Power quality in offshore grids

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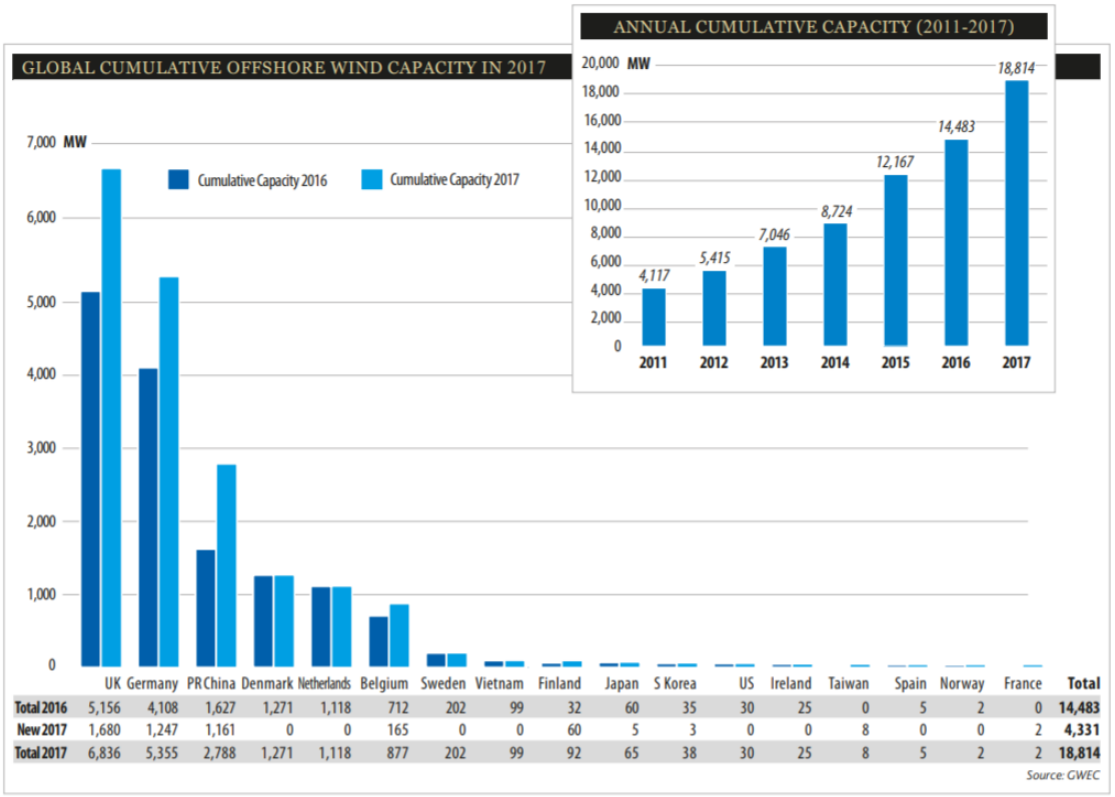
Trondheim, 17 January 2019

Presentation lay-out

- Trends in offshore generation
- Overview of power quality issues in offshore grids:
  - in distribution systems
    - Offshore wind farms
    - Other marine energy farms
    - Oil and gas platforms
  - in transmission systems
- Conclusions

Offshore wind - Trends

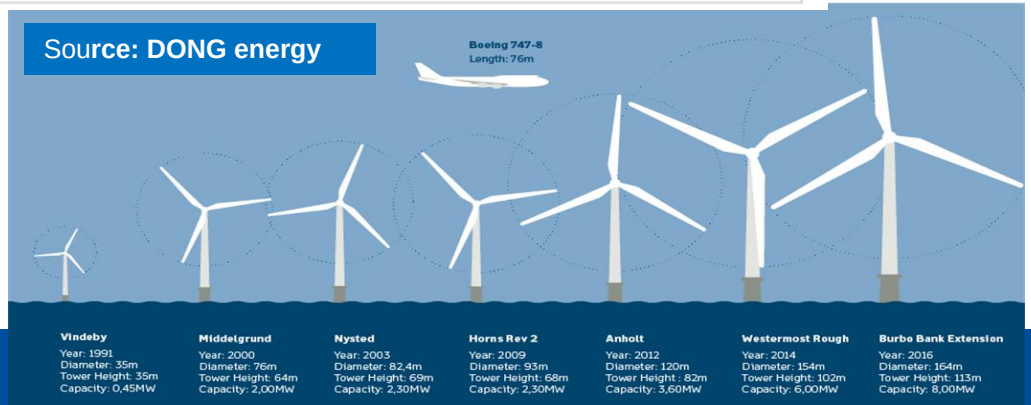


	UK	Germany	PR China	Denmark	Netherlands	Belgium	Sweden	Vietnam	Finland	Japan	S Korea	US	Ireland	Taiwan	Spain	Norway	France	Total
Total 2016	5,156	4,108	1,627	1,271	1,118	712	202	99	32	60	35	30	25	0	5	2	0	14,483
New 2017	1,680	1,247	1,161	0	0	165	0	0	60	5	3	0	0	8	0	0	2	4,331
Total 2017	6,836	5,355	2,788	1,271	1,118	877	202	99	92	65	38	30	25	8	5	2	2	18,814

Source: GWEC

Offshore wind represents 3.5% of the global installed wind capacity

In Europe, offshore wind is expected to increase from 15.8 GW in 2017 to 66 GW in 2030



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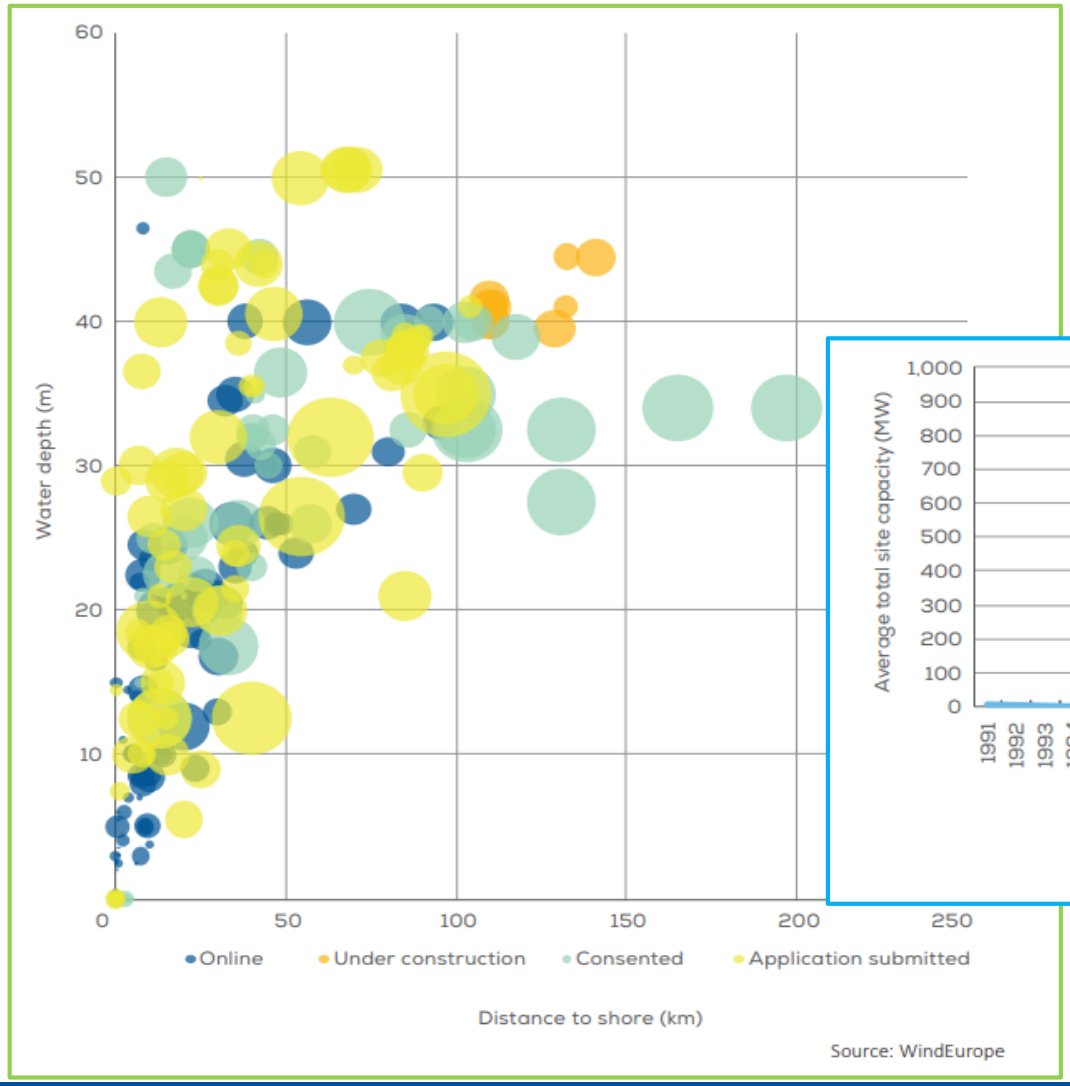
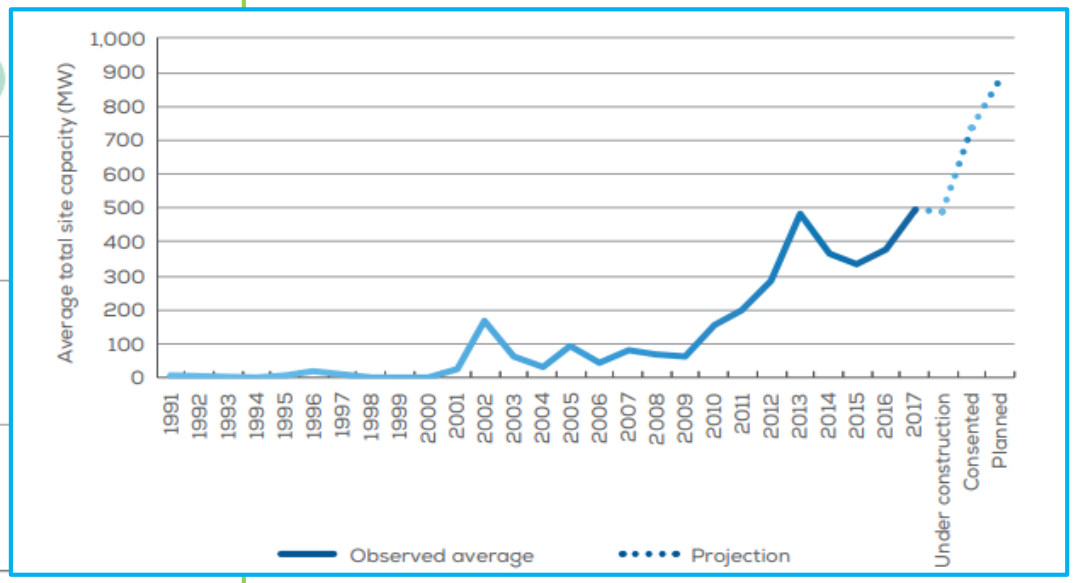
Offshore wind development



Increasing wind farm capacity, water depth and distance from shore



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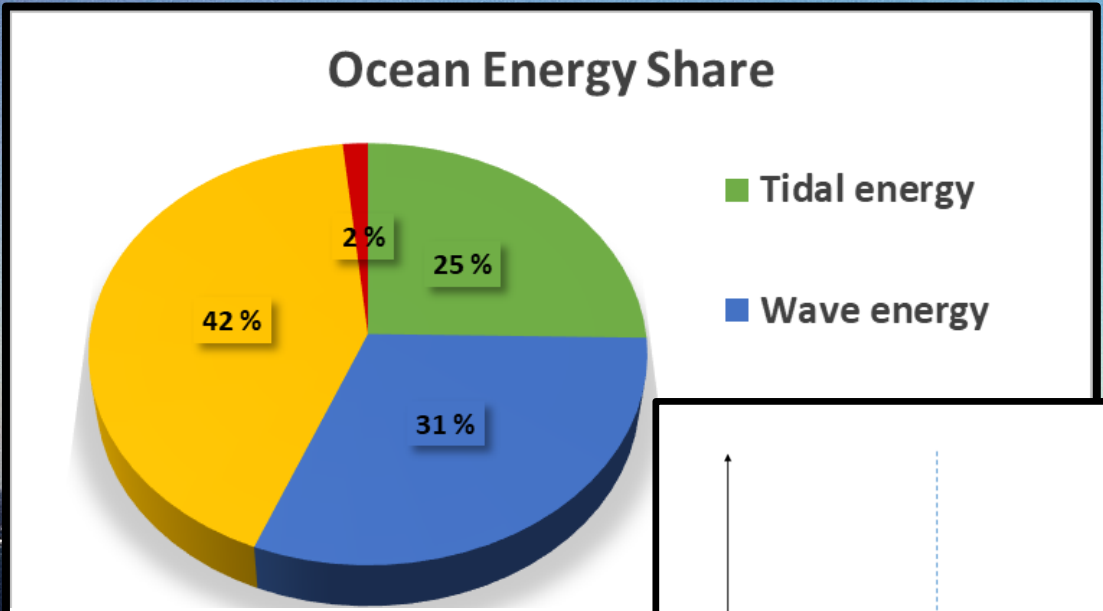
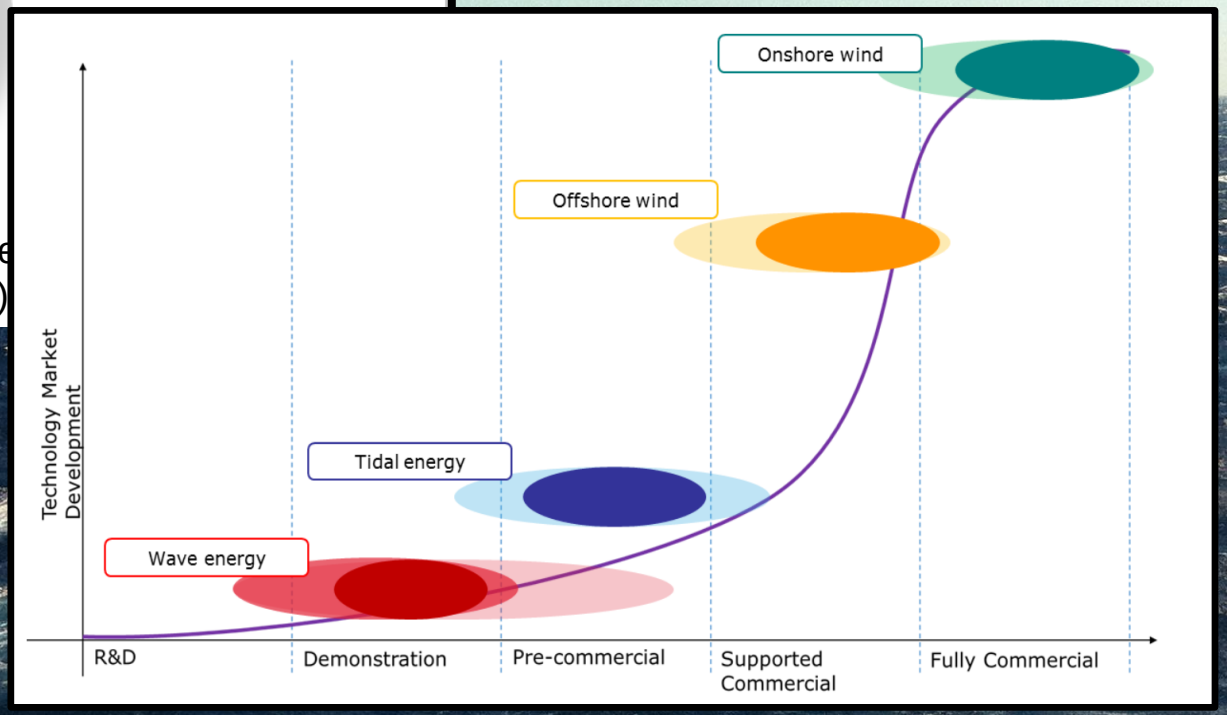
Marine Energy - Background



Source: IPCC Special Report on Rene
and Climate Change Mitigation (2011)

Lower technological maturity than other renewables



Source: D. Magagna, JRC, European Commission (2017)

Possibility to reach 100 GW of installed power by 2050

Power quality (PQ) in offshore grids

Power quality

- Voltage variations
- Voltage fluctuations (flicker)
- Waveform distortion
- Frequency variation
- Reactive power
- Unbalance

High

Penetration Level

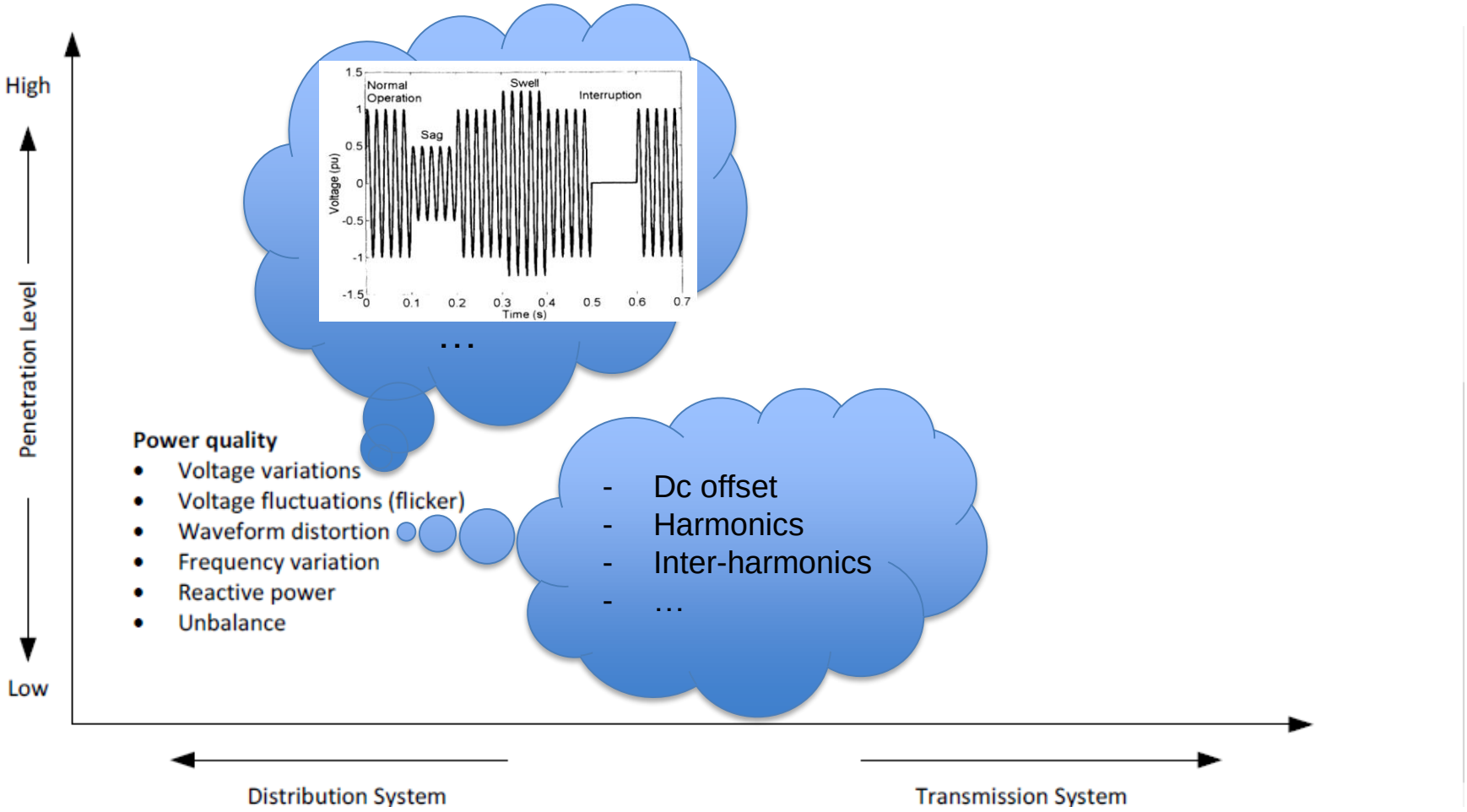
Low

Distribution System

Transmission System

*excluding transients events

Power quality (PQ) in offshore grids



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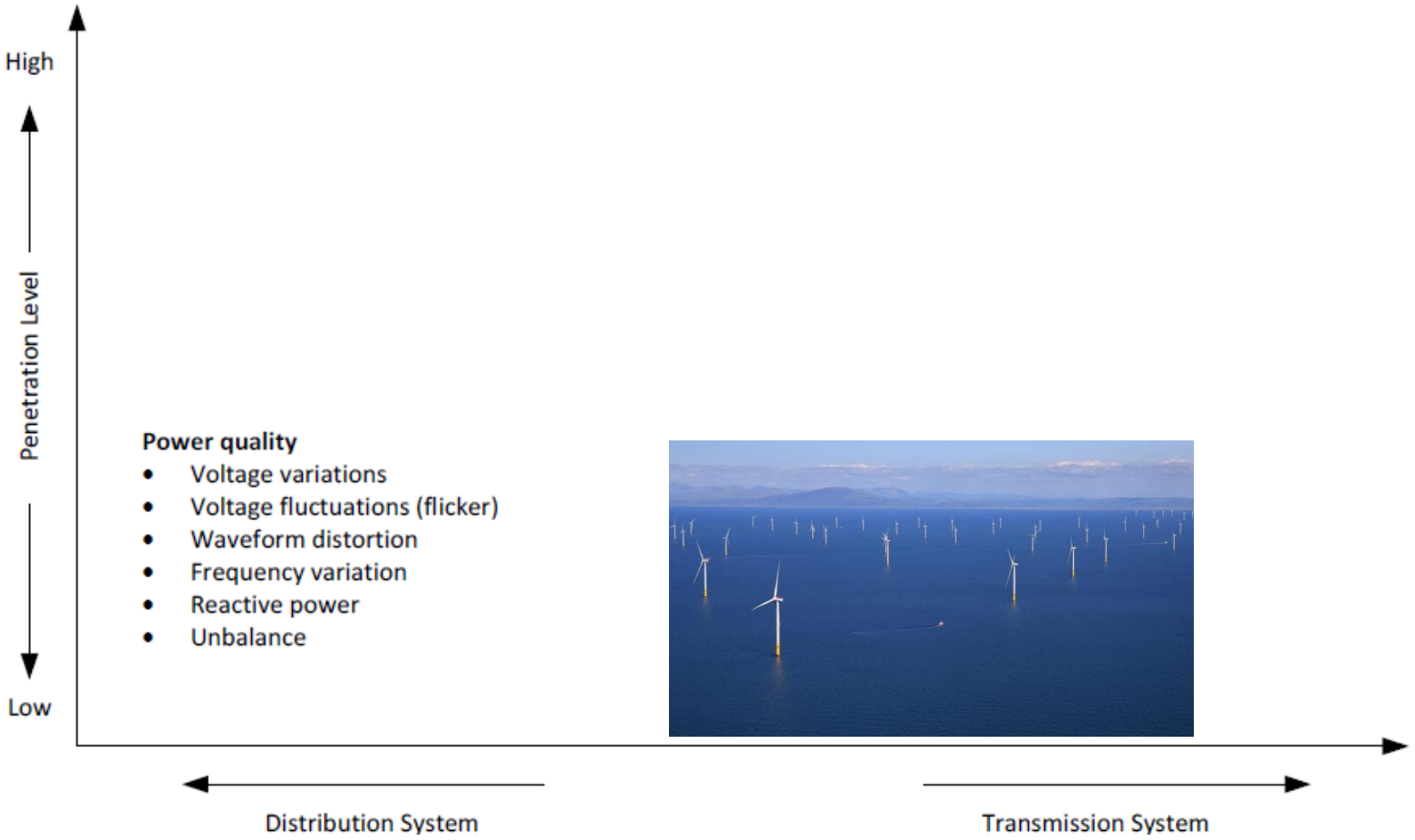

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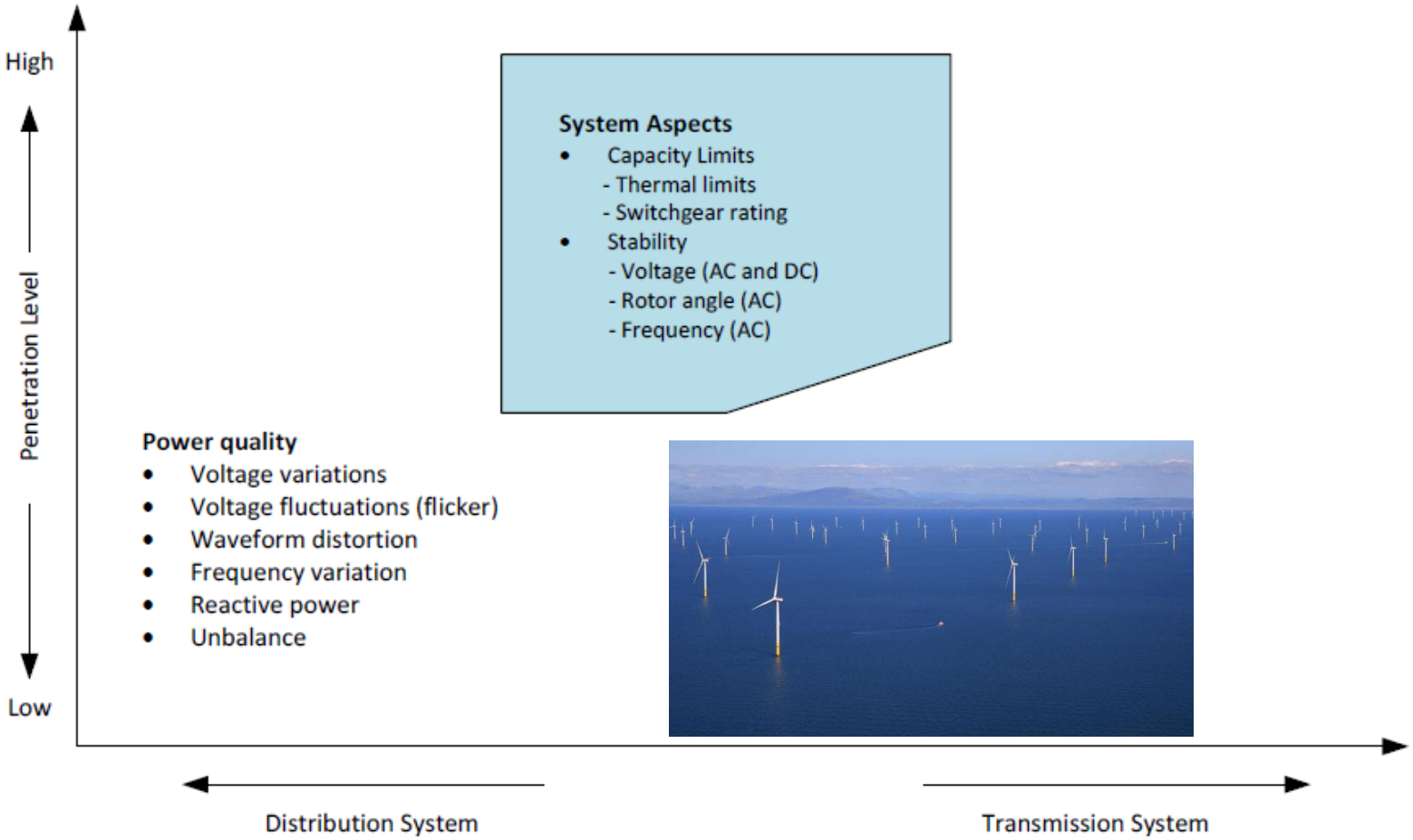

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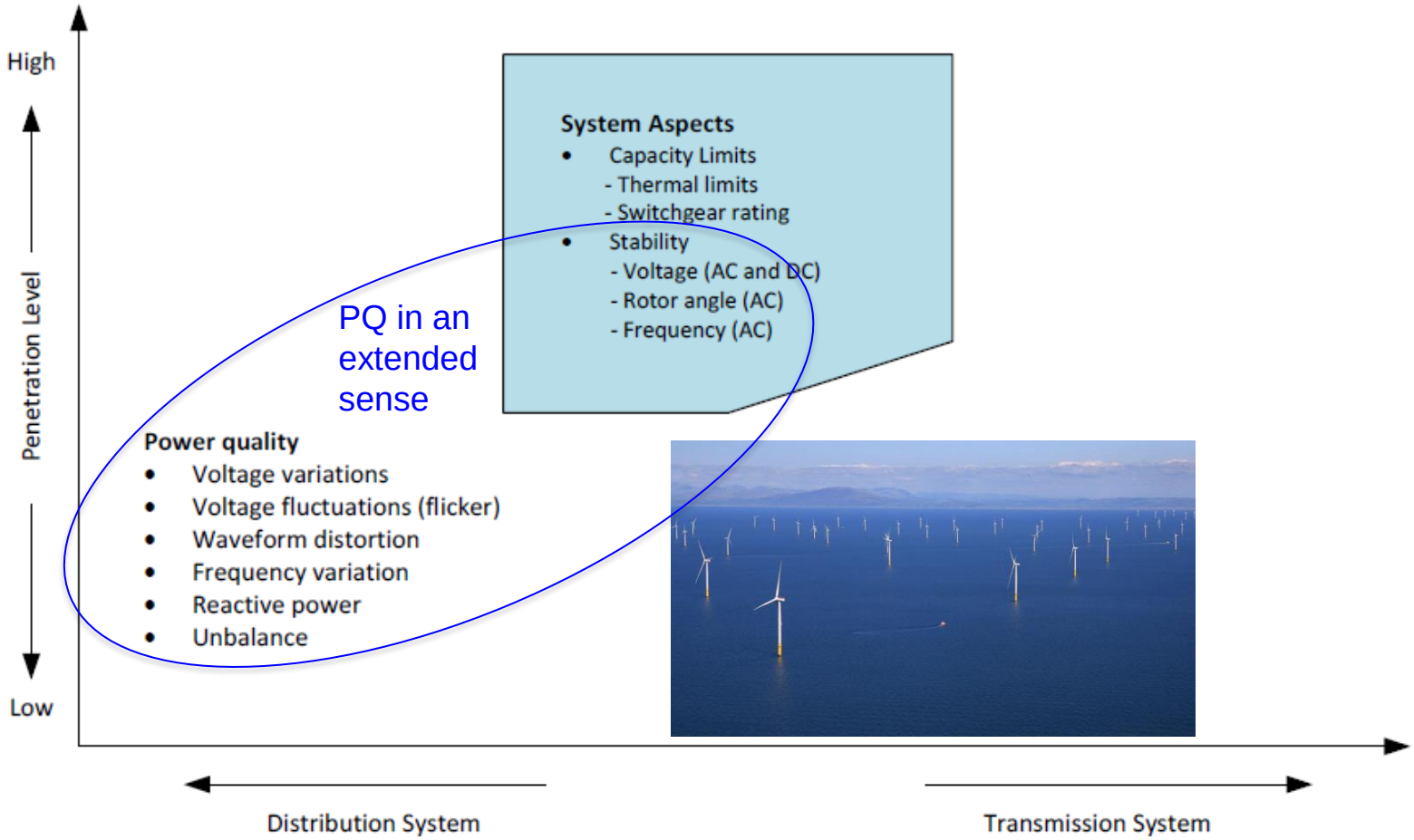

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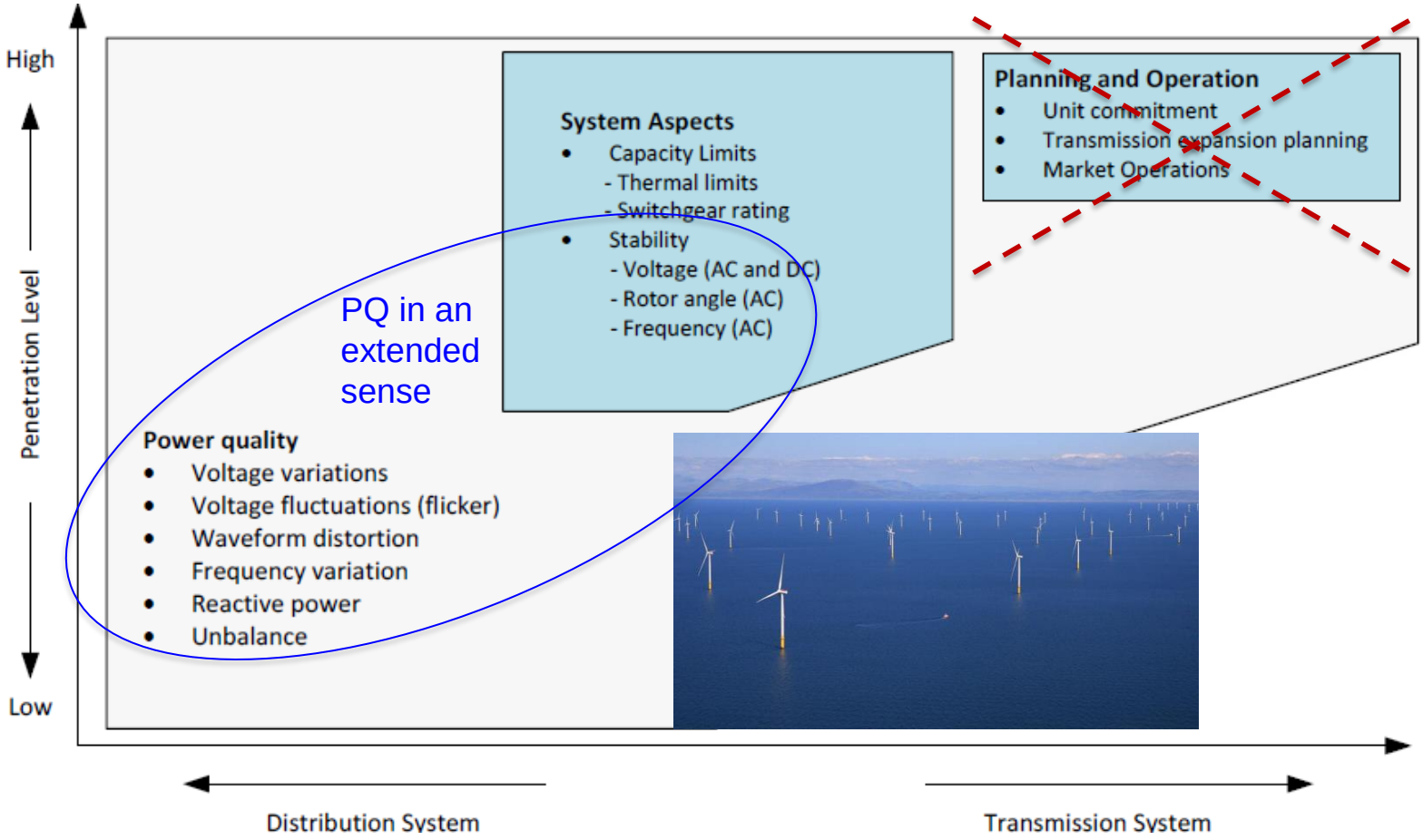

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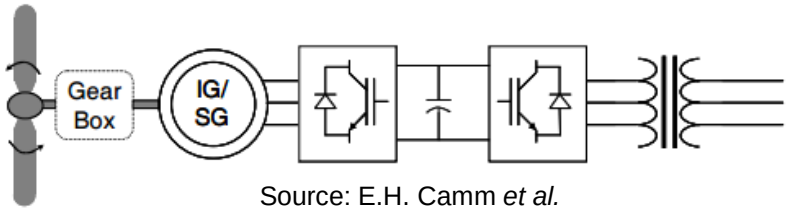
A. A. Taffese, E. Tedeschi, “Electrical Power Transmission and Grid Integration”, Chapter 8 of the book “Renewable Energy from the Oceans: From wave, tidal and gradient systems to marine-based wind and solar” Institution of Engineering and Technology (IET) (2019 - *in press*)

PQ in AC offshore grids: wind farms

Waveform distortion

The type of (generators,) power electronic interfaces and their control impact the harmonic generation…

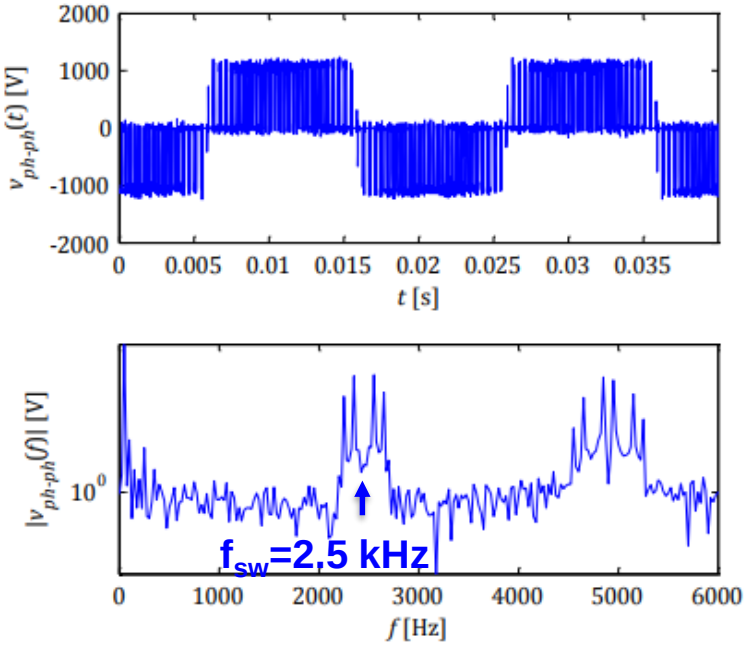
Type 4 Wind turbine



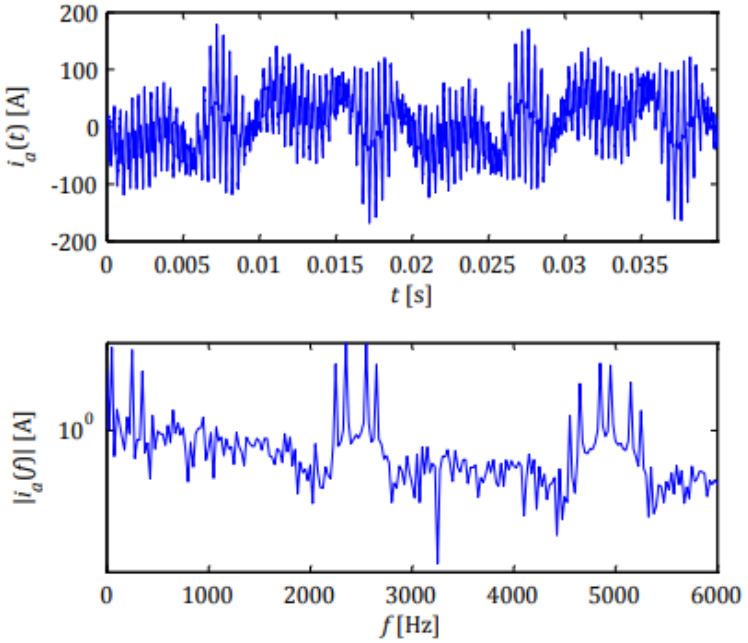
Source: E.H. Camm *et al.*

Measurements at Gunfleet Sands wind farm (low production)

Voltage



Current



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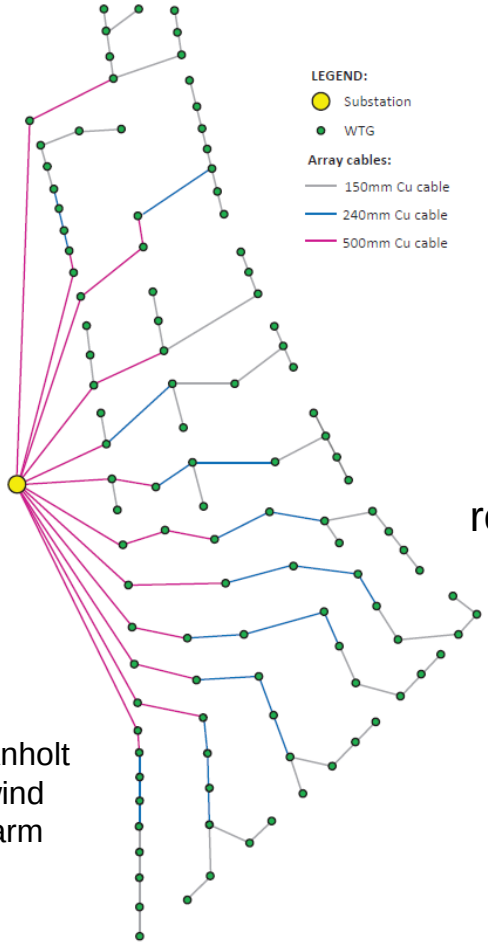
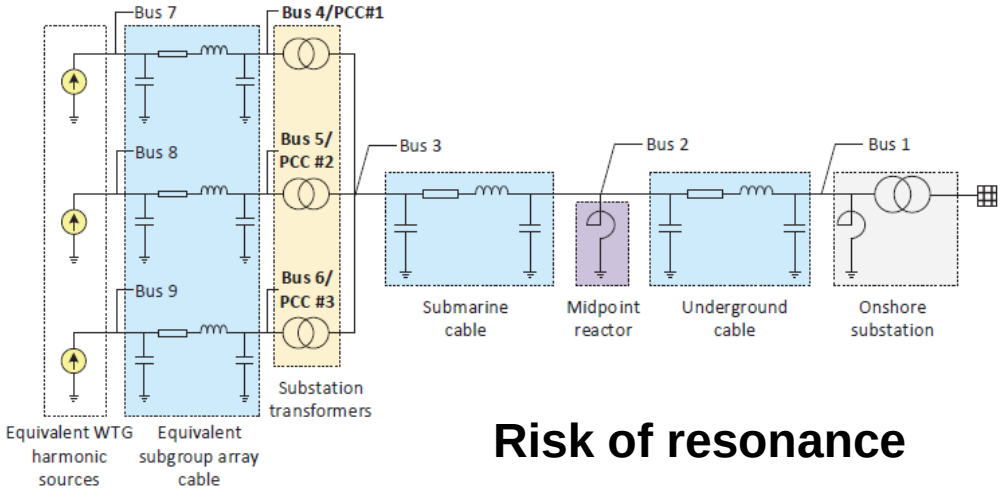
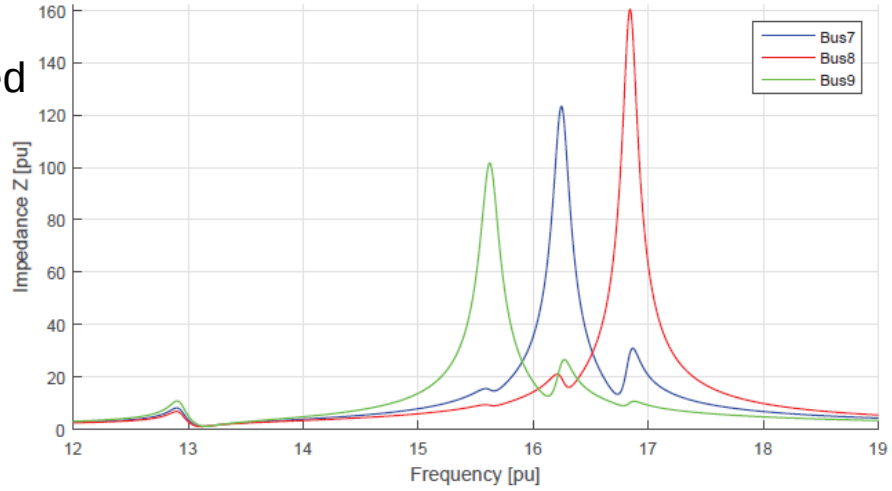


Anholt wind farm



Risk of resonance

Driving impedance and resonance are affected by environmental factors, n. of turbines in operation, farm configura-tion etc.

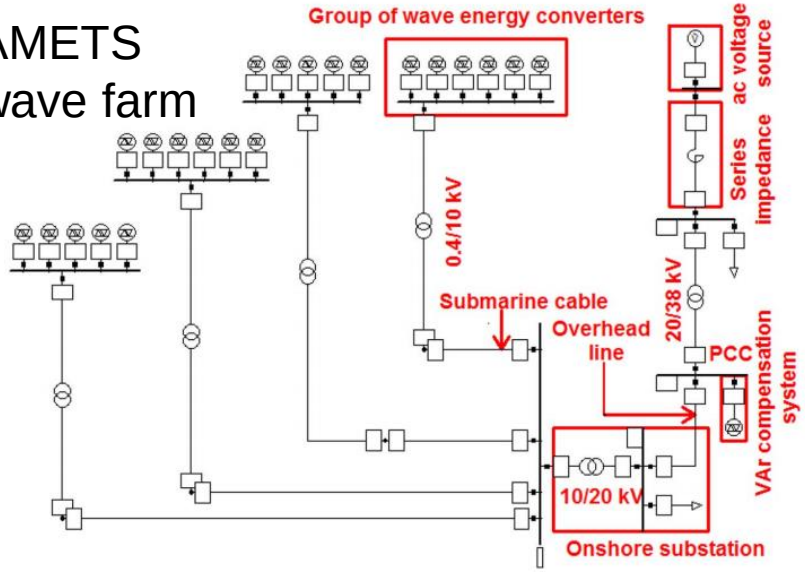


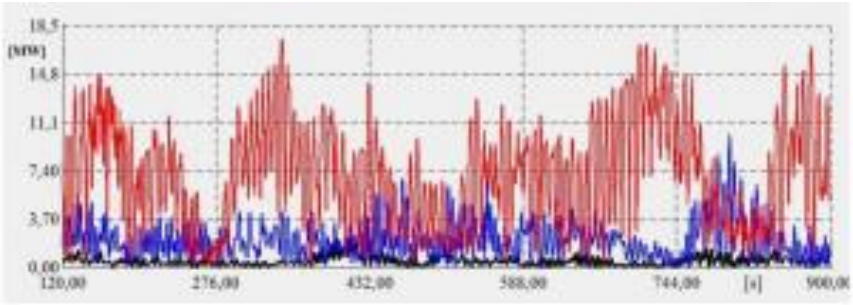
H. Brantsæther, “Harmonic Resonance Mode Analysis and Application for Offshore Wind Power Plants”. MSc Thesis, Department of Electric Power Engineering, NTNU, 2015.

PQ in AC offshore grids: wave farms

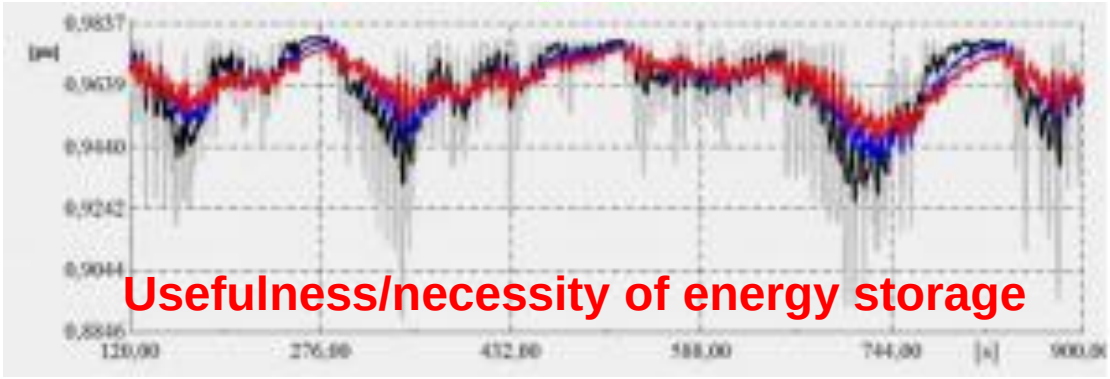
Flicker and voltage variations

AMETS wave farm

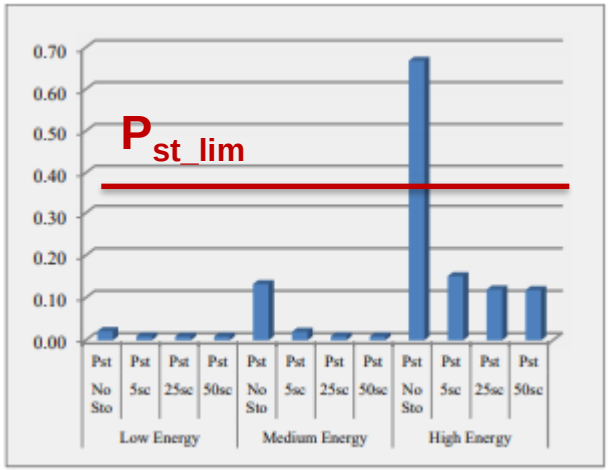




Power variability due to resource intermittency



Usefulness/necessity of energy storage

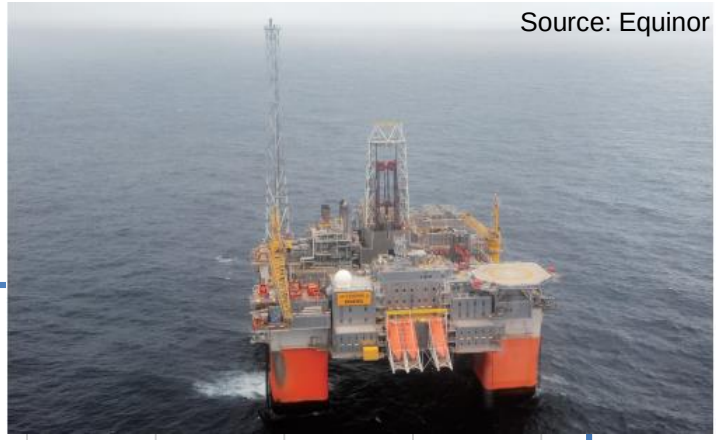


Criticality of voltage fluctuations

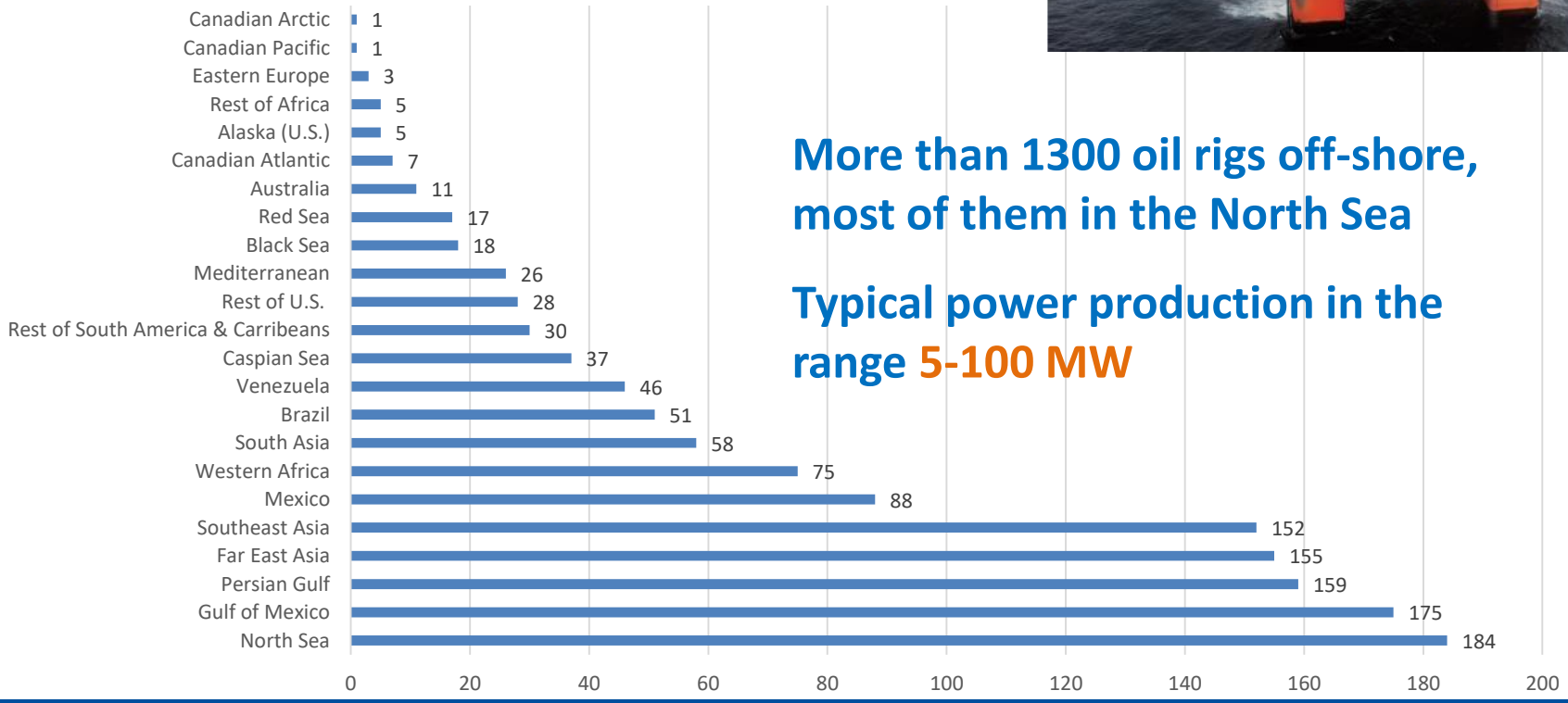
M. Santos, A. Blavette, E. Tedeschi, D. O'Sullivan, F. Salcedo, "Case studies on the benefits of energy storage for power quality enhancement: point absorber arrays" 4th International Conference on Ocean Energy 2012 (ICOE12), Dublin, 17-19 October 2012

Offshore Oil and Gas - Status

Offshore production accounts for 30% of global oil production and 27% of global gas production


Source: Equinor

Number of offshore rigs (January 2018)

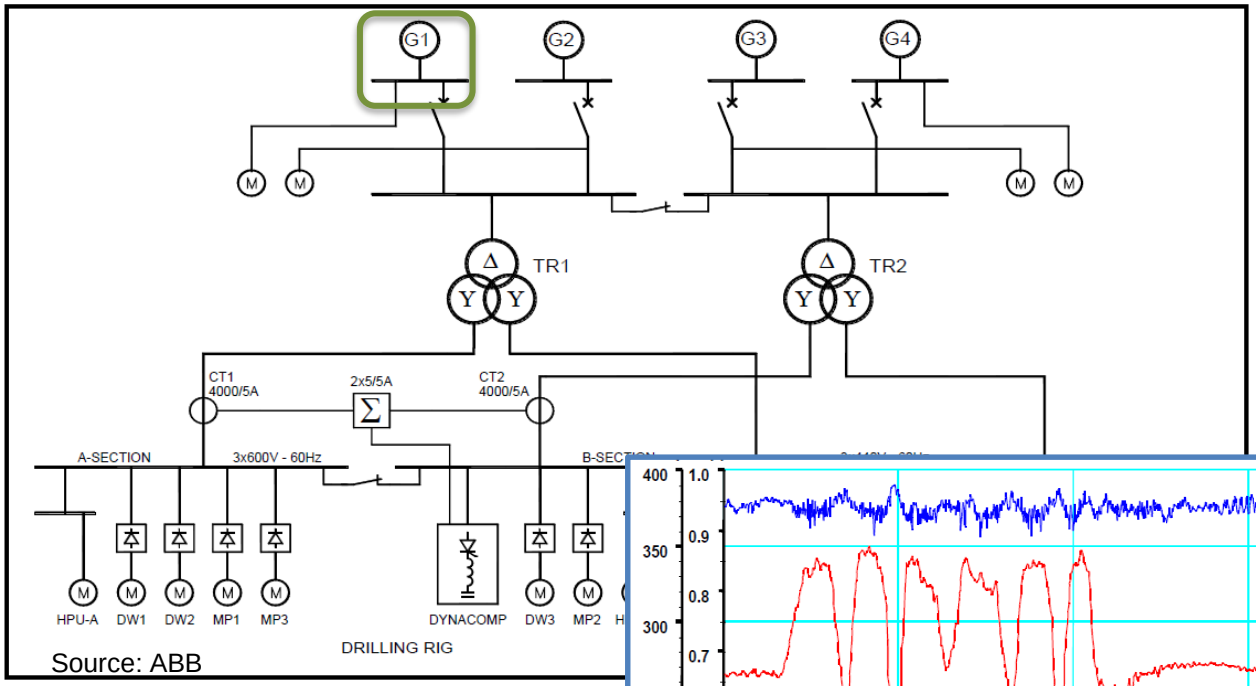


More than 1300 oil rigs off-shore, most of them in the North Sea

Typical power production in the range 5-100 MW

Source: Statista (2018)

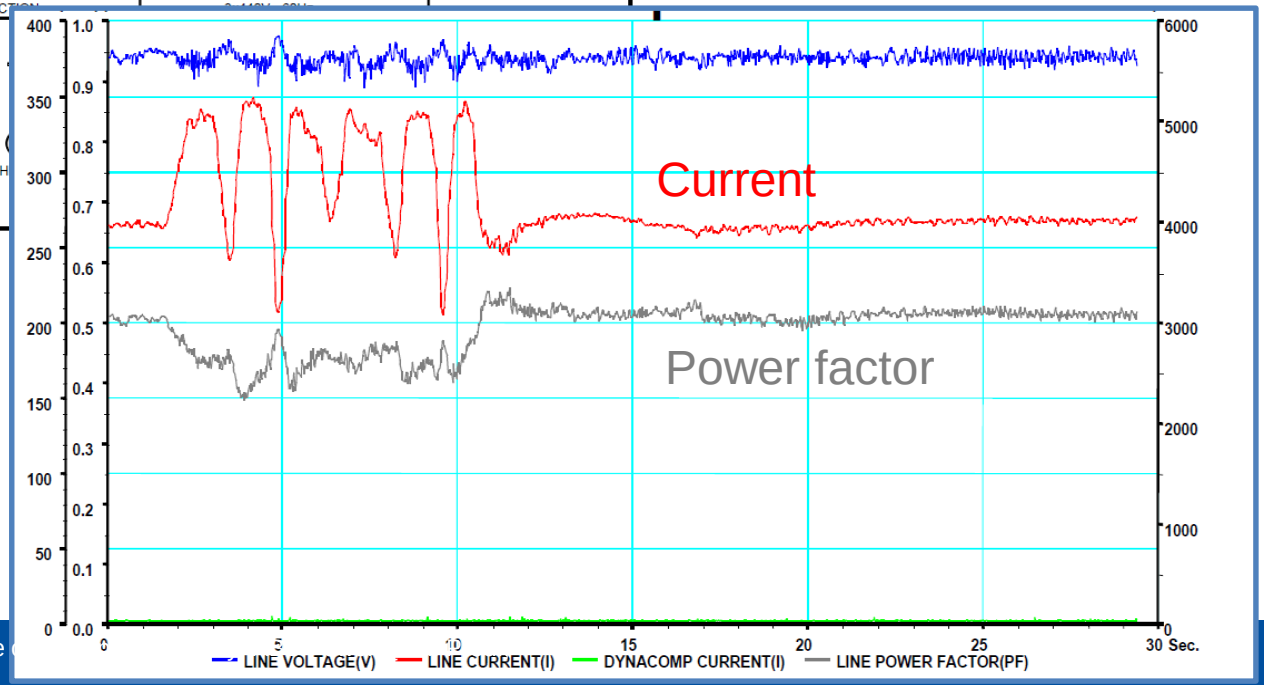
Electrical power system on O&G rigs



Source: ABB

O&G platforms can be classified as electrically «weak grids»

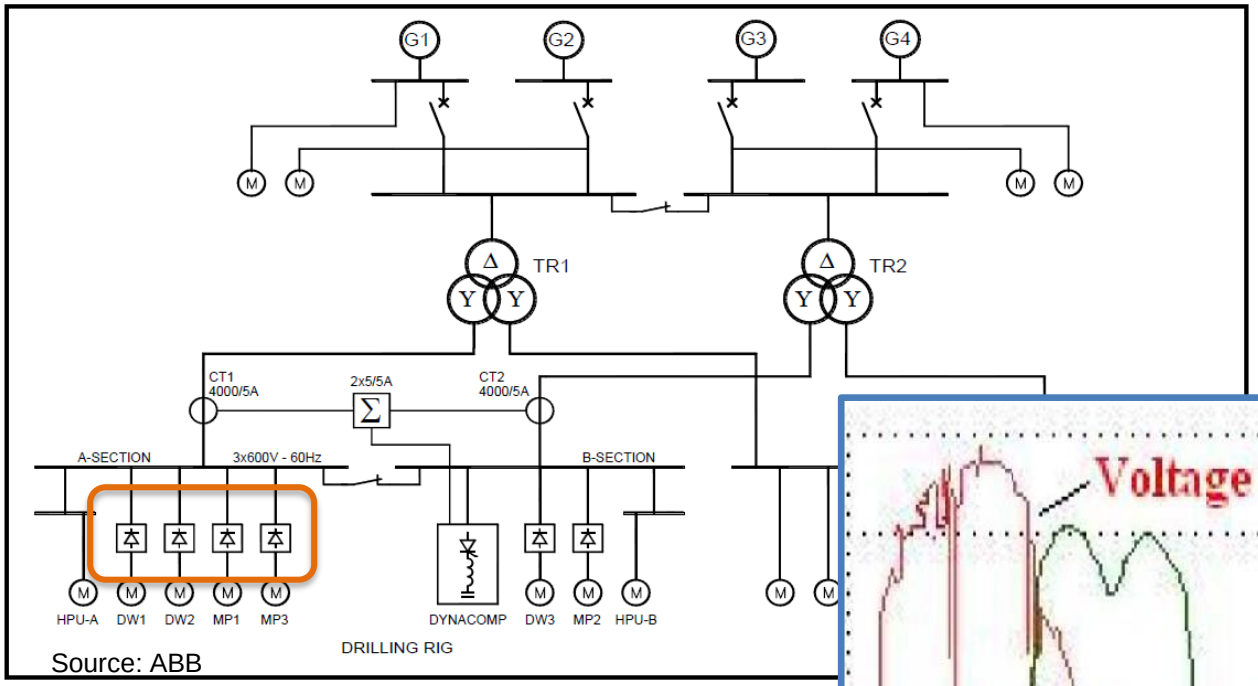
Power quality is low



- High reactive power demand/low power factor

Schipman, K., & Delincé, F. (2010). The importance
Charleroi, Belgium, ABB Review

Electrical power system on O&G rigs



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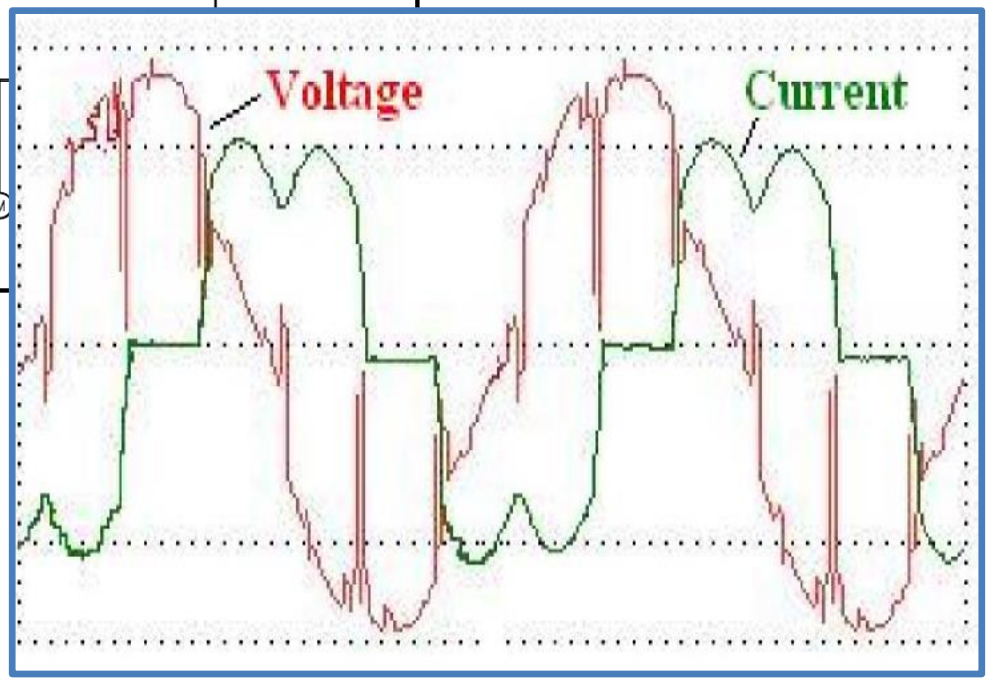


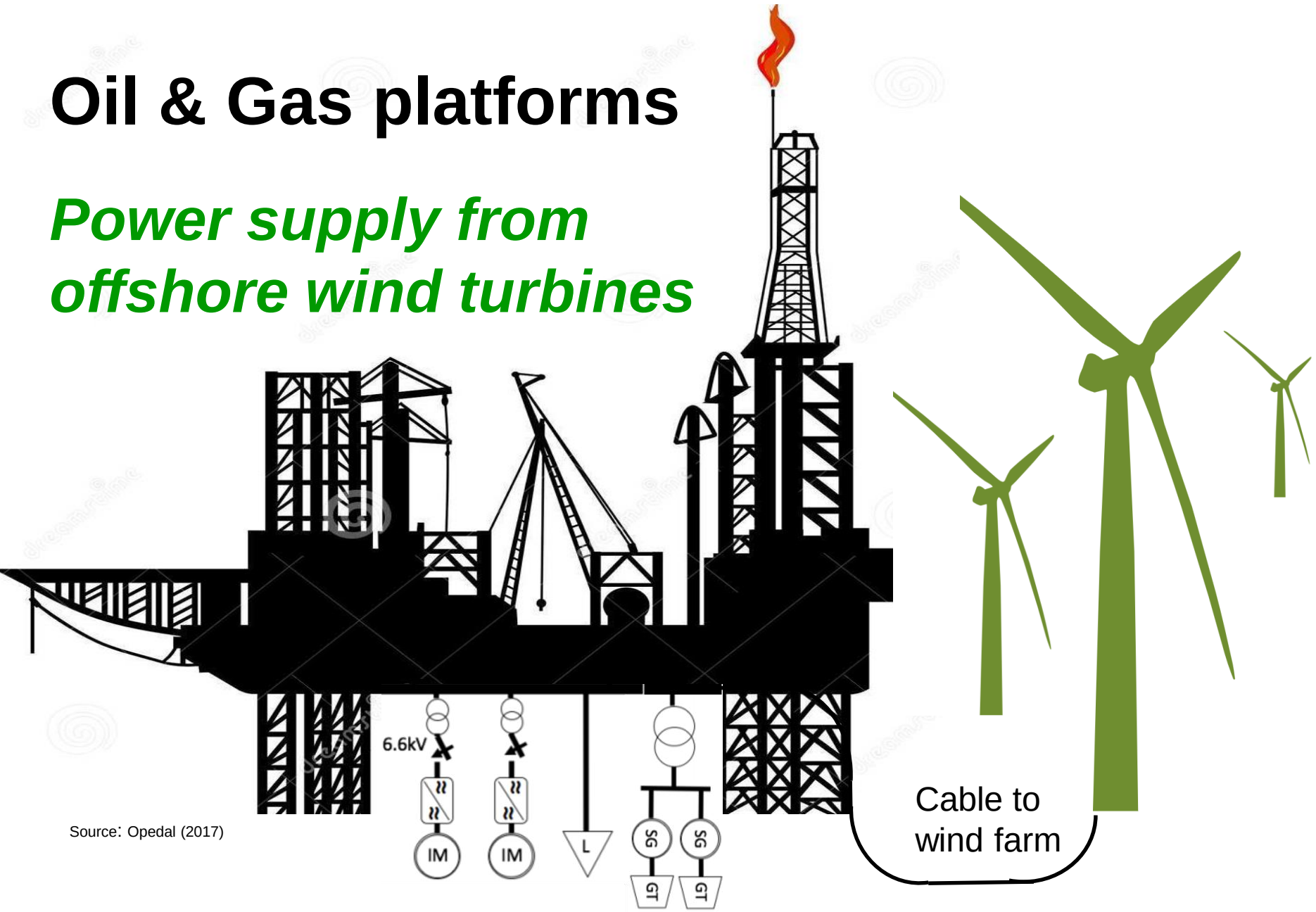
- **Voltage notching**

Estimated financial loss (2010) for incidents due to poor power quality in O&G is 250-750 KEUR/day

Evans, I. C., & Richards, M. J. (2011, April). The price of poor power quality. In 2011 AADE National Technical Conference (pp. 1-17).

Oil & Gas platforms

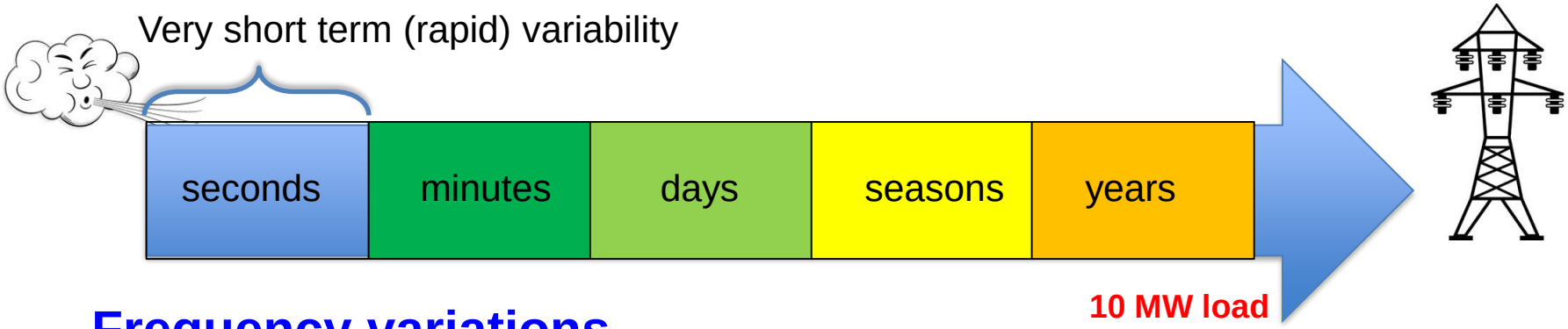
Power supply from offshore wind turbines



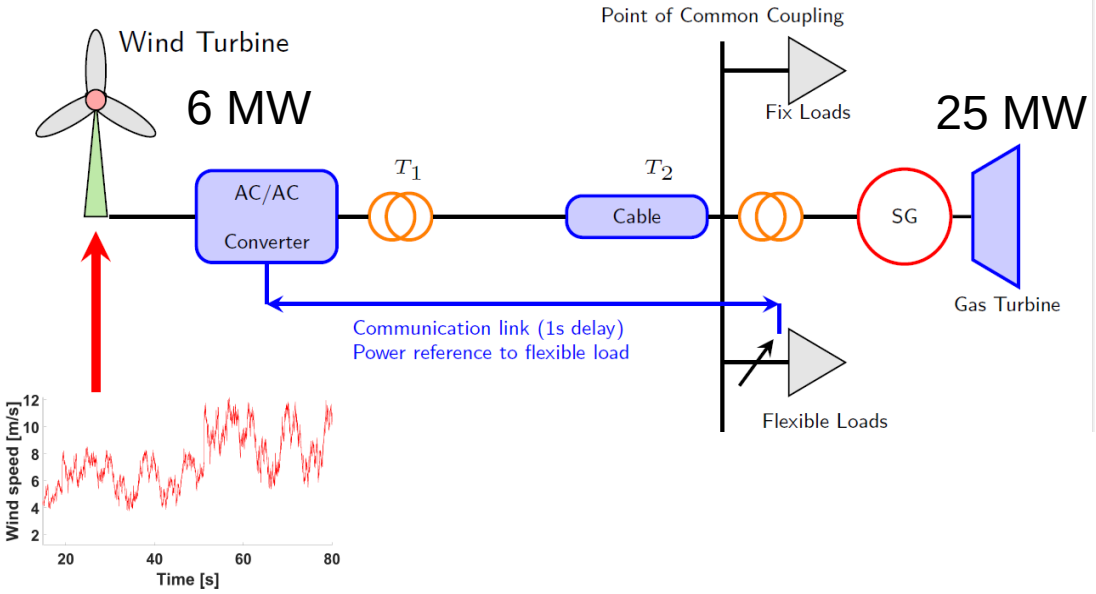
Source: Opedal (2017)

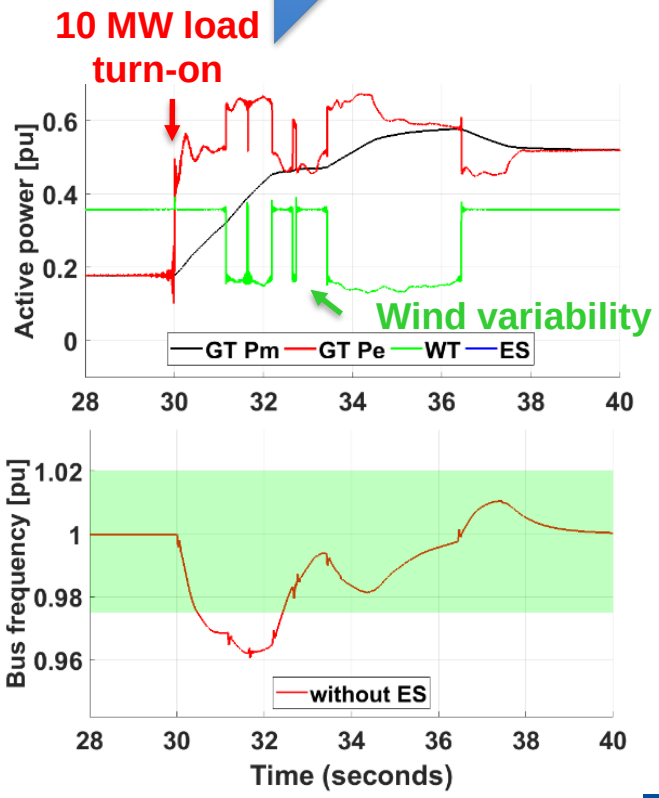
Effect of the wind variability

Very short term (rapid) variability



Frequency variations





S. Sanchez, E. Tedeschi, J. Silva, M. Jafar and A. Marichalar, "Smart load management of water injection systems in offshore oil and gas platforms integrating wind power," in *IET Renewable Power Generation*, vol. 11, no. 9, pp. 1153-1162, 12, 7 2017.

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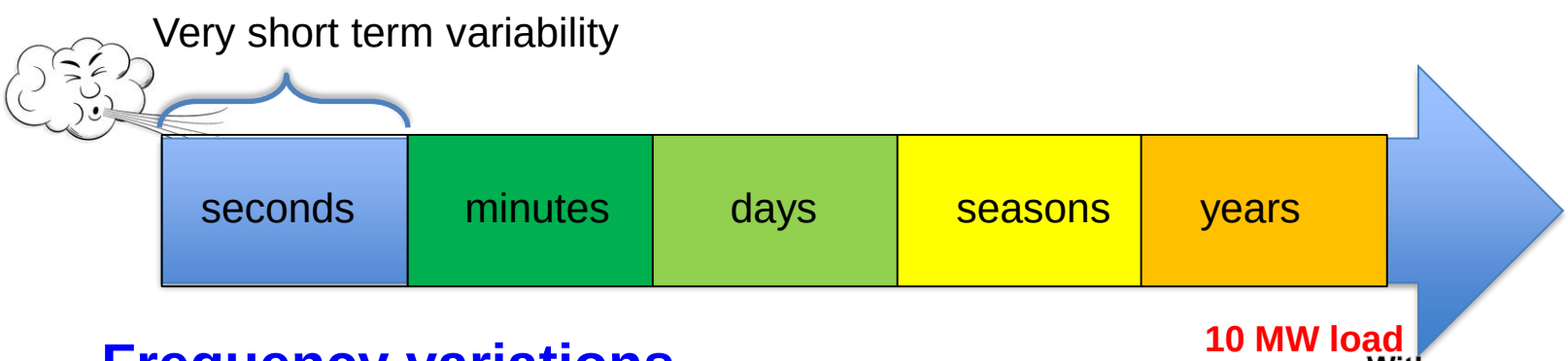

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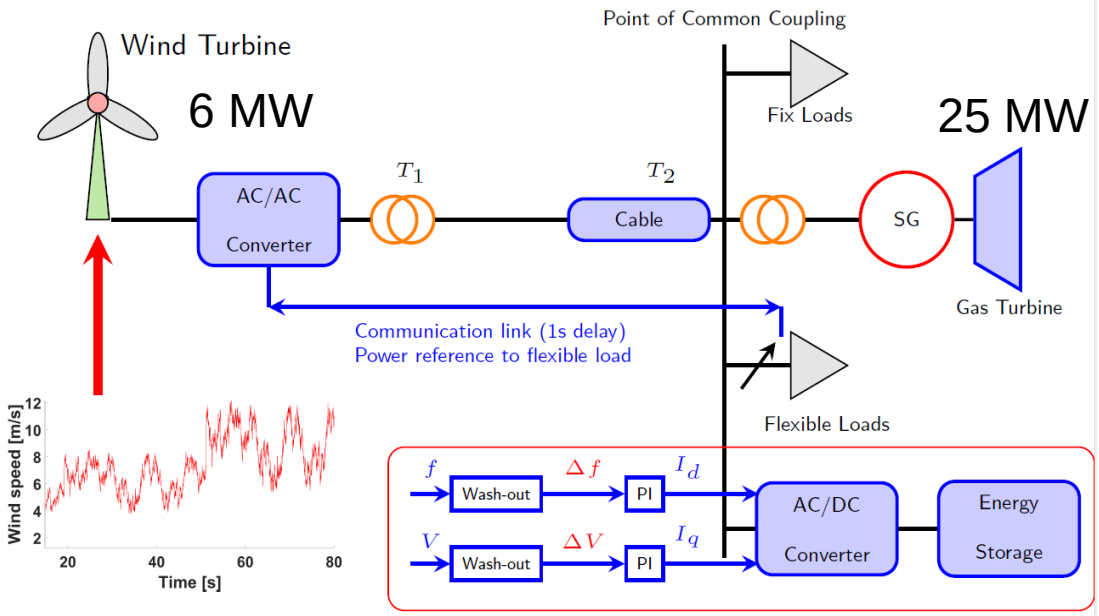
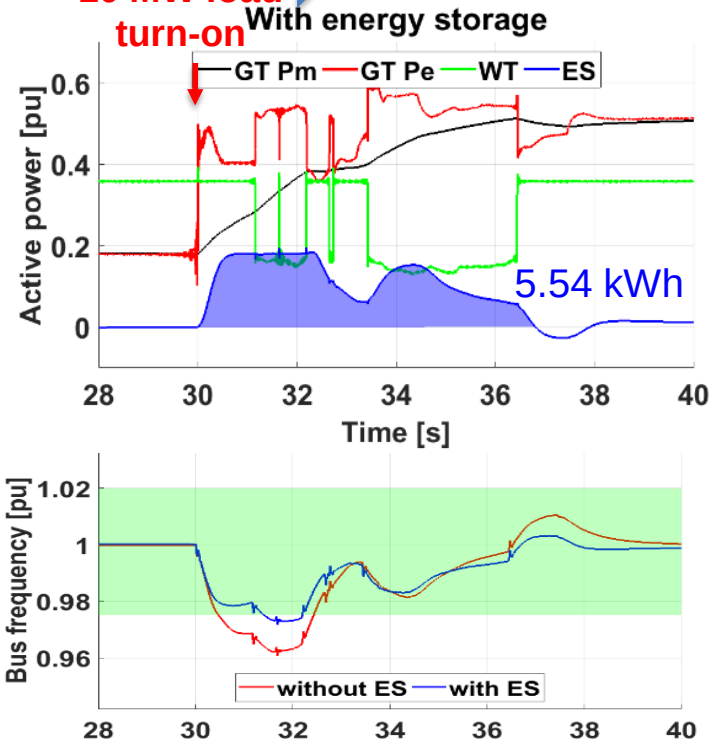


Inertial and voltage support



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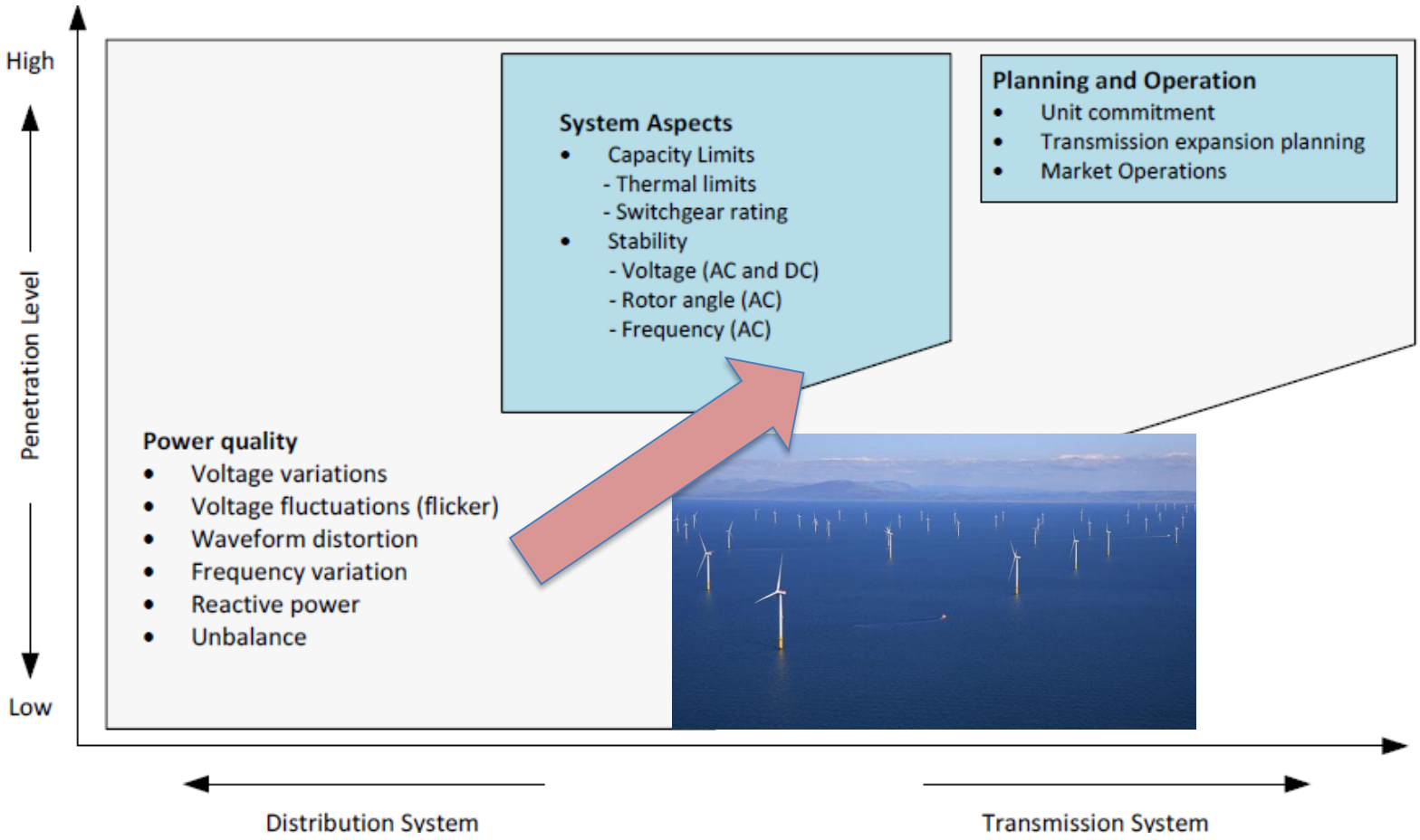
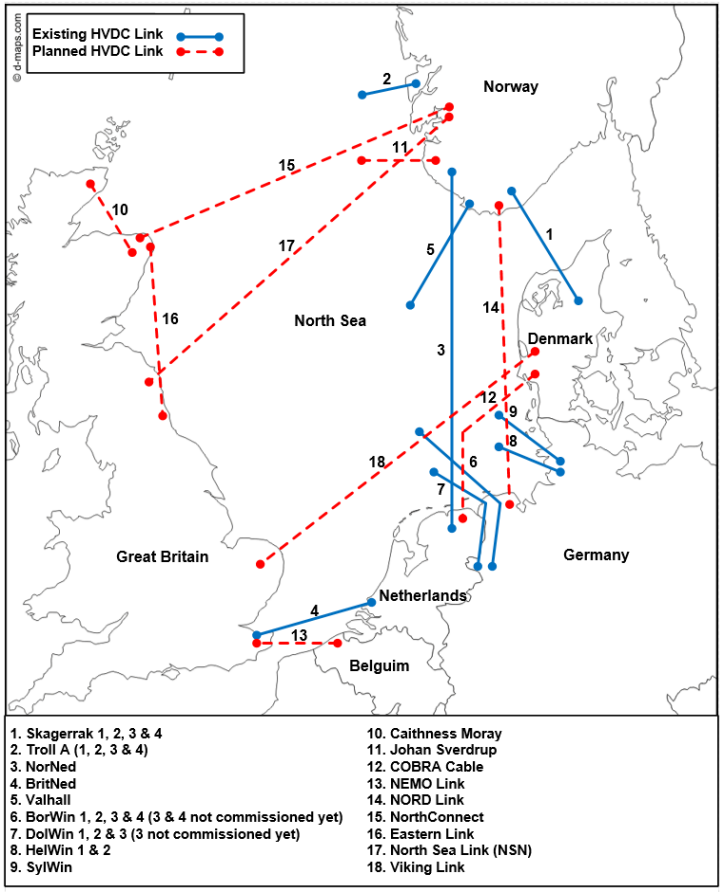
Power quality (PQ) in offshore grids

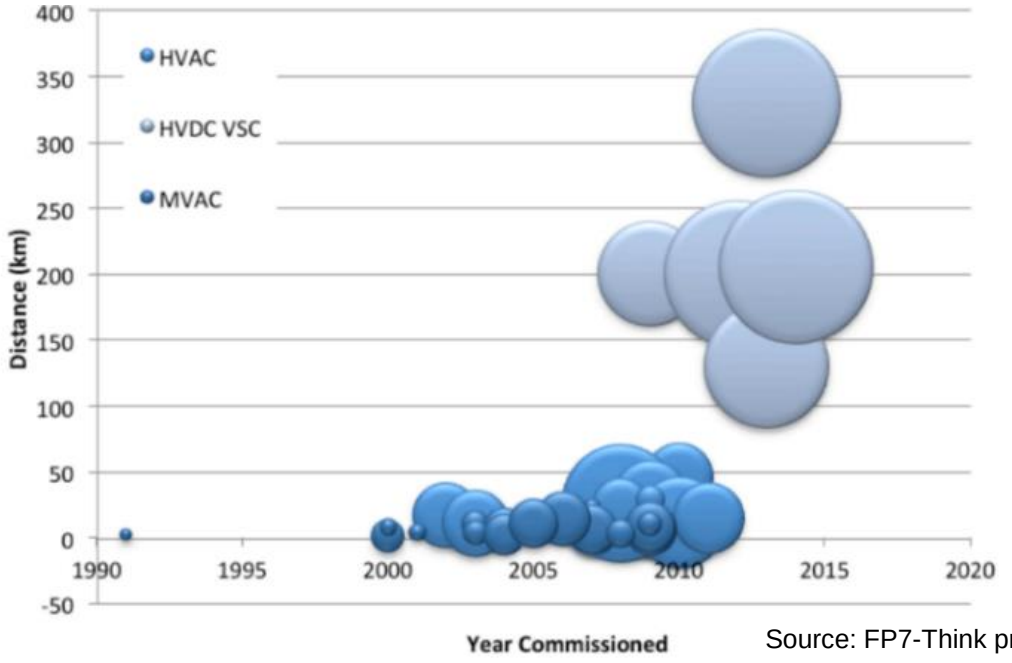


*excluding transients events

Offshore transmission - Trends

Technology shift from HVAC to HVDC transmission





Source: FP7-Think project

Increasing number of HVDC links in the North Sea

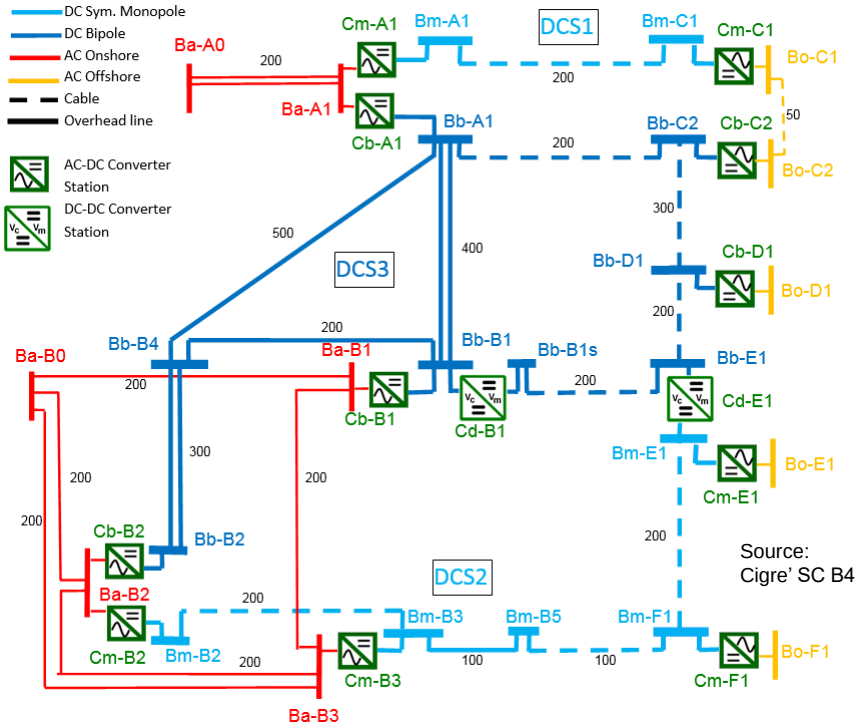
Power quality in (HV)DC offshore grids

The concept of PQ in DC grids:

- No reactive power and frequency concern
- Less harmonic pollution
- Voltage as power balance indicator
- Different dynamics time-scales and higher relevance of control strategies design

- Increased power electronic penetration

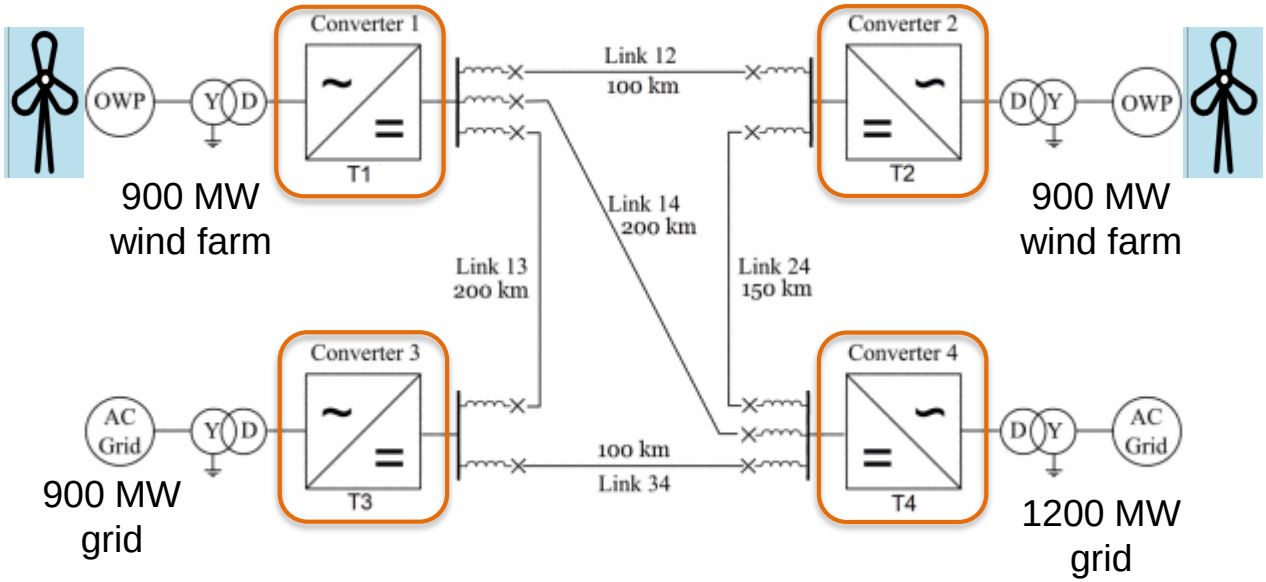
- AC/DC grid hybridization



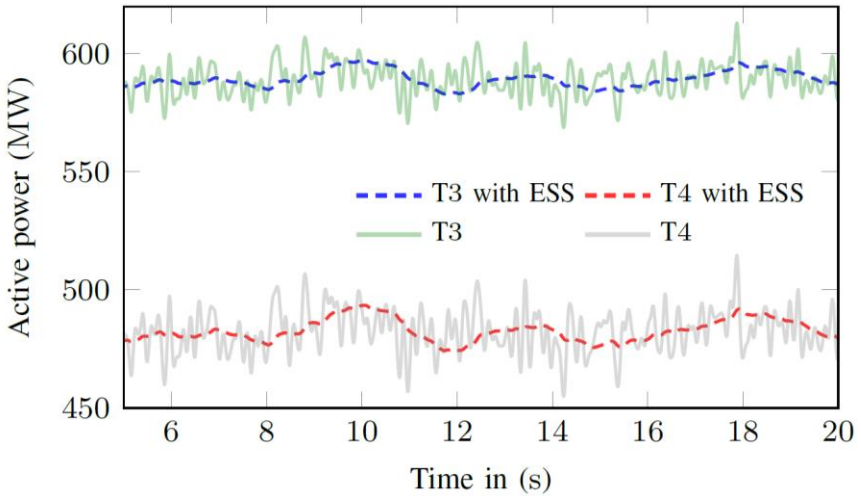
Different converters can provide ancillary services, to enhance AC grid performance, e.g.

- Power oscillation damping
- Frequency support
- AC and DC voltage support

Power quality in (HV)DC offshore grids



Active power smoothening

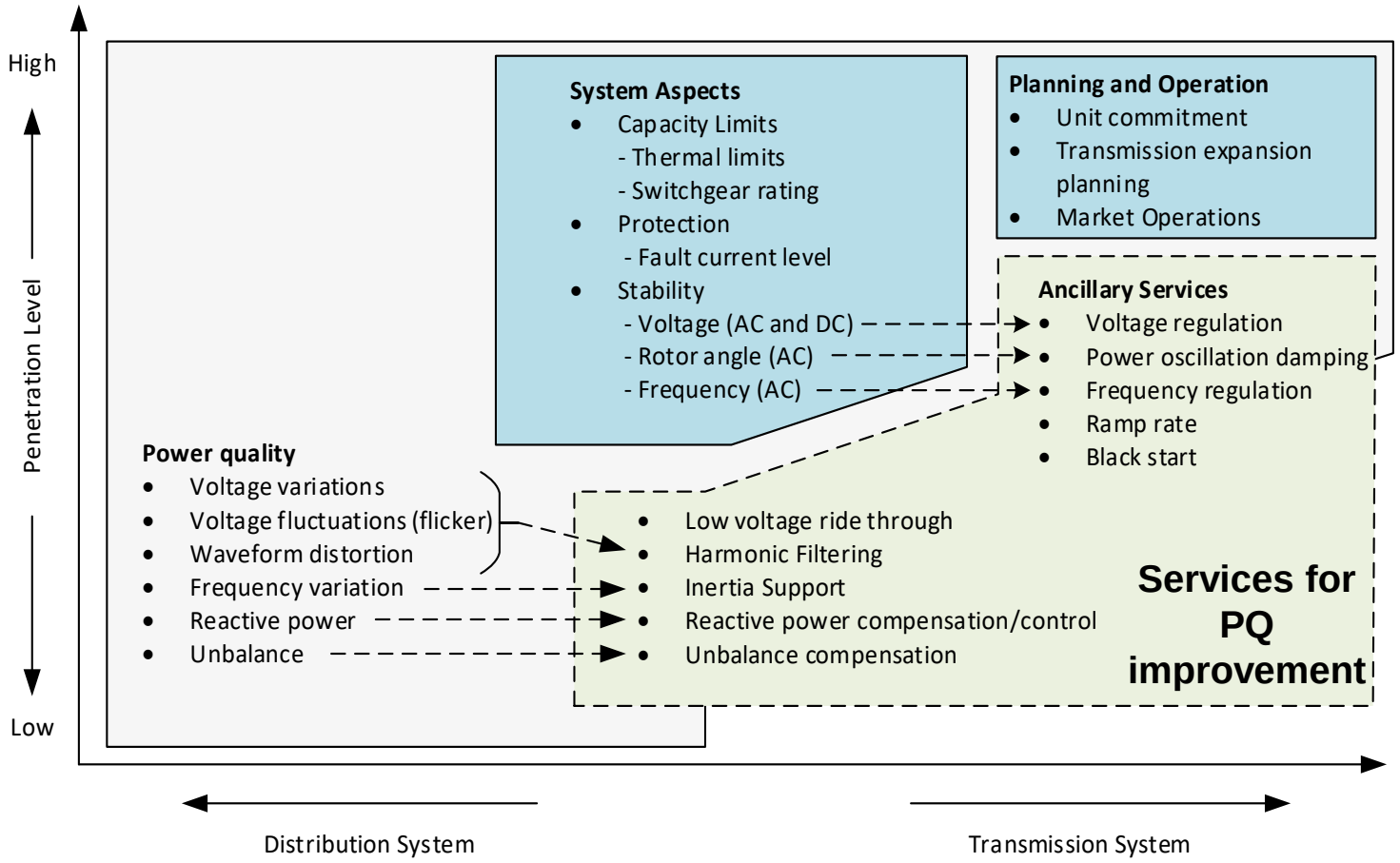


Wind-induced variation of active power in the AC grids is reduced using the Energy Storage embedded in Modular Multilevel Converters

Valid for rapid variations in the [ms-s] range

A. A. Taffese, A. Endegnanew, S. Sanchez, E. Tedeschi, "Reducing Rapid Wind Farm Power Fluctuations Using Energy Storage of the Modular Multilevel Converter" Deepwind19, 16-18 January 2019, Trondheim.

Power quality in offshore grids



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Conclusions

- **Intermittency of wind and marine sources significantly affects the power quality of the electric grid**
- **Power electronics can contribute to the problem, but also help providing countermeasures**
- **Use of energy storage may be pivotal with the increase of offshore energy penetration**
- **Need for harmonization in the grid codes**

E. Robles, M. Haro-Larrode, M. Santos-Mugica, A. Etxegarai, E. Tedeschi, “Comparative analysis of European grid codes relevant to offshore renewable energy installations”, Renewable and Sustainable Energy Reviews, Volume 102 pp 171-185, 2019,

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- A. Elahidoost, E. Tedeschi, “Expansion of Offshore HVDC Grids” RTUCON 2017, 12-13 October 2017, Riga, Latvia
- A. A. Taffese, A. Endegnanew, S. Sanchez, E. Tedeschi, “Reducing Rapid Wind Farm Power Fluctuations Using Energy Storage of the Modular Multilevel Converter” Deepwind19, 16-18 January 2019, Trondheim
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Thanks for your attention!

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