Institut de Recerca en Energia de Catalunya
Catalonia Institute for Energy Research

Operation of offshore wind power plants connected with HVDC

Trondheim, February 2015

O. Gomis-Bellmunt (IREC / CITCEA-UPC)

with support from M. de-Prada, A. Egea, J.L. Dominguez, E. Prieto, J. Sau, F. Diaz and M. Aragüés

Agenda

- Context. Offshore wind power plants connected with VSC-HVDC.
- Functional requirements for offshore WPP connected with VSC-HVDC.
- Coordinated control for power reduction.
- Conclusions.

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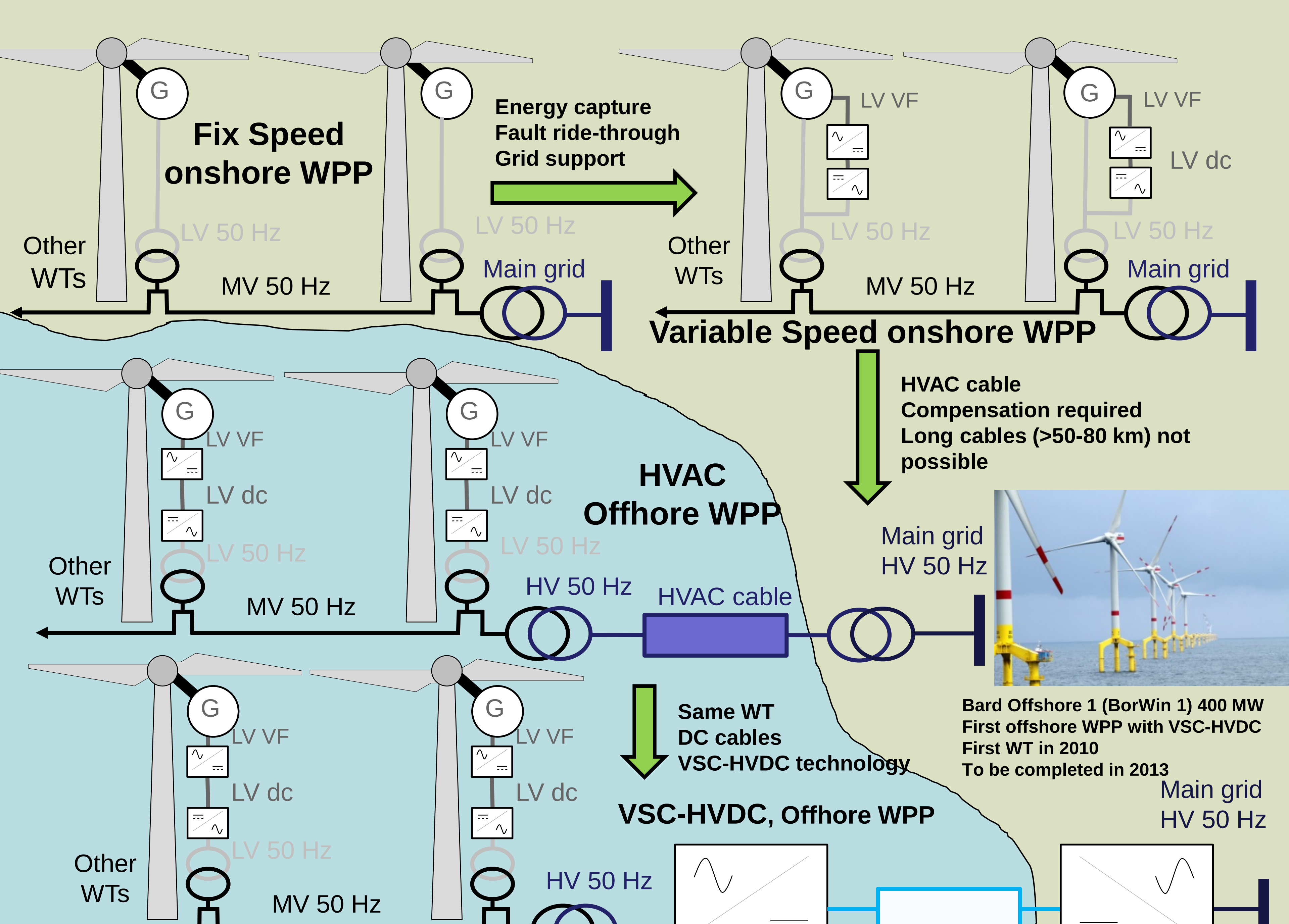
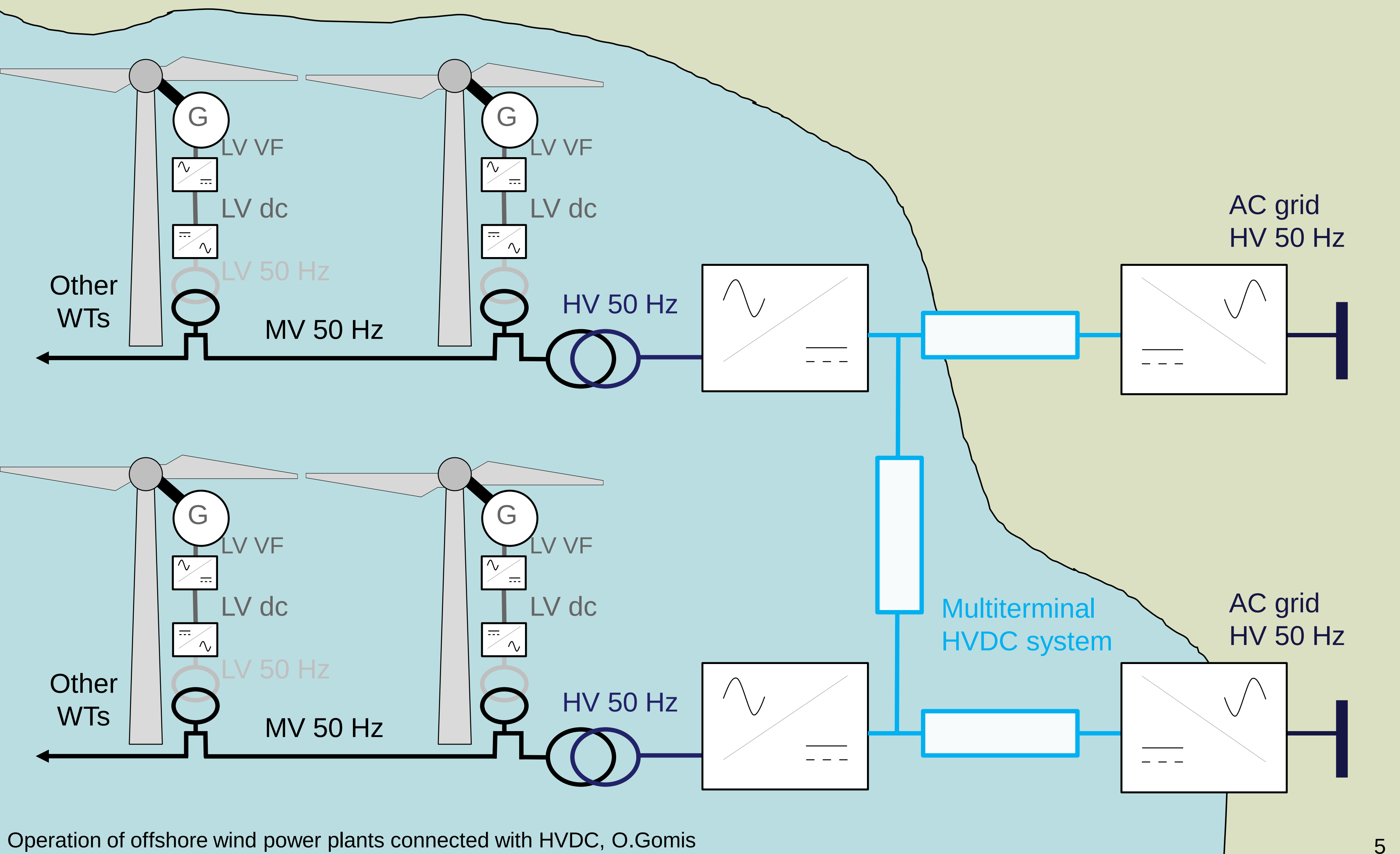
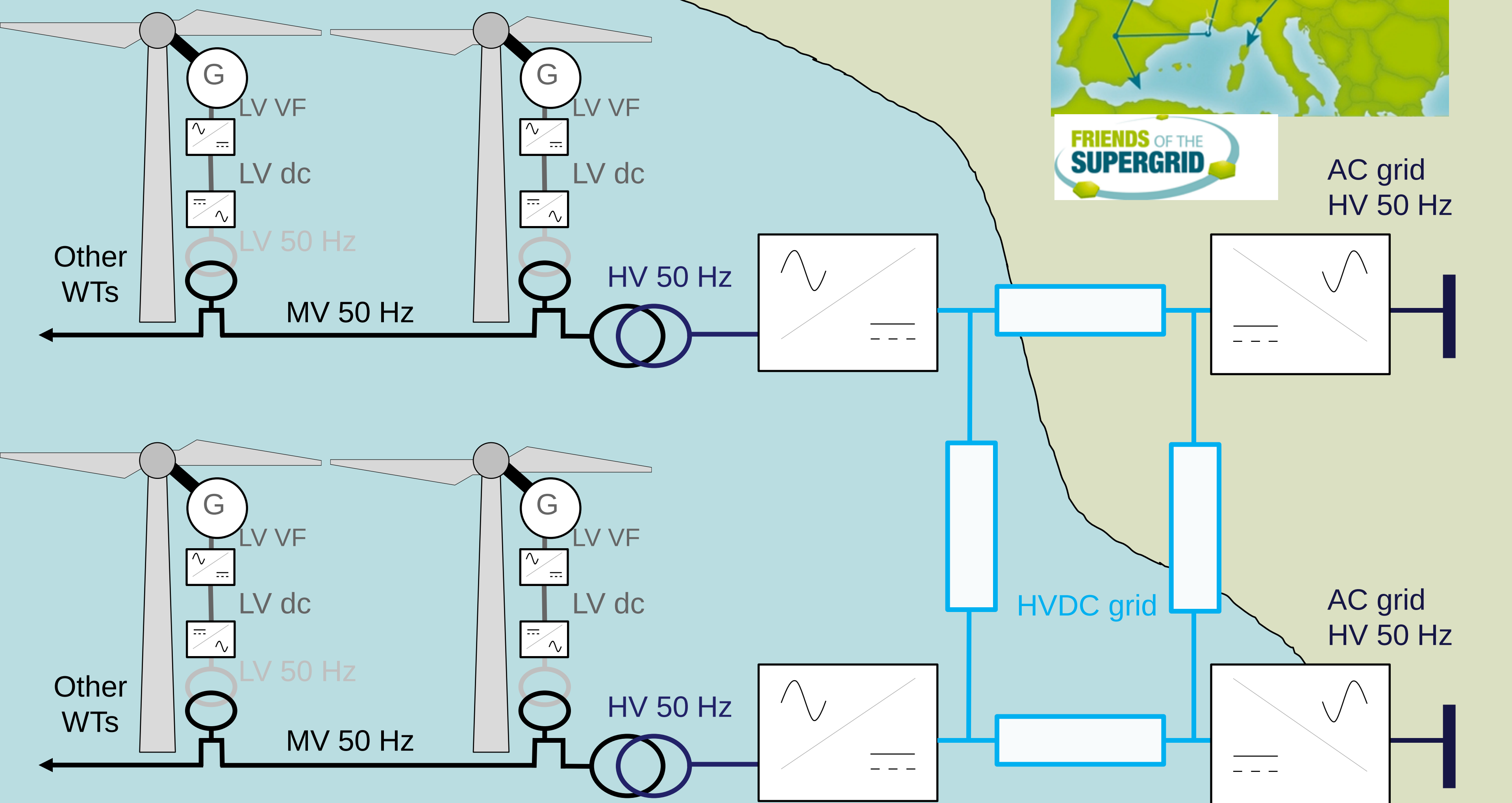

G
Fix Speed
onshore WPP
LV 50 Hz
Other
WTs
MV 50 Hz
Main grid
Energy capture
Fault ride-through
Grid support
LV VF
LV dc
Variable Speed onshore WPP
HVAC cable
Compensation required
Long cables (>50-80 km) not
possible
HVAC
Offhore WPP
HV 50 Hz
HVAC cable
Main grid
HV 50 Hz
Bard Offshore 1 (BorWin 1) 400 MW
First offshore WPP with VSC-HVDC
First WT in 2010
To be completed in 2013
Same WT
DC cables
VSC-HVDC technology
VSC-HVDC, Offhore WPP
HVDC cable

Multiterminal VSC-HVDC

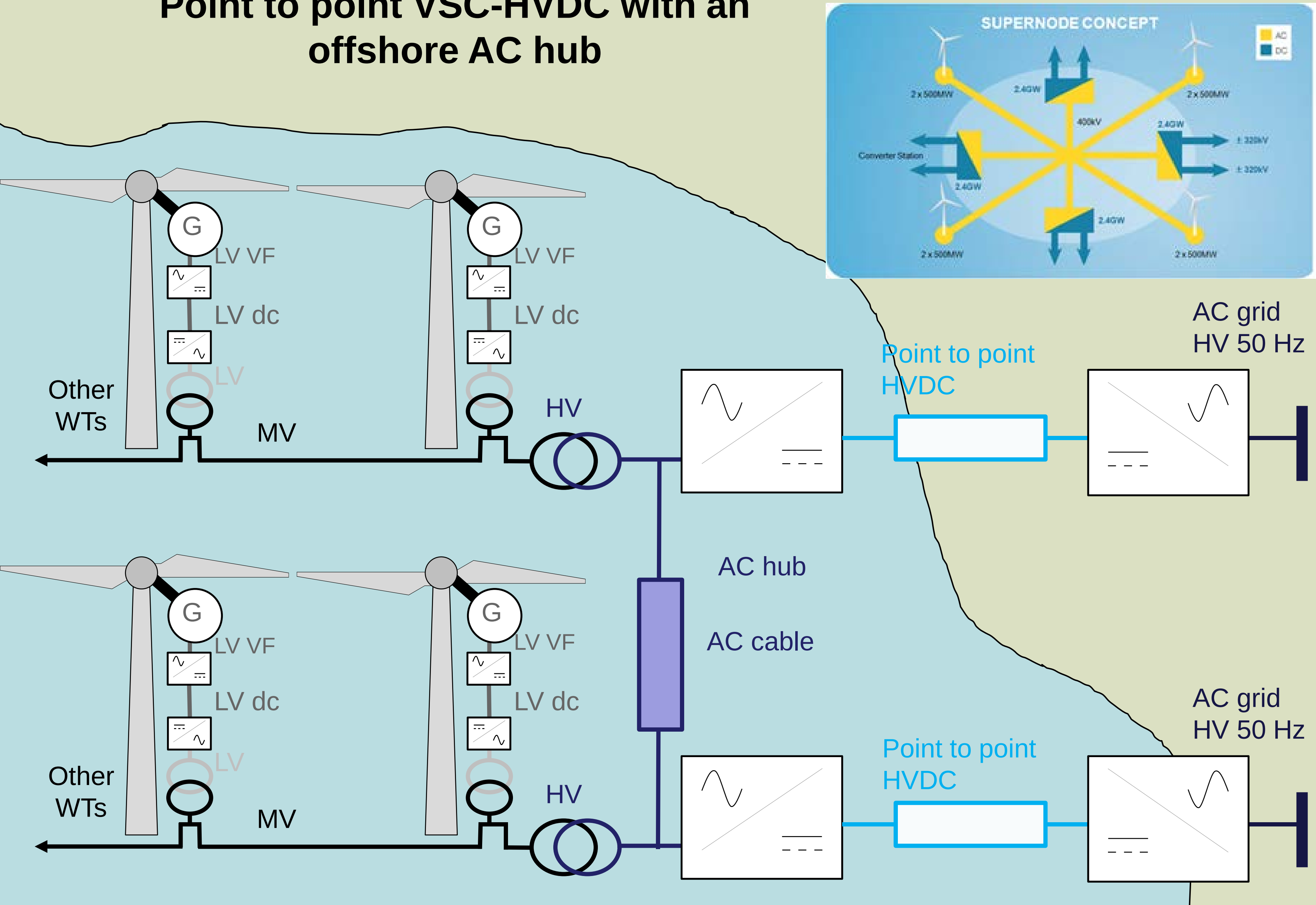


VSC-HVDC grid



Point to point VSC-HVDC with an offshore AC hub

Mainstream Renewable Power



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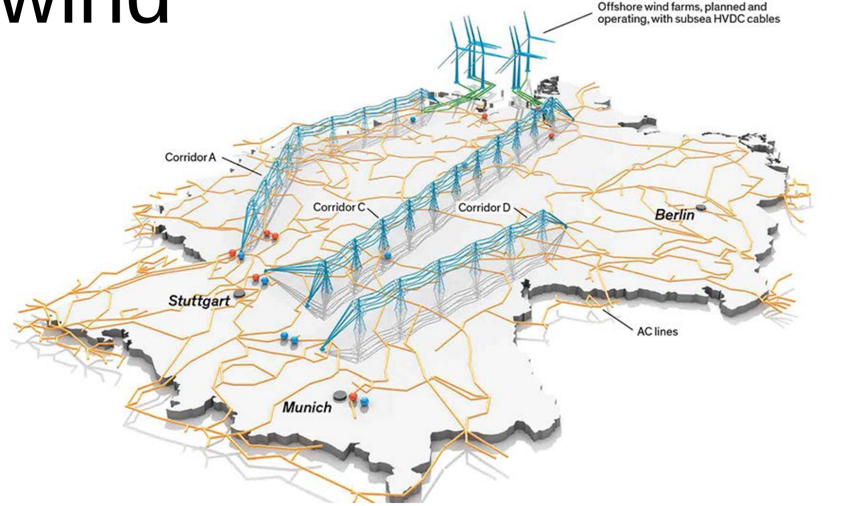
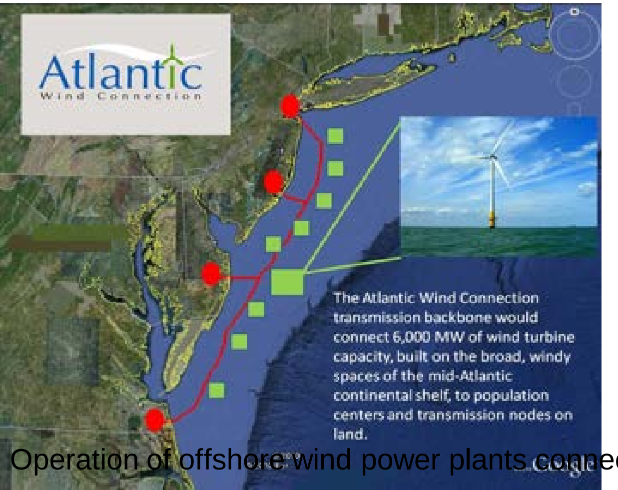
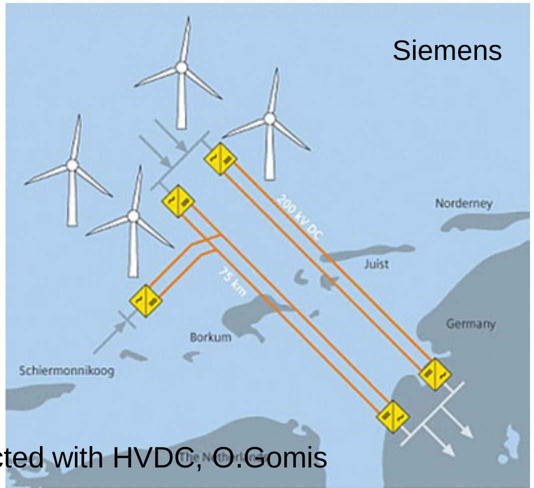
HVDC technology concepts for future transmission systems for offshore wind

- Point to point HVDC
- Multiterminal HVDC
- HVDC grid
- Offshore AC hubs
- AC systems with HVDC links
- <u>All the previous combined</u>



Germany Takes the Lead in HVDC, IEEE Spectrum 2013





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WPP concepts

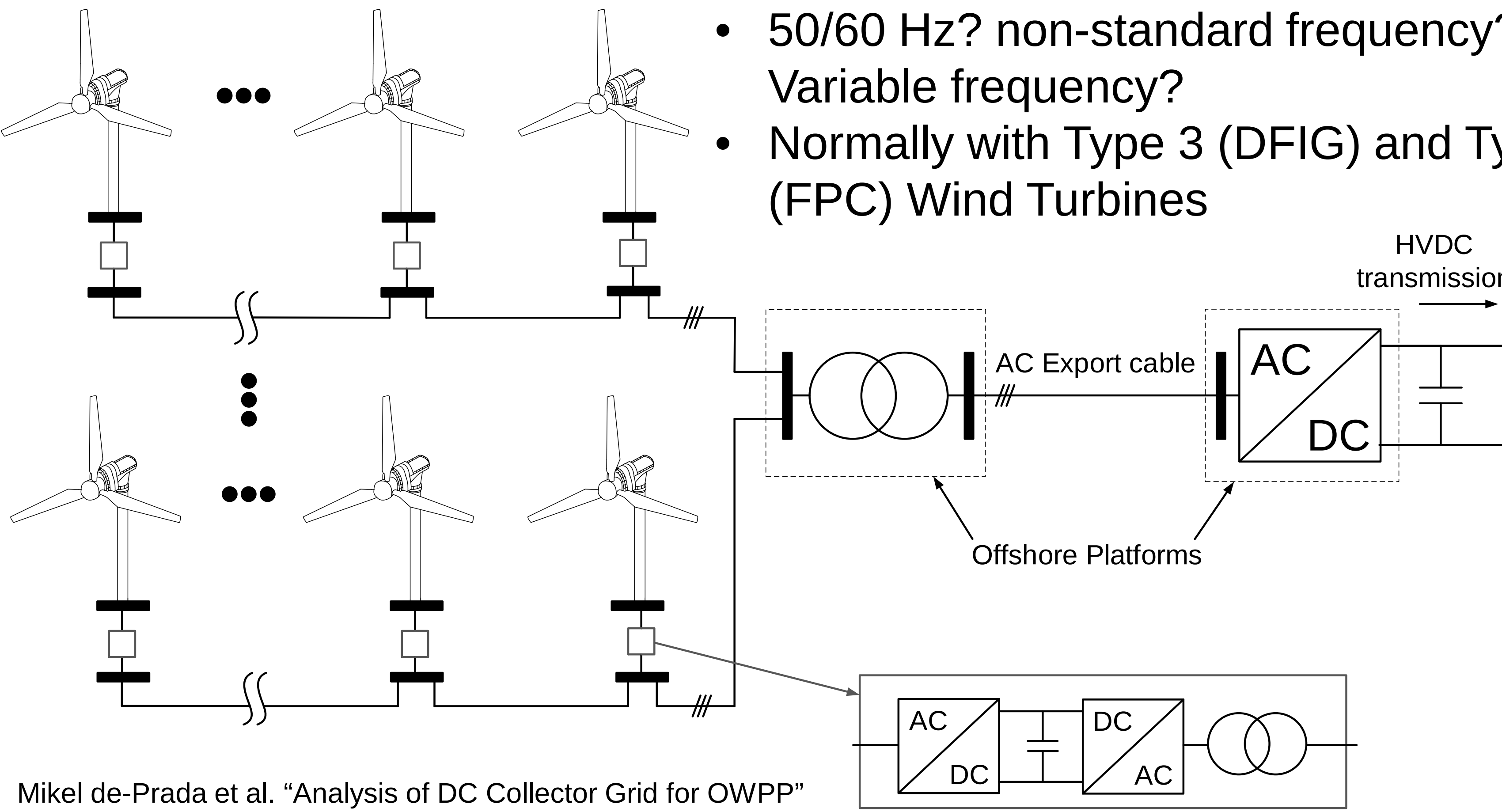
- AC WPP standard/non-standard frequency
- AC WPP variable frequency
- DC WPP
- Hybrid DC-AC

Cost?
Efficiency?
Reliability?
Availability?
Maintainability?

http://www.bard-offshore.de/en

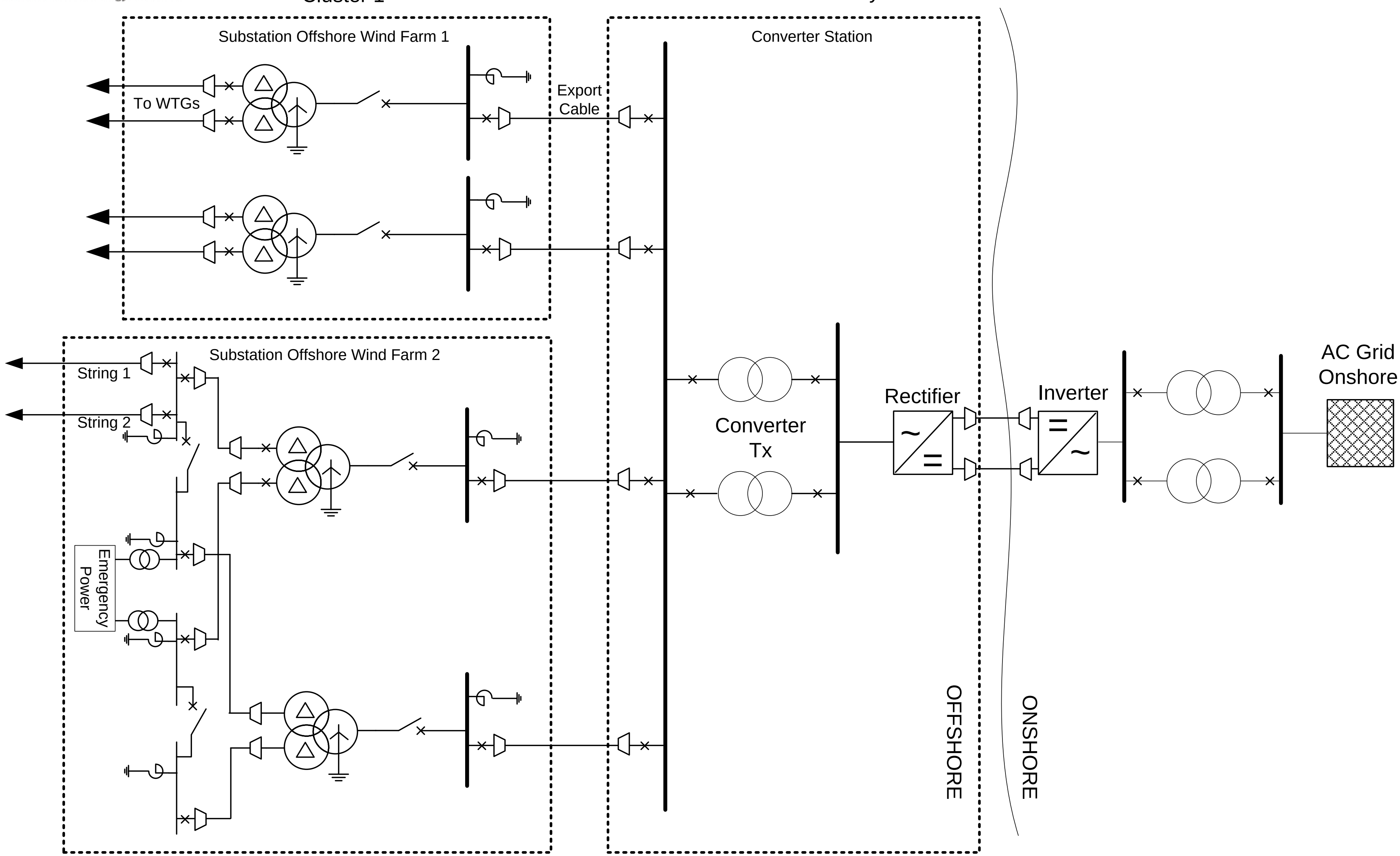
AC collection

- WPP AC voltage ratings ↑↑ 33 kV → 66 kV?
- 50/60 Hz? non-standard frequency? Variable frequency?
- Normally with Type 3 (DFIG) and Type 4 (FPC) Wind Turbines



Mikel de-Prada et al. “Analysis of DC Collector Grid for OWPP”
12th Wind Integration Workshop, London, October 2013

Cluster 1



Cluster 2

Cigré WG B4-55 HVDC connection of offshore wind power plants (under development)

Projects (WPP with VSC-HVDC) with AC collection 50 Hz

Borwin 1 (Transpower offshore, 2009, +/- 150 kV, 400 MW,125+75 km) for BARD Offshore 1 - 2x1 km

DolWin 1 (TenneT, 2013, +/- 320 kV, 800 MW, 75+90 km) for Meg Offshore 1 - 2x13 km and Borkum West II - 2x7.5 km

DolWin 2 (TenneT, 2015, +/- 320 kV, 900 MW, 45+90 km) for Gode Wind I - 7 km and Gode Wind II - 12 km

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Borwin 2 (Transpower offshore, 2014, +/- 300 kV, 800 MW,125+75 km) for Veja Mate – 2x10 km and GlobalTech 1 – 2x30 km

Helwin 1 (Transpower offshore, 2014, +/- 250 kV, 576 MW,85+45.5 km) for Nordsee Ost – 2x4.2 km, Meerwind phase 1 – 2x7.6 km and 2 – 2x 20 km

Sylwin 1 (TenneT, 2014, +/- 320 kV, 864 MW, 159 + 45.5 km) for Dan Tysk– 2x9.7 km, Butendiek – 2x40 km and Sandbank 24 – 2x35 km

Helwin 2 (TennetT, 2015, +/- 320 kV, 690 MW,85+45.5 km) for Amrumbank – 3x8 km, Hochsee Testfeld Helgoland – 2x4 km and Kaskasi – 2x3.5 km

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DolWin 3 (TenneT, 2017, +/- 320 kV, 900 MW, 84.5+76.5 km) for OWP Borkum Riffgrund West 1, OWP Borkum Riffgrund West 2 and OWP Borkum West 2

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WPP connected to VSC-HVDC Functional requirements

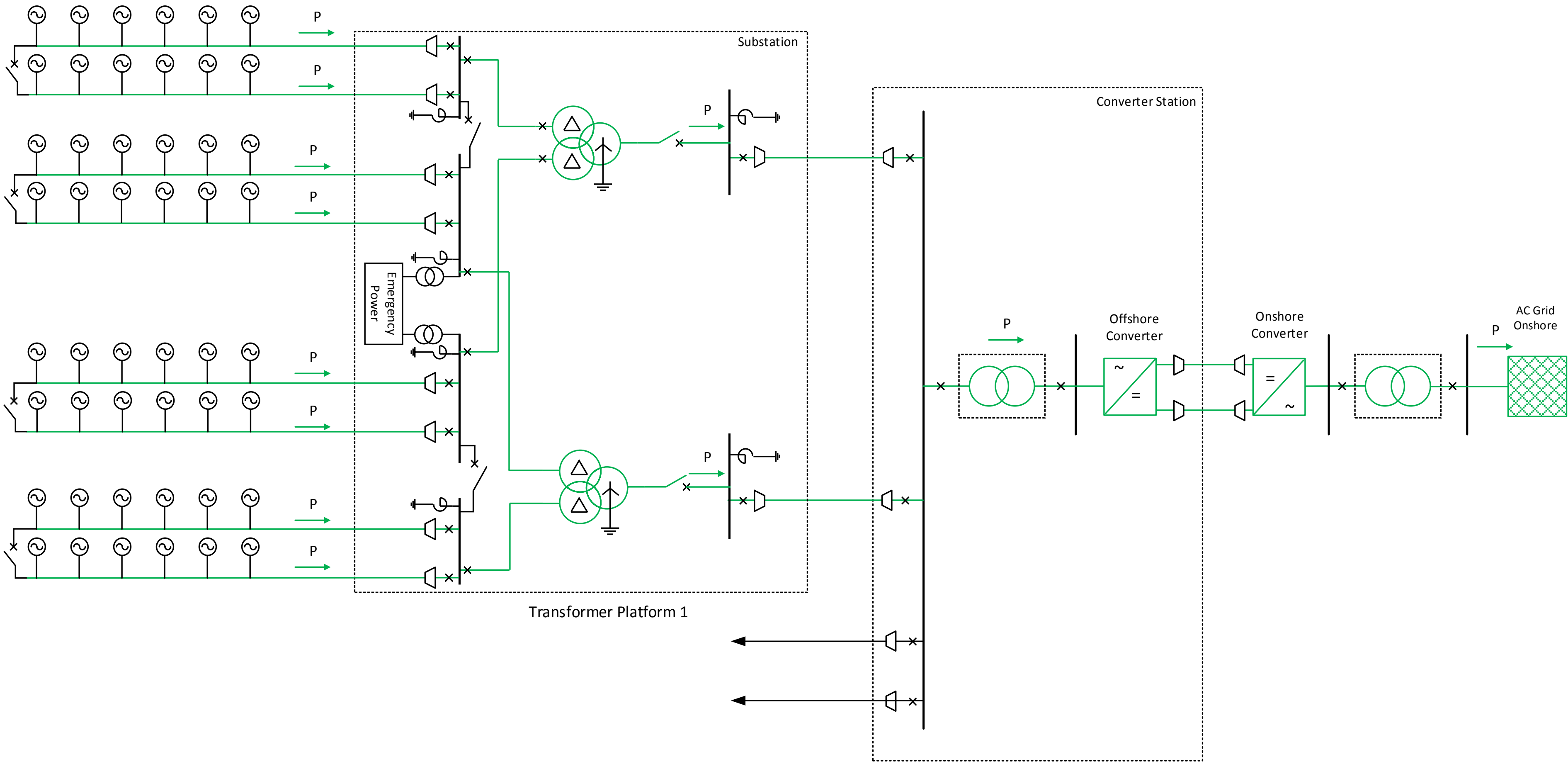
- Collect the wind power and inject it in the VSC-HVDC cable
- Provide support to the main AC grid
- Provide support to the DC grid (if exists)
- Ensure the proper offshore grid operation
- Maintain stability in normal and fault conditions

WPP connected to VSC-HVDC
Functional requirements

Specific requirements:

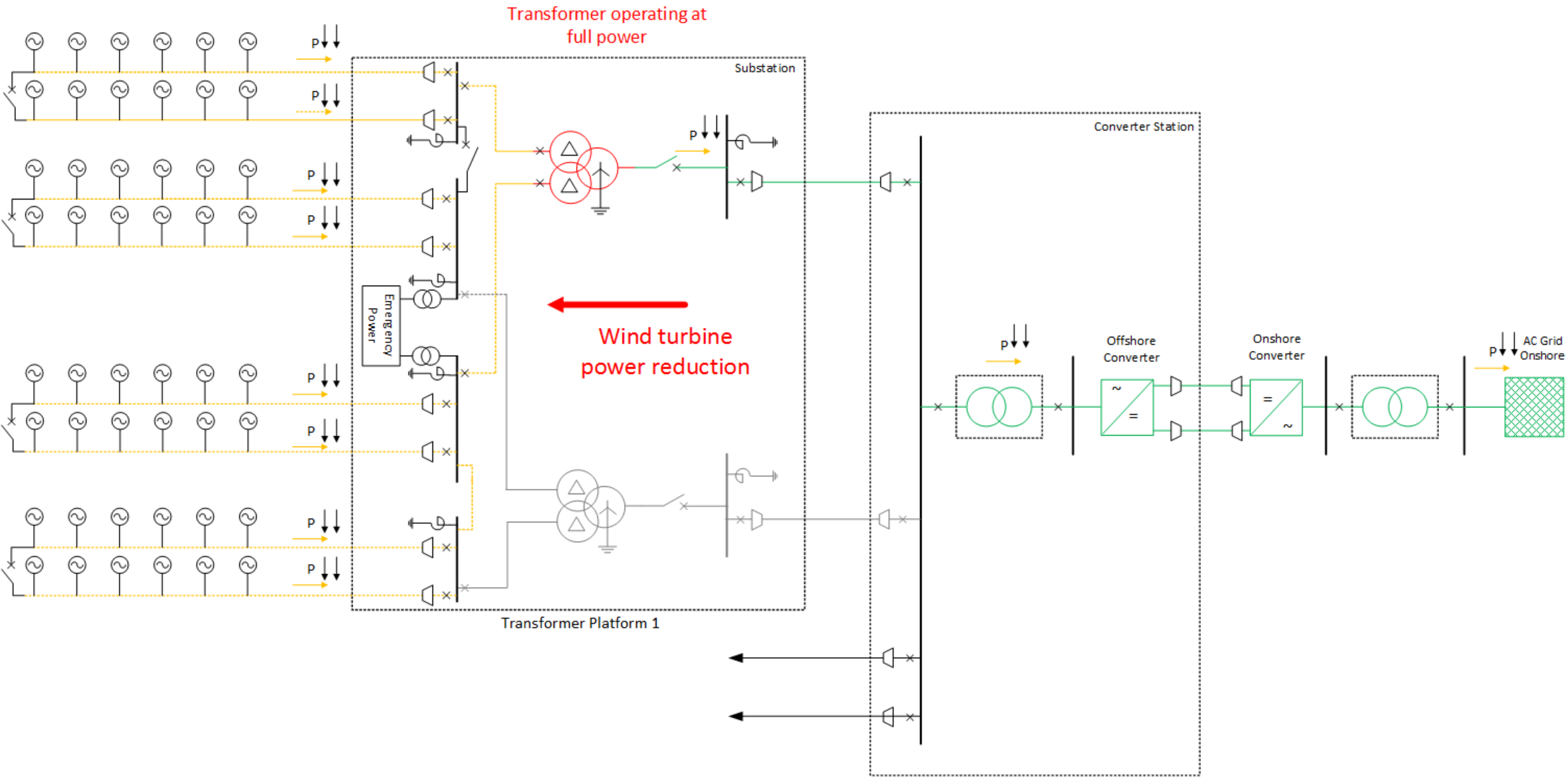
- Reactive power management. Offshore grid voltage control (HVDC rectifier + WTs)
- Active power management
- Offshore grid frequency control (VSC-HVDC rectifier)
- Start/stop sequence
- Fault ride-through capability
- Main grid support:
  - Voltage support
  - Frequency support may be required
  - Virtual (synthetic inertia) may be required
  - Power oscillation damping may be required
- Control coordination between WPP control and VSC-HVDC control
- Operation under communication failure
- Provide auxiliary power to the WPP when there is no available generation (no wind or excessively high wind)

Normal operation



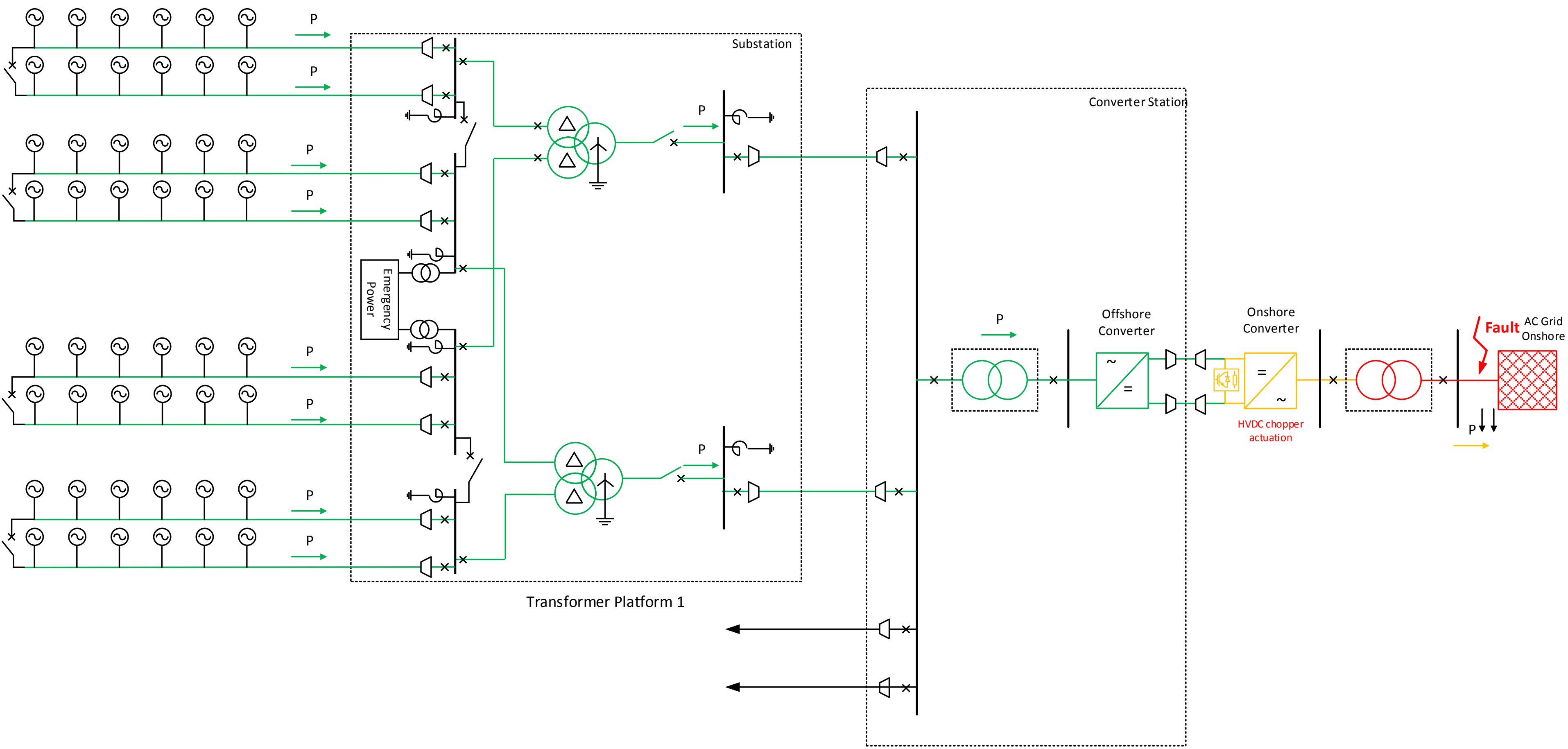
Draft from Cigré B4-55 WG “HVDC connection of offshore WPP”

Restricted operation



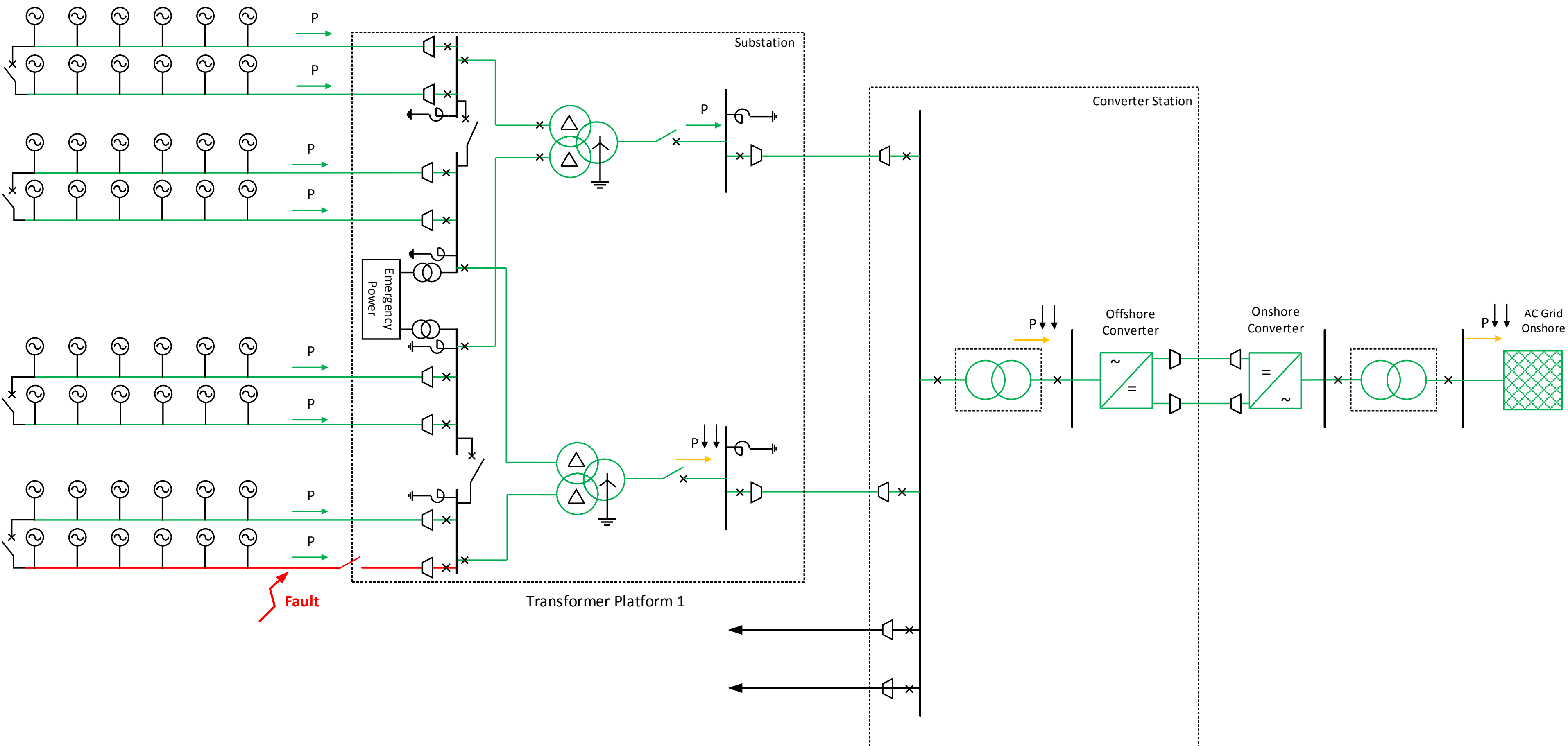
Draft from Cigré B4-55 WG “HVDC connection of offshore WPP”

Main AC grid fault



Draft from Cigré B4-55 WG “HVDC connection of offshore WPP”

WPP fault



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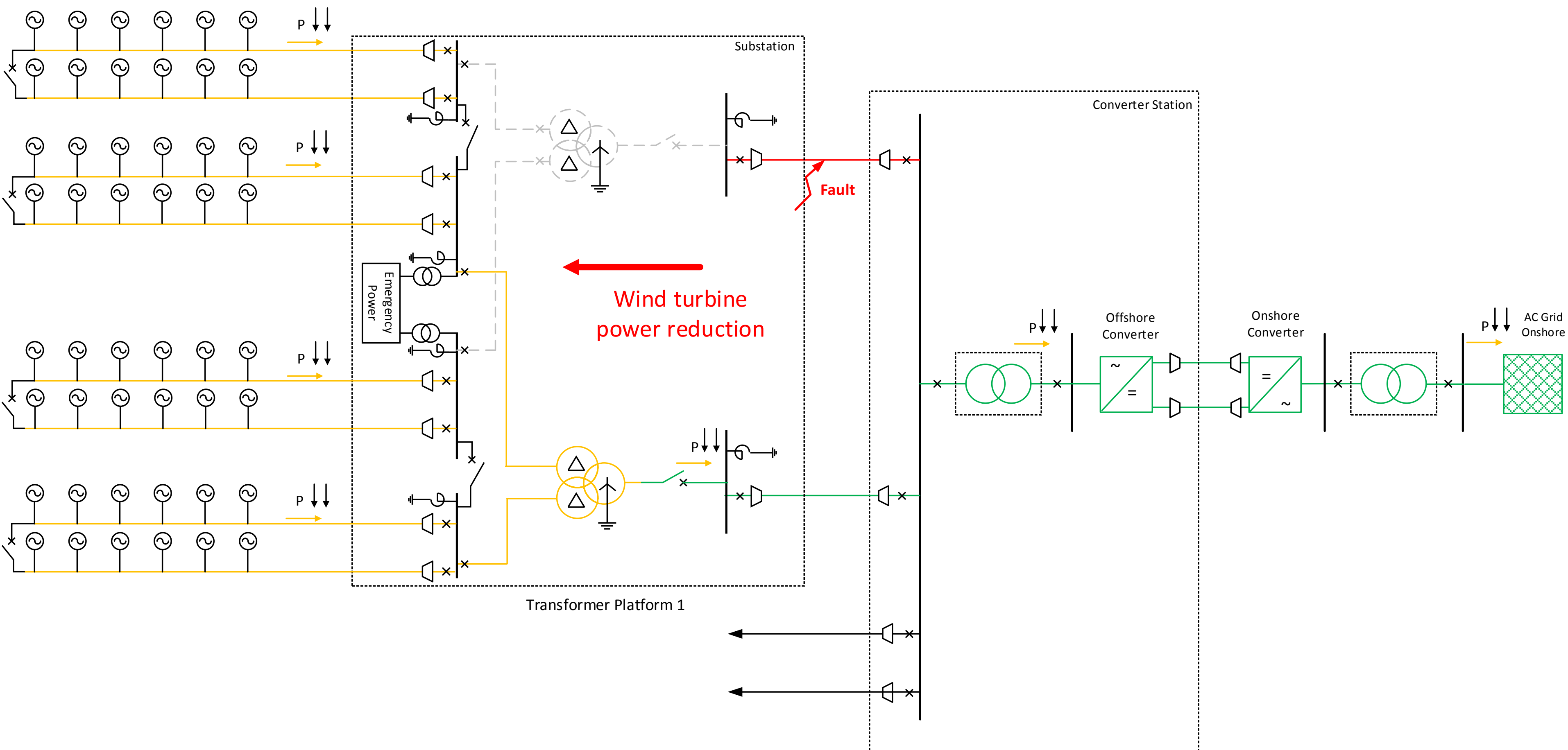
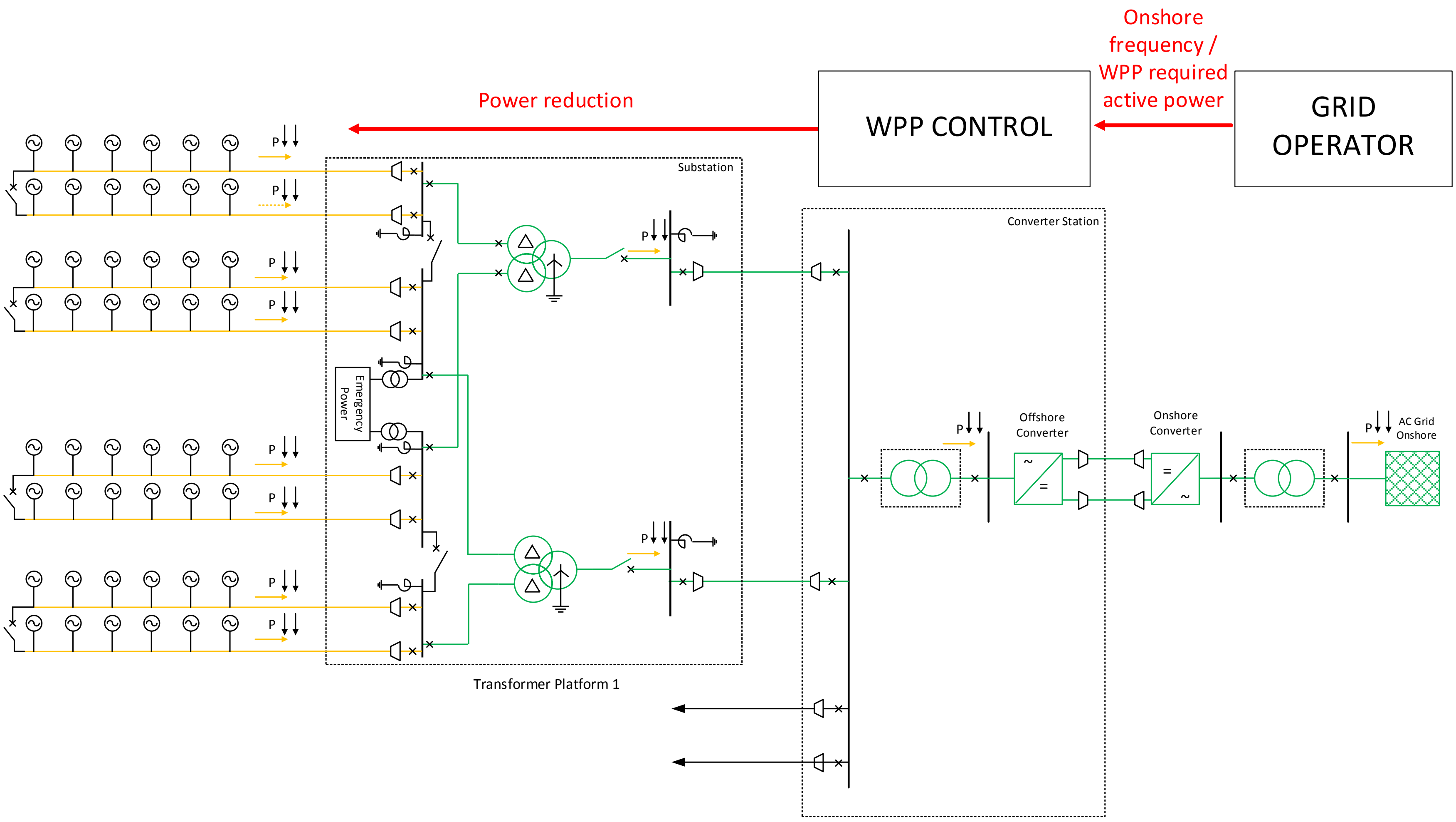
Export cable fault



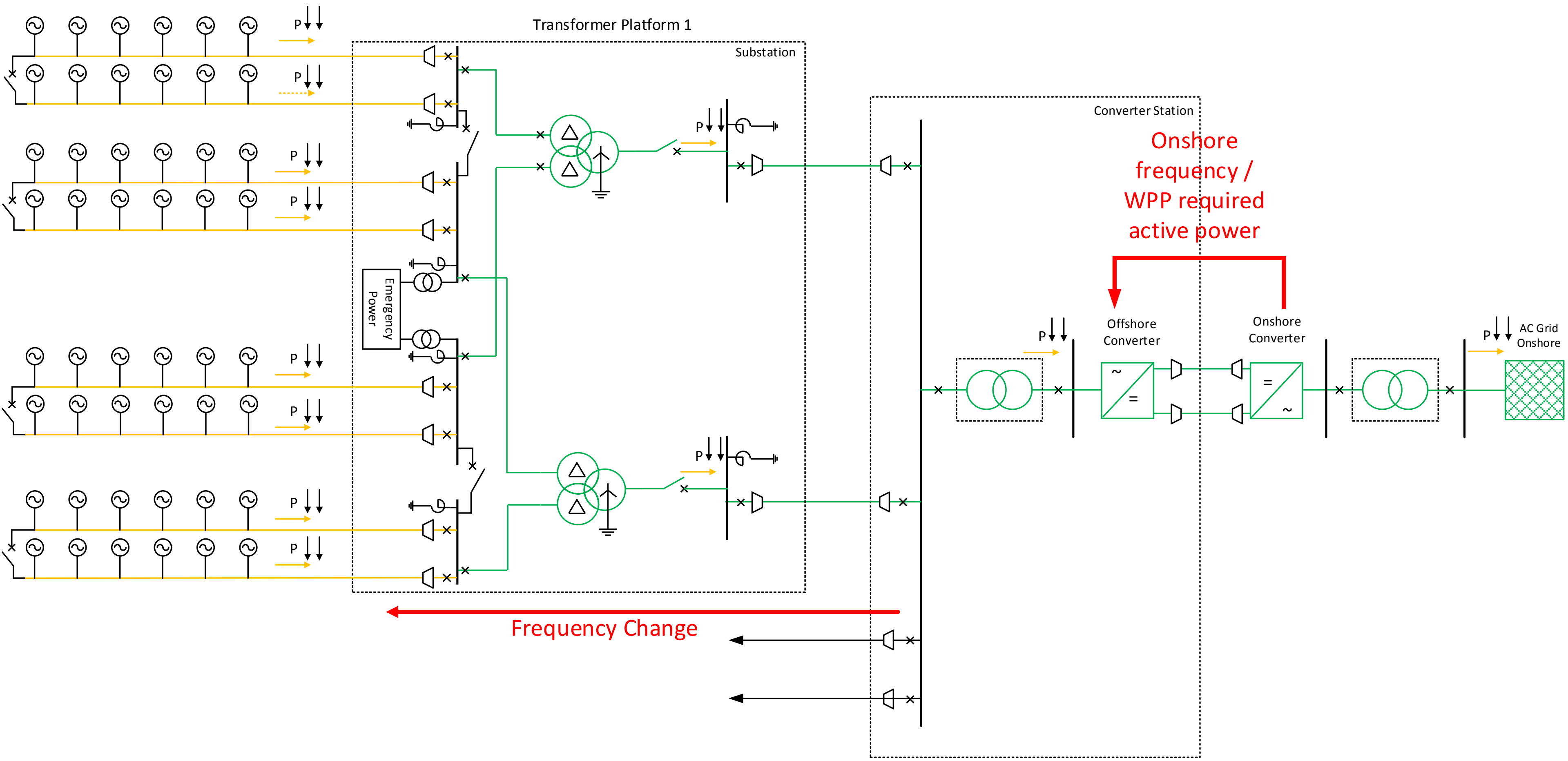
Draft from Cigré B4-55 WG “HVDC connection of offshore WPP”

Frequency response using WPP control



Draft from Cigré B4-55 WG “HVDC connection of offshore WPP”

Frequency response using VSC-HVDC converters



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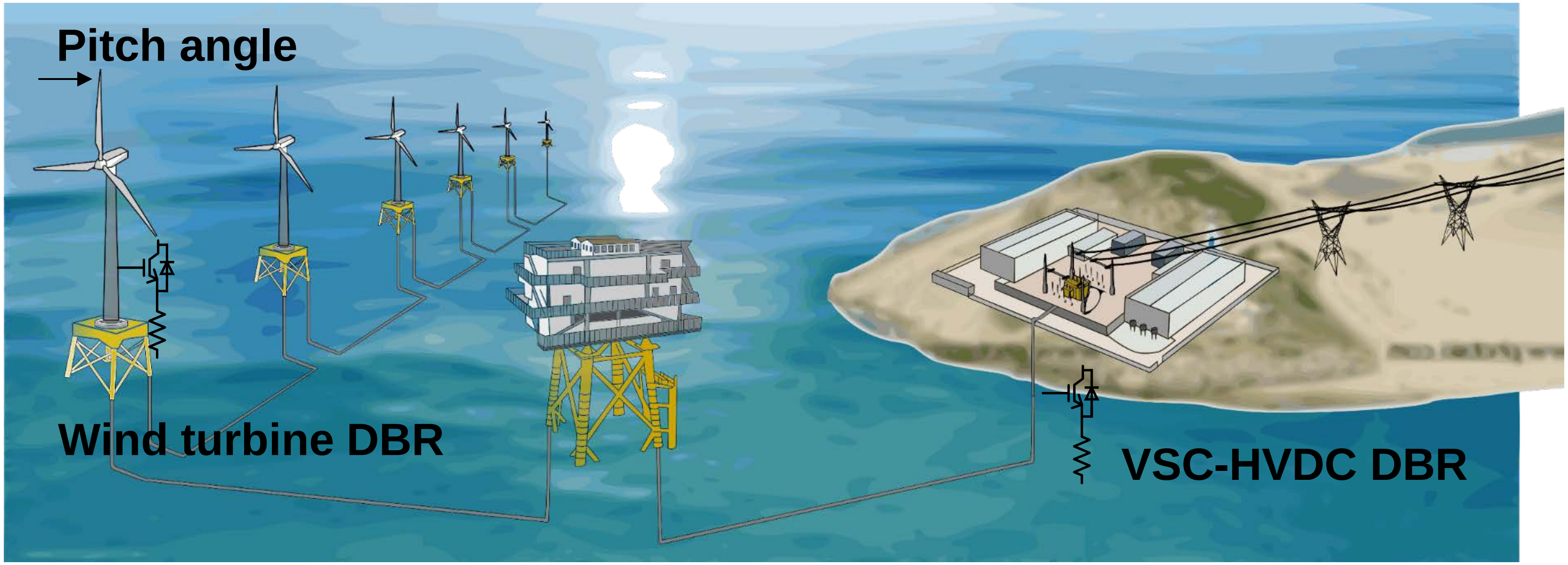
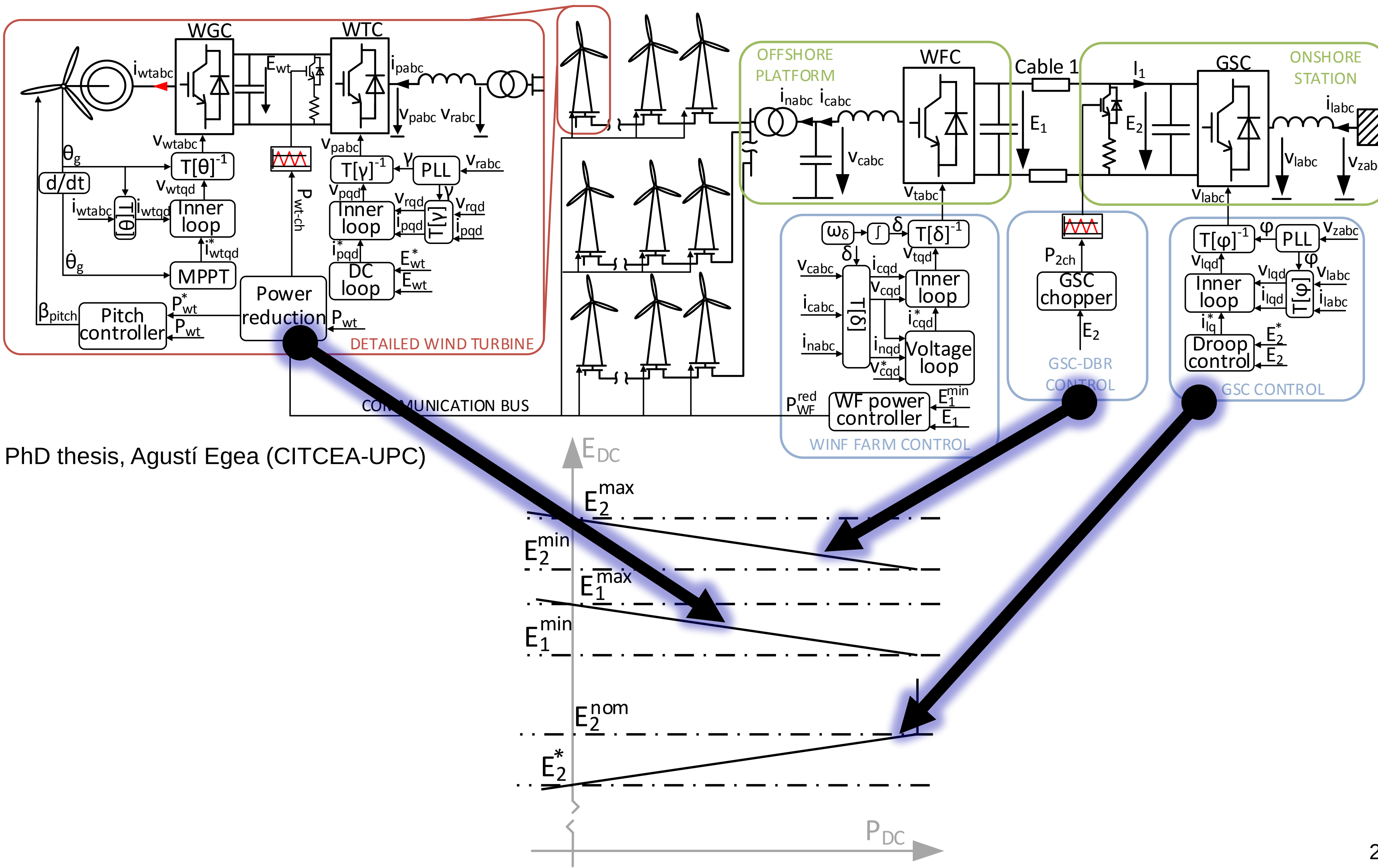
Example coordination for power reduction

- How can we provide power reduction (without fast communication between offshore and onshore VSC-HVDC)?
  - **Onshore VSC-HVDC DBR, fast but available limited time. (not offshore ->footprint!)**
  - **Wind turbine DBR, fast but available limited time.**
  - **Pitch angle. Slow response but good for steady-state.**
  - Fast wind turbine torque reduction with the power converter? Electrically possible, but not allowed. (Turbine loads)

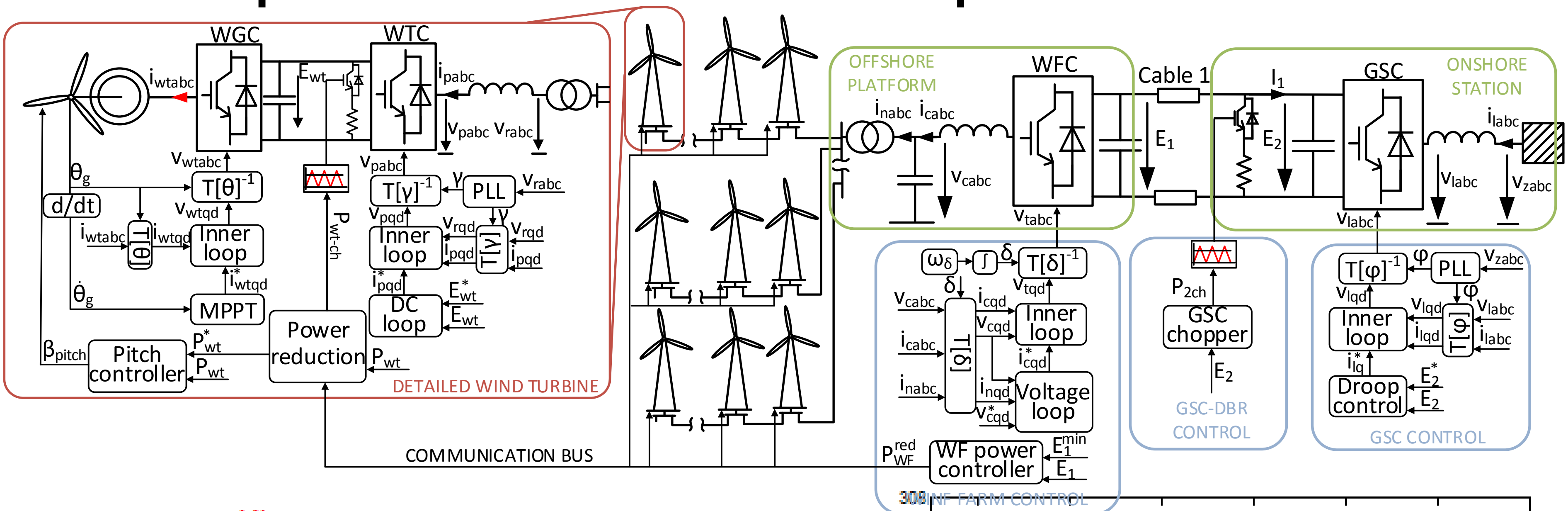


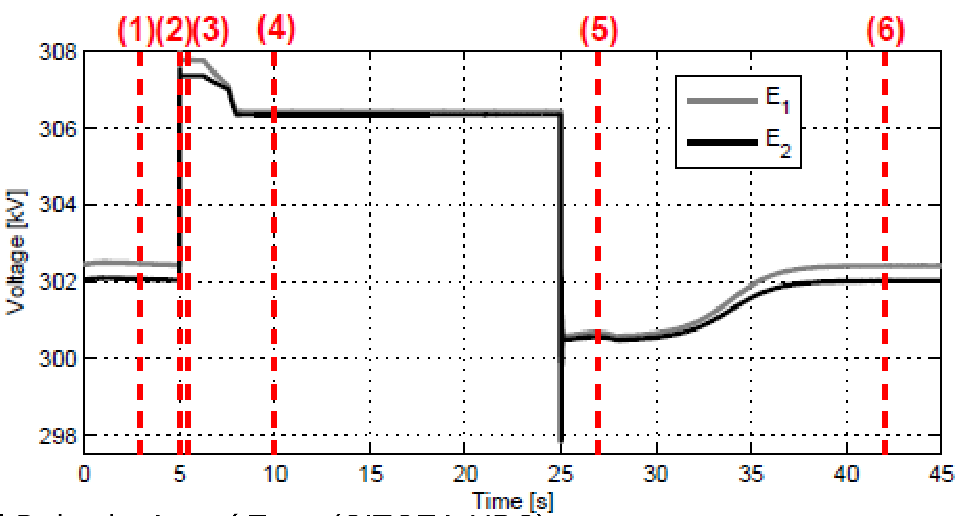
Example coordination for power reduction

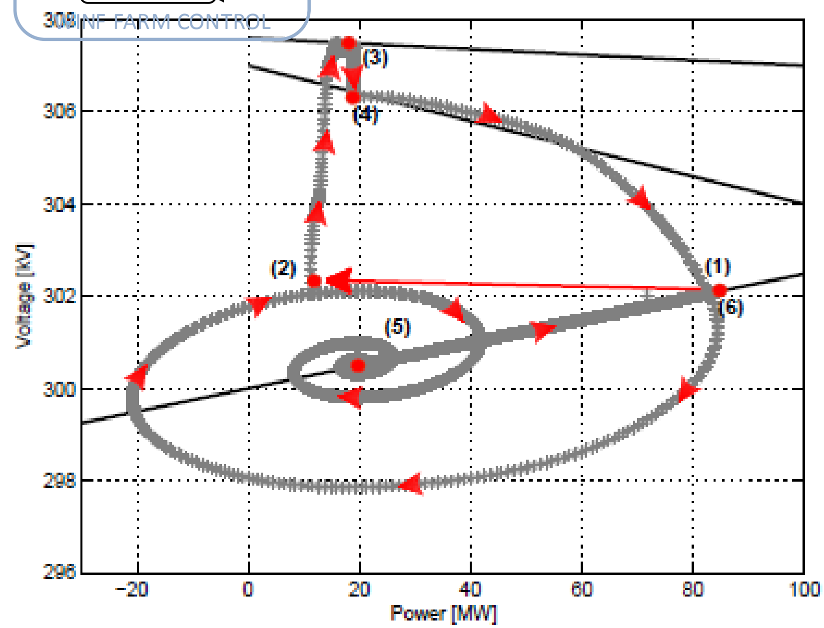


PhD thesis, Agustí Egea (CITCEA-UPC)

Example coordination for power reduction







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Conclusions

- Offshore wind power plants connected with VSC-HVDC have special characteristics:
  - The VSC-HVDC converter needs to create an offshore grid where the frequency can be freely chosen.
  - As the offshore grid is an only “power electronics” grid, the protections need to be carefully designed. Standard approaches may not be useful.
  - The interactions between wind turbines and VSC-HVDC converters need to be studied.
- Offshore wind power plants need to:
  - Collect the wind power and inject it in the HVDC cable
  - Provide support to the main AC grid and DC grid.
  - Maintain stability in normal and fault conditions

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Thanks for your attention!

oriol.gomis@upc.edu