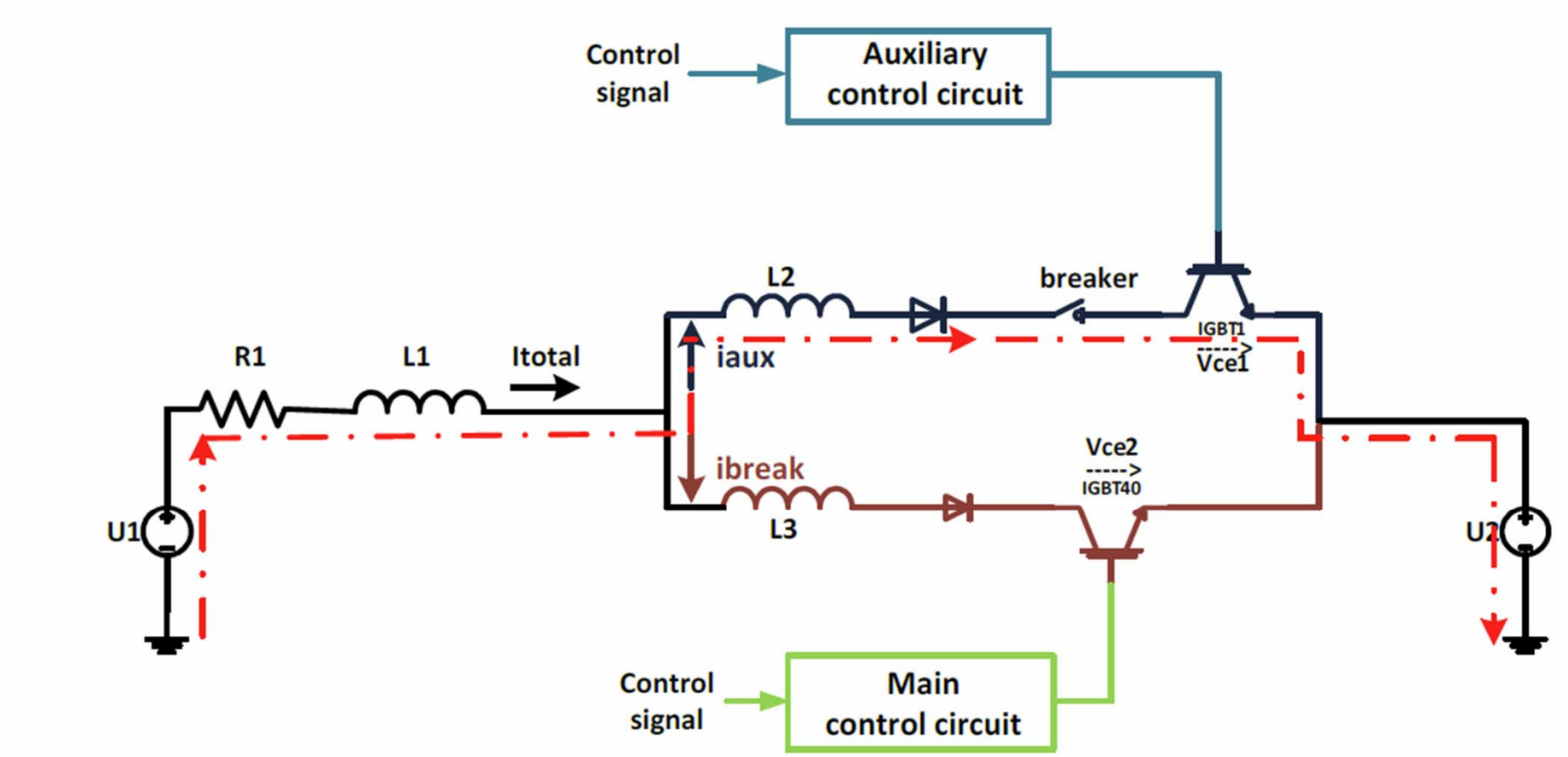
No 50 Hz transformers



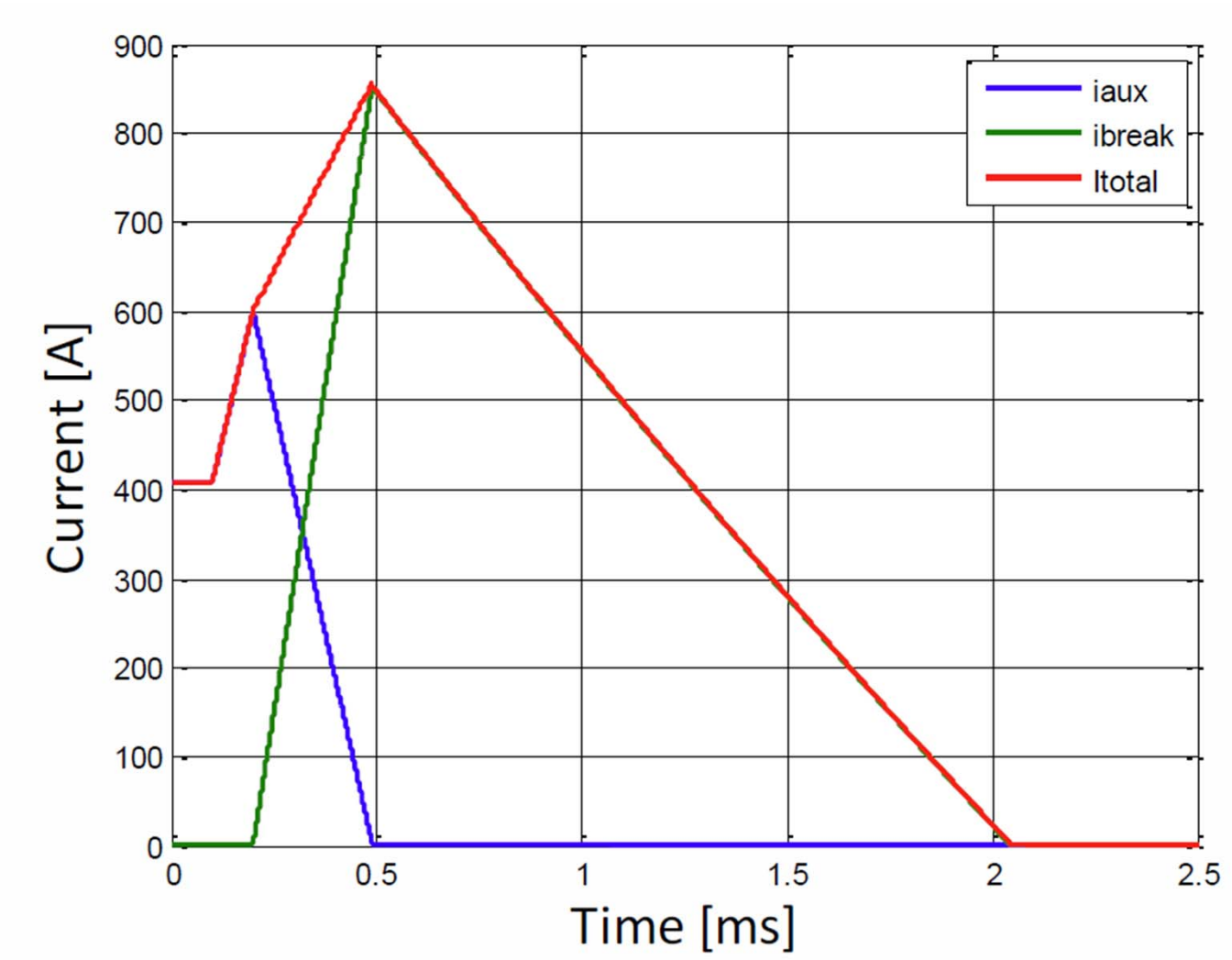
Grid Code


Line-to-line
voltage $\frac{U}{U_N}$
100%
150
1500
Fault occured
Time in ms
(a)
Required additional
reactive current
$\frac{\Delta I_B}{I_N}$ → reactive current
→ rated current
-50%
m=2
Voltage drop
$\frac{\Delta U}{U_N}$
-100%
(b)

DC breaking


Control signal
Auxiliary control circuit
L2
breaker
IGBT1
Vce1
R1
L1
Itotal
iaux
ibreak
L3
Vce2
IGBT40
U1
U2
Control signal
Main control circuit

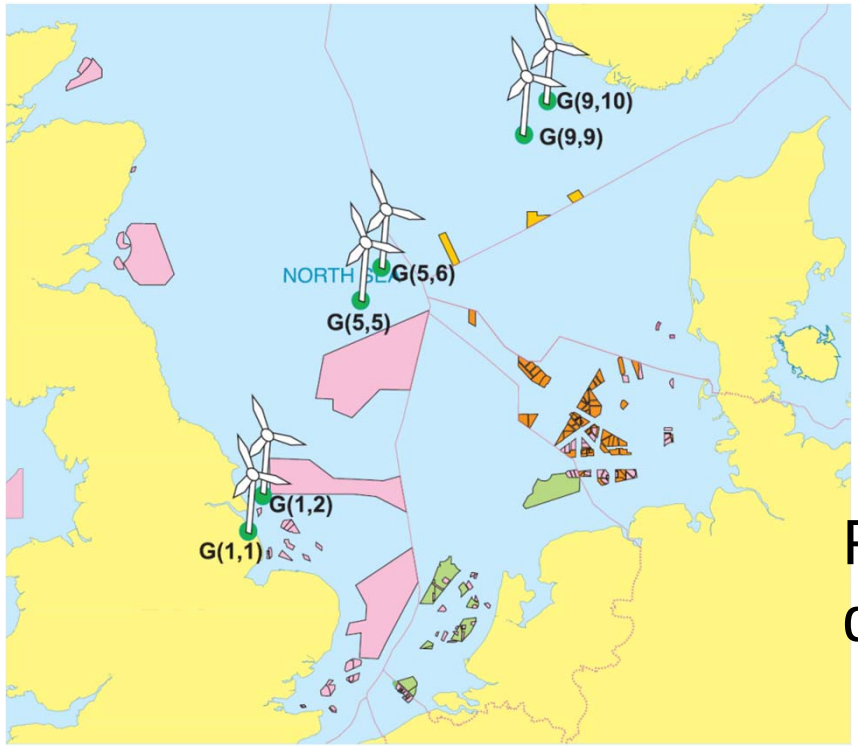
DC breaker current

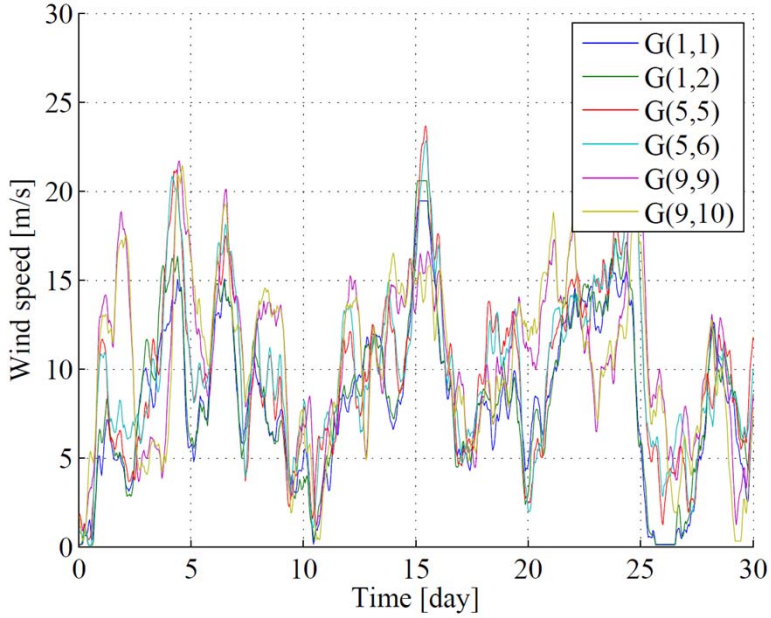


Some research examples

Example of system study

- Geographical locations

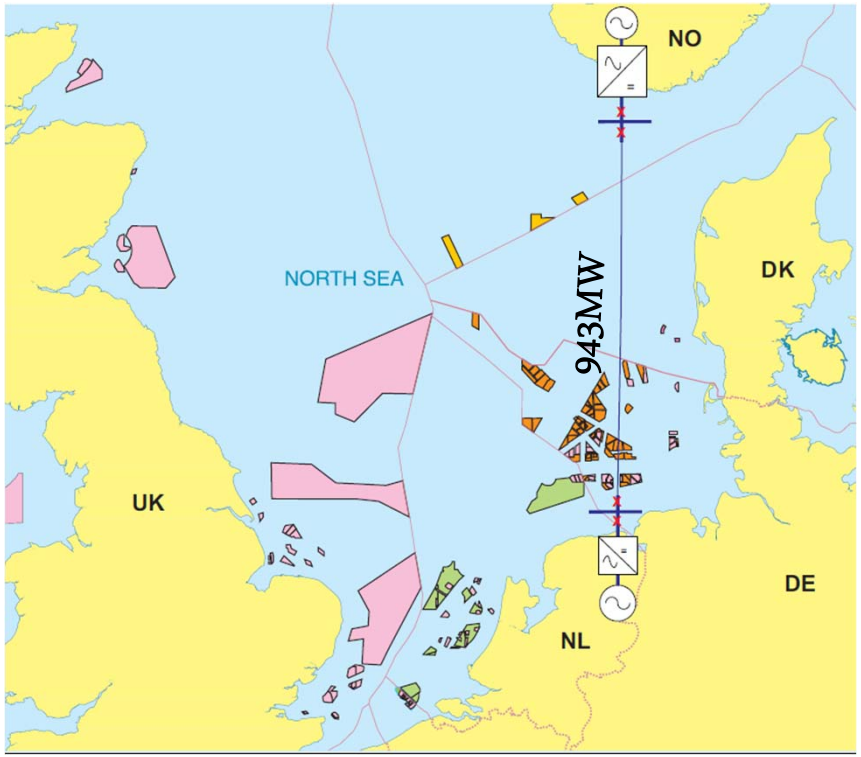




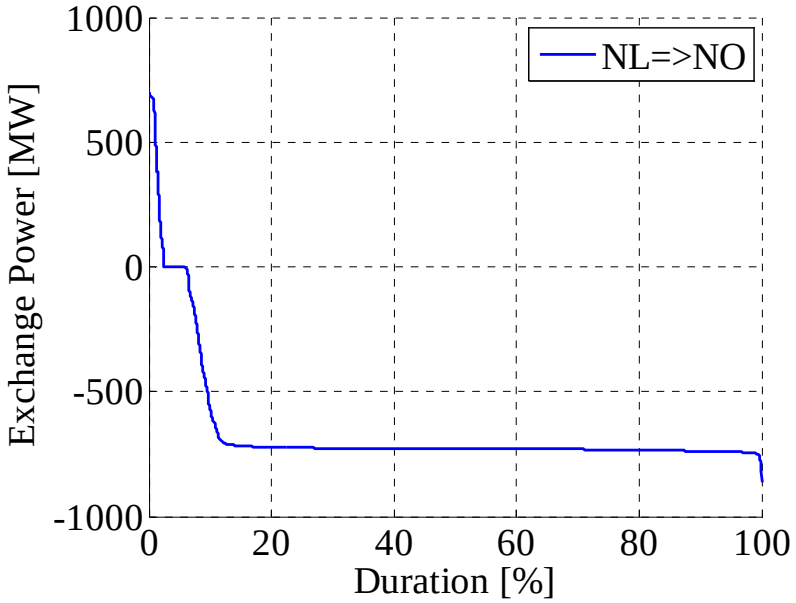
For hourly average wind speed data in the North Sea region

Vector ARIMA(6,0,0)

Existing HVDC transmission



Real exchange power

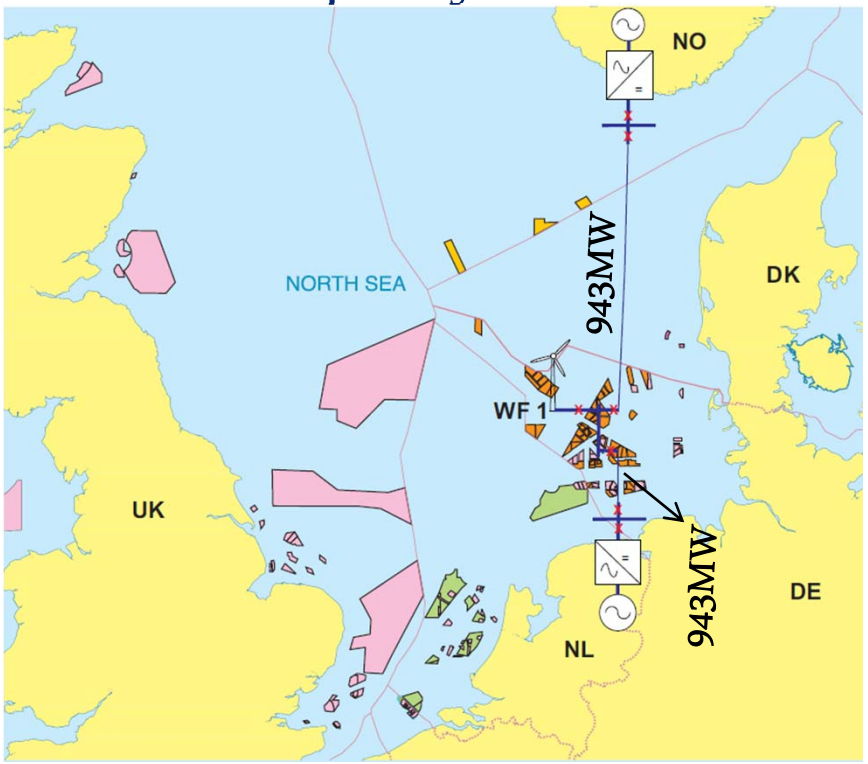


System dimensions

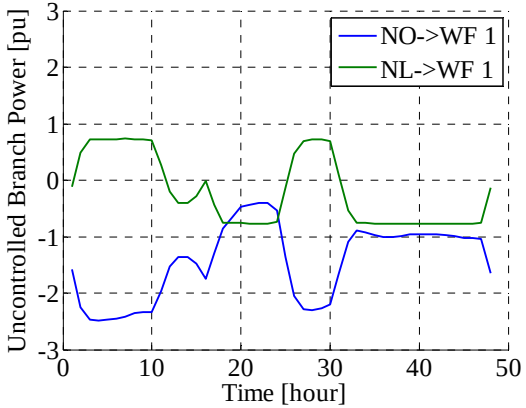
From bus	To bus	Length (km)	Power(MW)	Area(mm^2)
NO	NL	580	943x1	1200x1

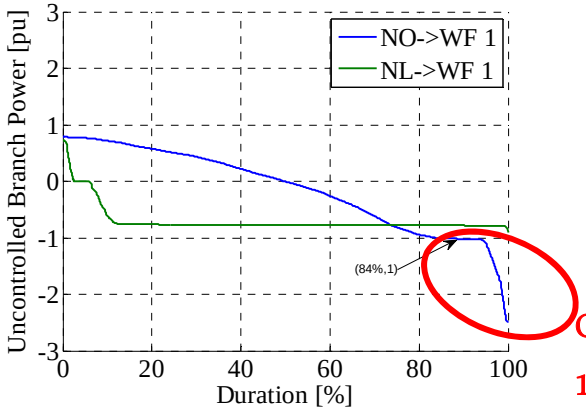
Adding a wind farm of 1700 MW

- WF 1 capacity=1700 MW



Branch power

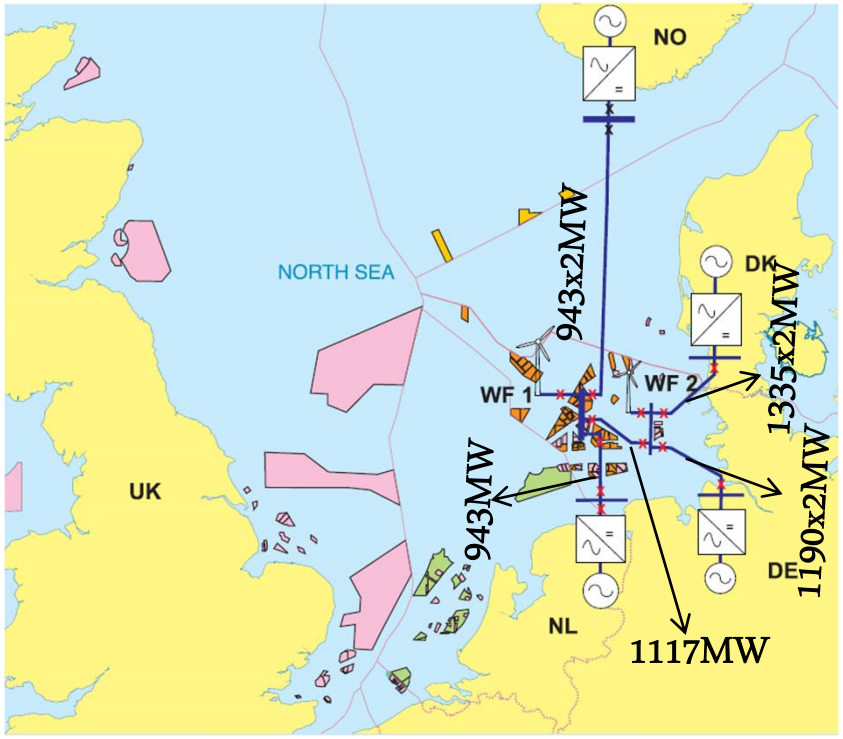




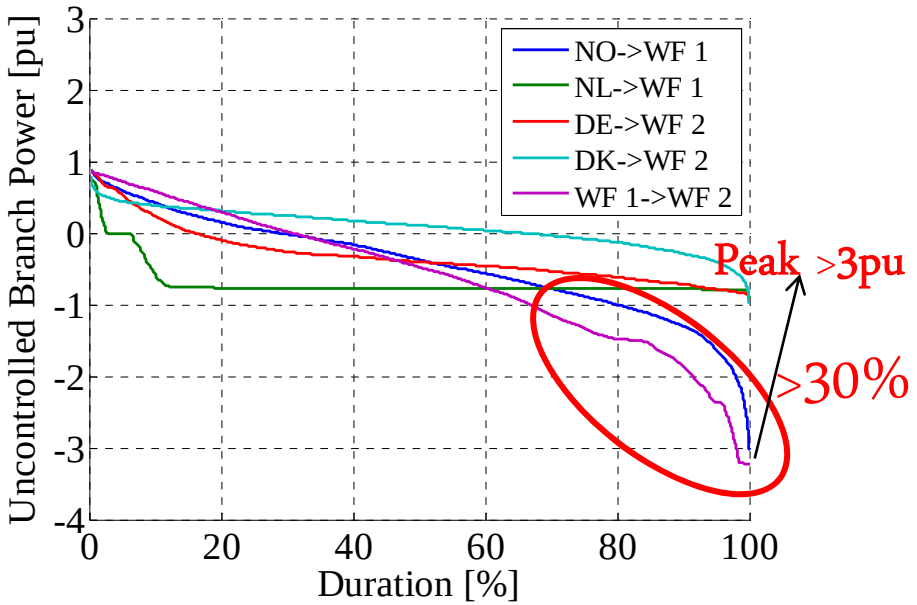
Over loaded for about 15% of the year

Multiterminal with added wind farms

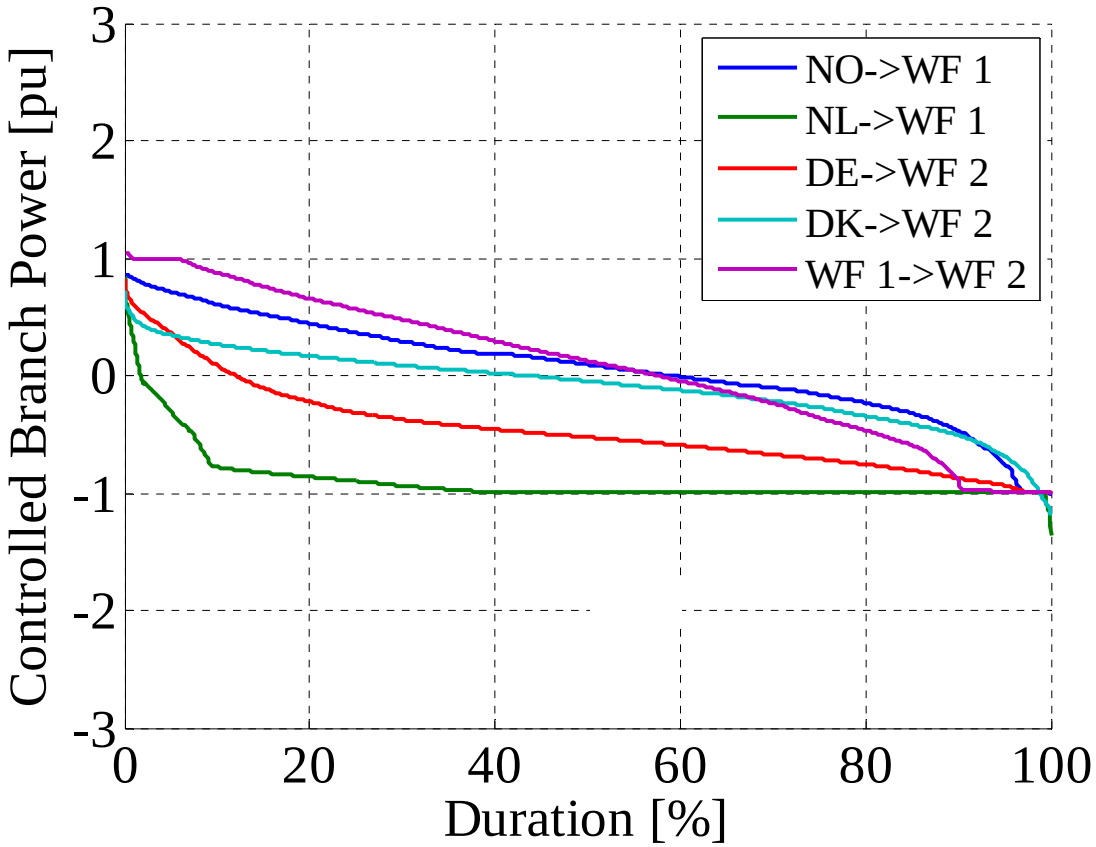
- [WF1 WF2] capacity=[1700 2700] MW



Exchange power

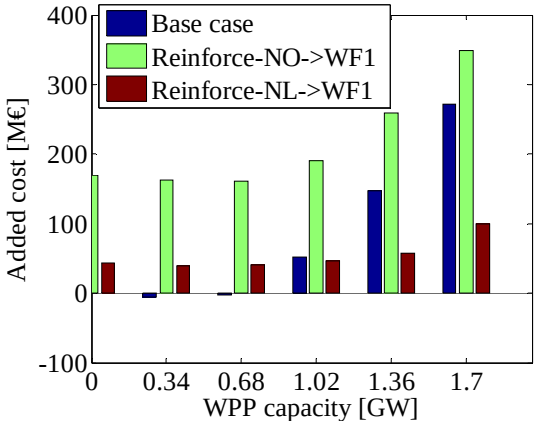


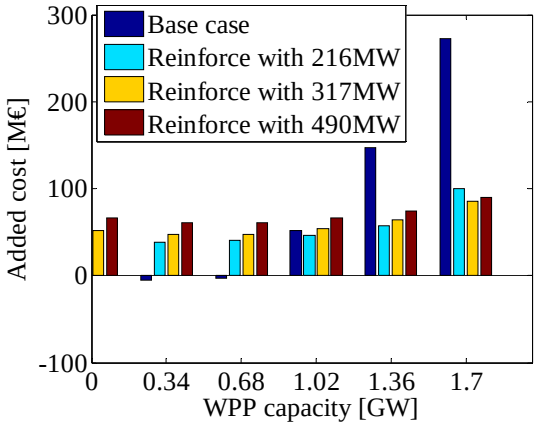
Multiterminal with added wind farms

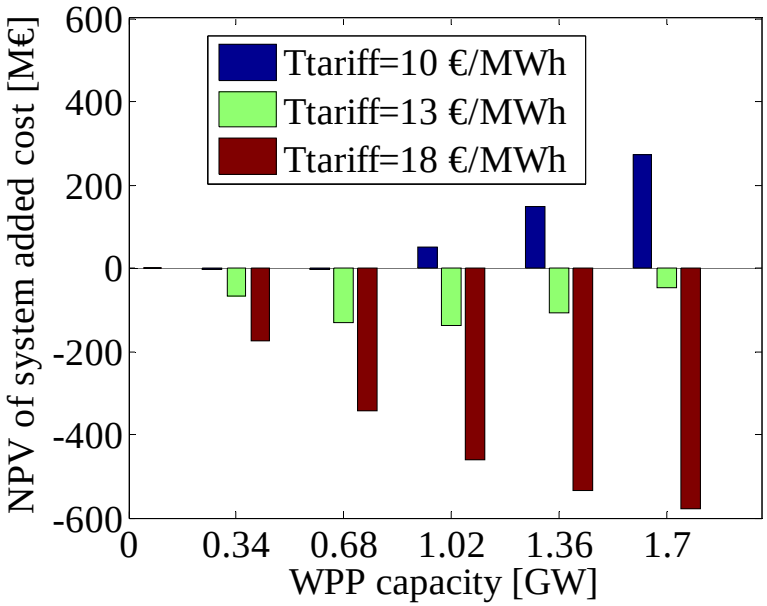


Added cost and reinforcement

Reinforcing the system

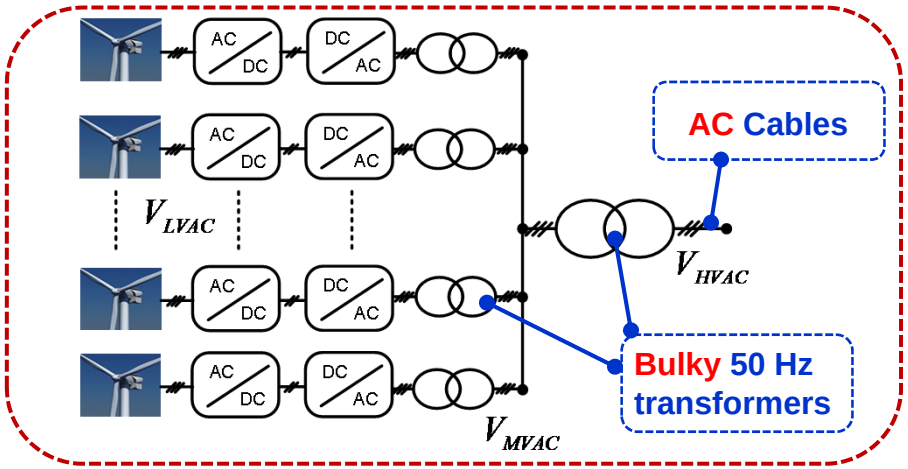




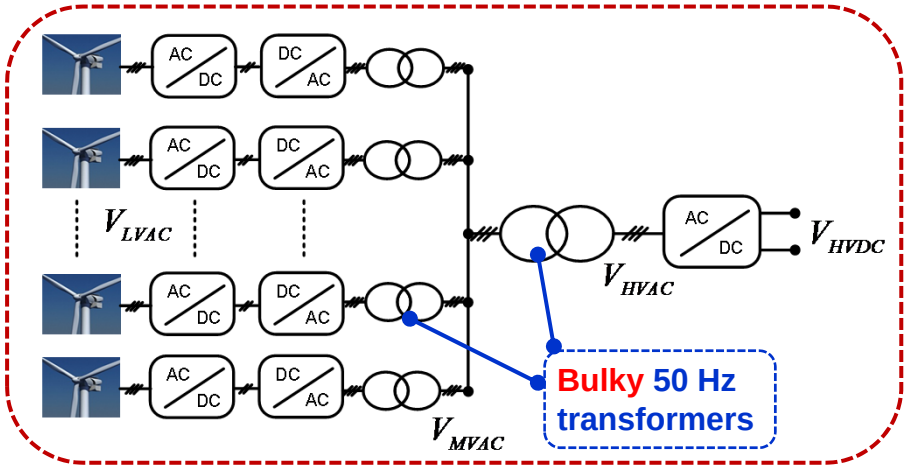


Collection grid of offshore wind farm

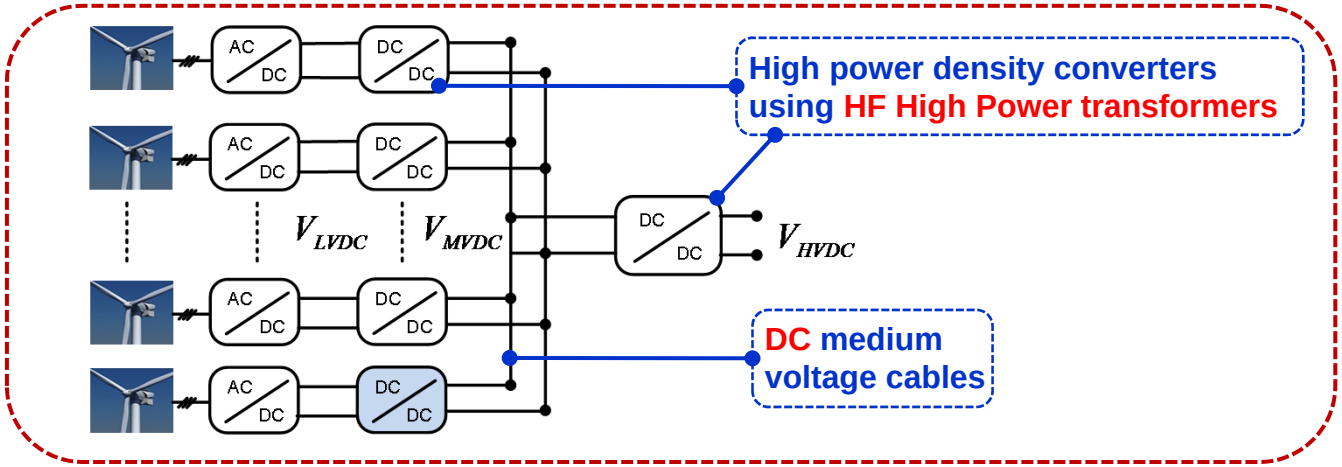
Typical offshore HVAC collection grid



Existing VSC-HVDC collection grid

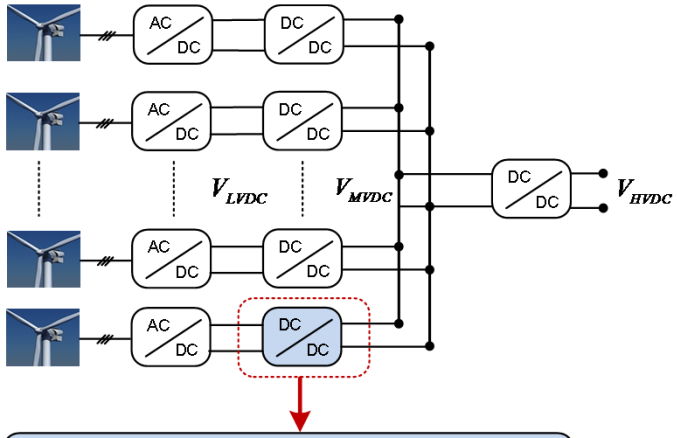


Future HVDC collection grid

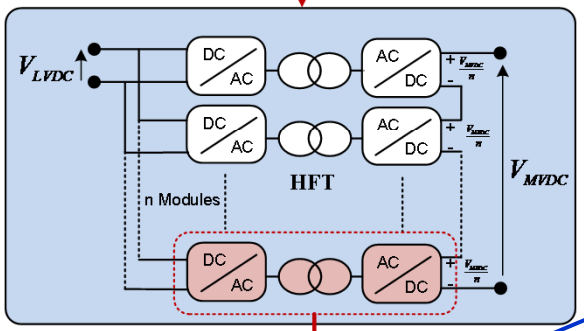


The dc-transformer

Future HVDC collection grid with HF / MF transformers :

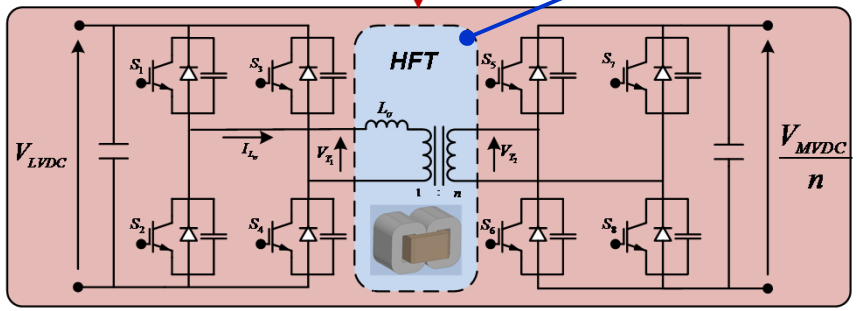


Modular structure (PISO) :



HF high power transformer + inductor

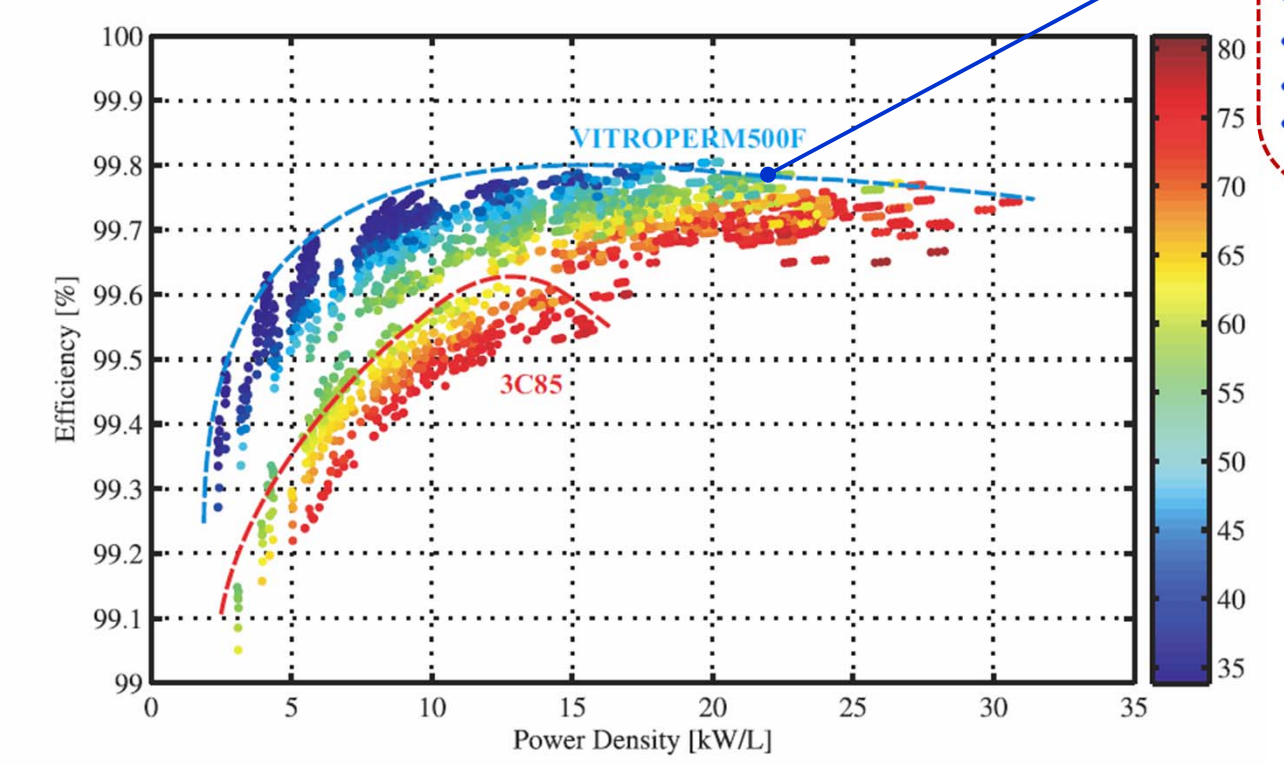
One module with HFT :



Design and Optimization (Case Study)

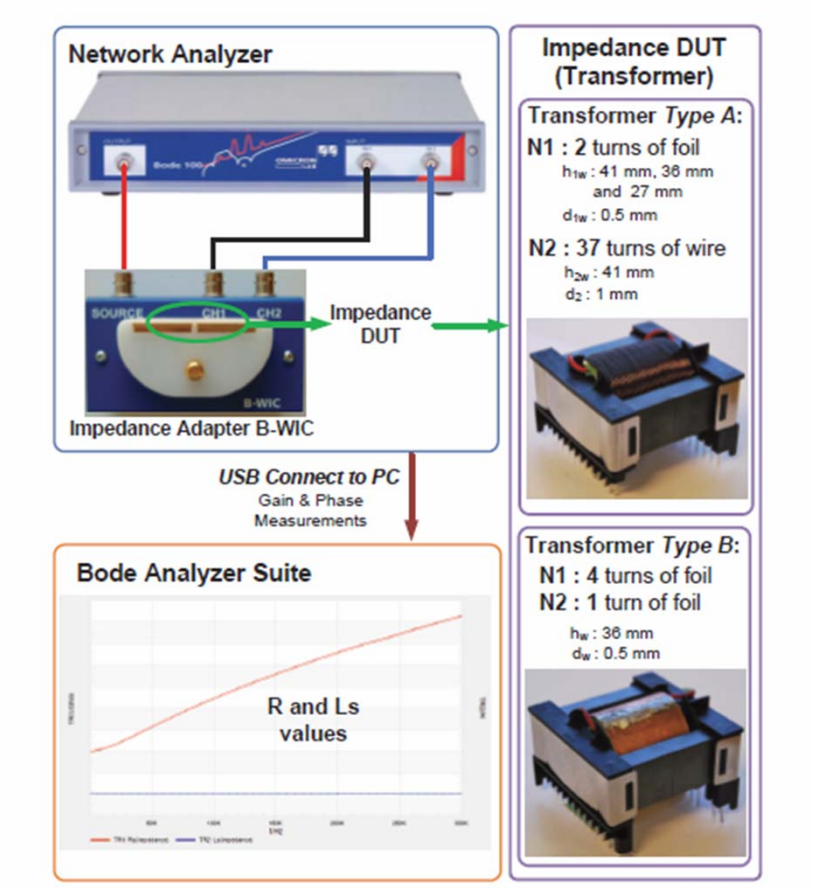
Optimization results

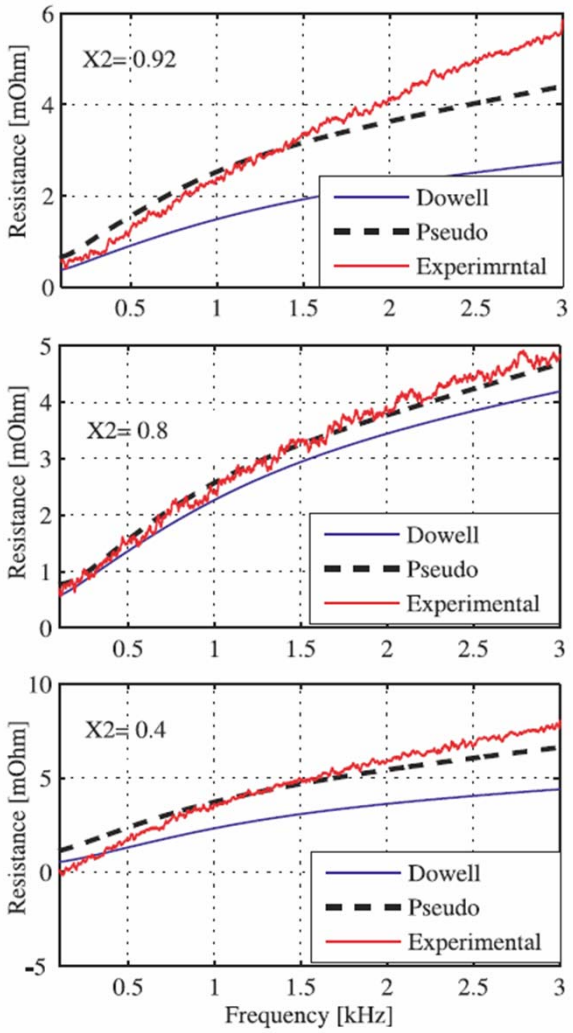
600'000 combinations of free parameters



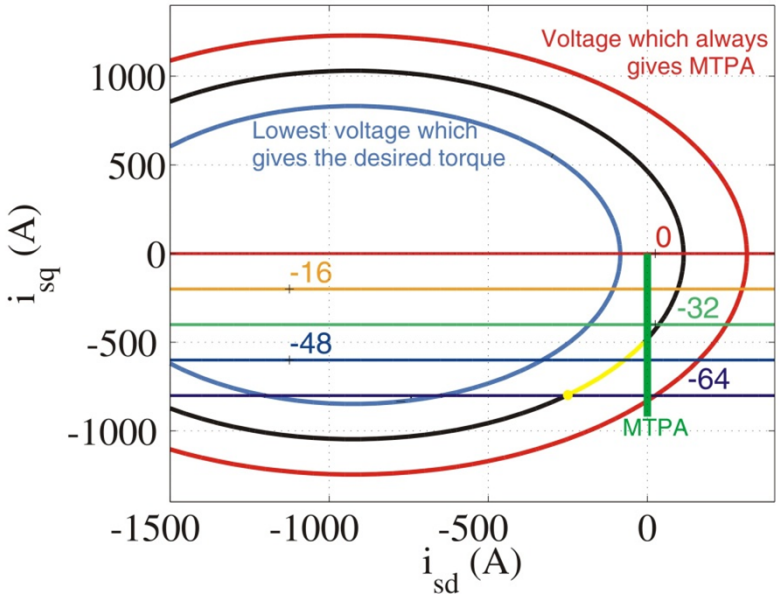
- Power density : 22.33 kW/L
- Efficiency : 99.74 %
- Length : 288 mm
- Width : 335 mm
- Height : 542 mm
- Total volume : 44.78 Liters
- d_{iso} : 48 mm
- n_c : 3

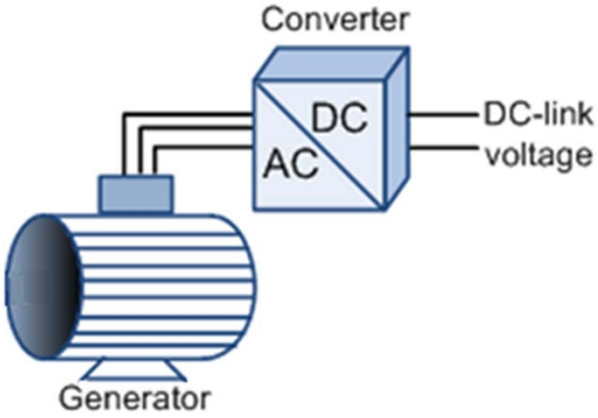
HF Resistance measurement



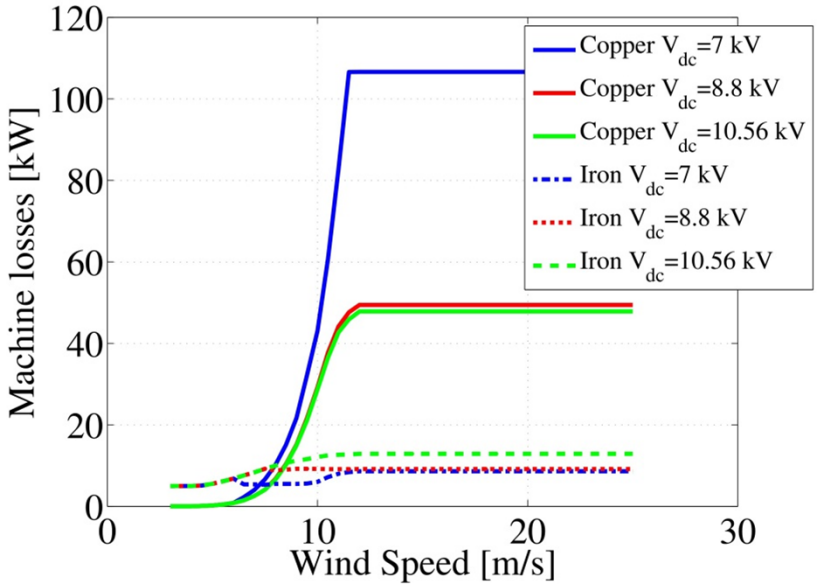


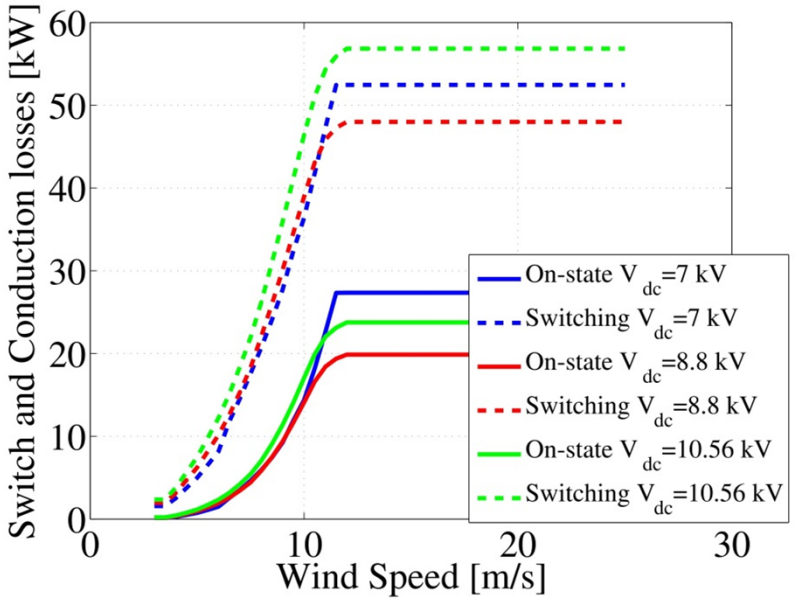
DC-link voltage selection





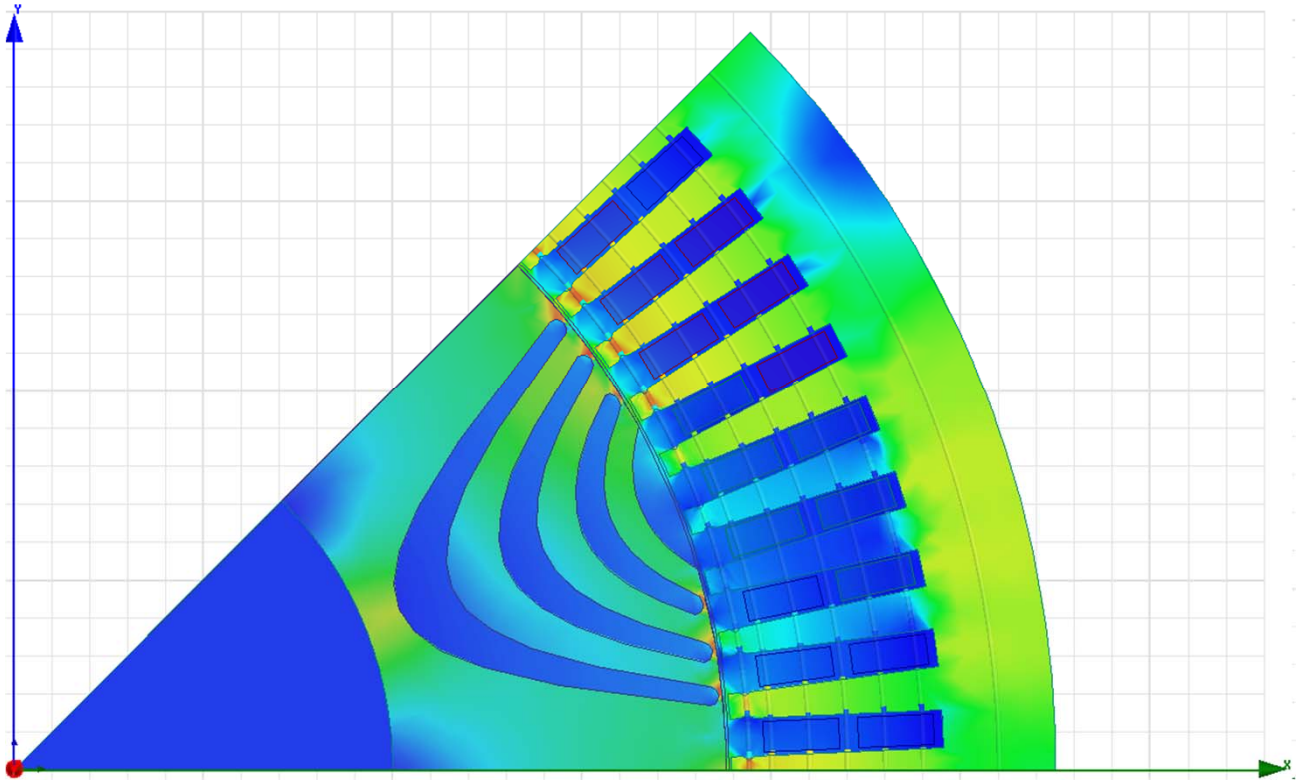
DC-link voltage and losses





Other generators - SynRG

- 74 % of power given the same volyme



Questions ?