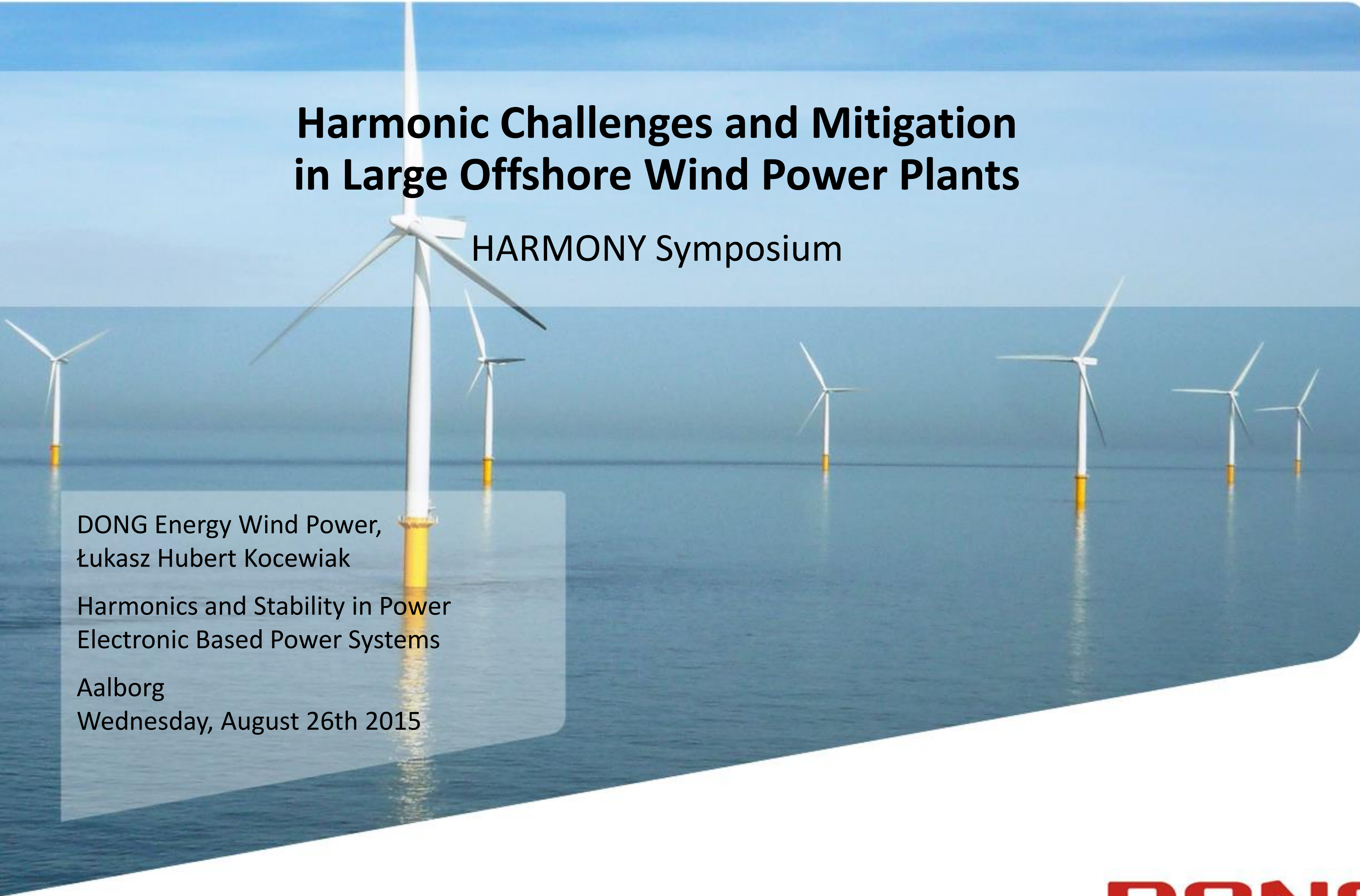

Harmonic Challenges and Mitigation in Large Offshore Wind Power Plants

HARMONY Symposium

DONG Energy Wind Power,
Łukasz Hubert Kocewiak

Harmonics and Stability in Power Electronic Based Power Systems

Aalborg
Wednesday, August 26th 2015

DONG energy

Outline

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- Harmonics in wind power plants

Harmonic problems

- Harmonic sources and effects

Harmonic mitigation

- Passive vs. active filtering

Summary

- Need for further research and standardization

DONG Energy Wind Power

company profile

Core activities

- Development, construction and operation of offshore wind farms

Market position

- Market leader in offshore wind, has built 38% of European capacity
- Strong pipeline of projects in lead-up to 2020)

Business drivers

- Wind conditions
- Availability
- Electricity prices and subsidies
- Industrialisation and maturing of value chain
- Securing supplies via framework agreements and partnerships
- Partnerships with industrial and financial investors

ROCE targets

- 2016: 6-8%
- 2020: 12-14%

Strategic targets for 2020

- Installed offshore wind capacity (before divestments): 6.5 GW
- Reducing offshore wind Cost of Energy to below EUR 100/MWh[3]

WIND POWER

Revenue, DKK billion (%)[1,2]	**7.8**	(9%)
EBITDA, DKK billion (%)[1]	**2.5**	(29%)
Gross investments, DKK billion (%)[1]	**12.7**	(65%)
Employees, FTE (%)[1]	**1,951**	(28%)

1 The percentages indicate the proportion of the Group that each business unit represented in 2012.
2 Intragroup revenue means that the business units' combined revenue exceeds consolidated revenue.
3 Cost to society based on projects in the UK where investment decisions will be made in 2020.

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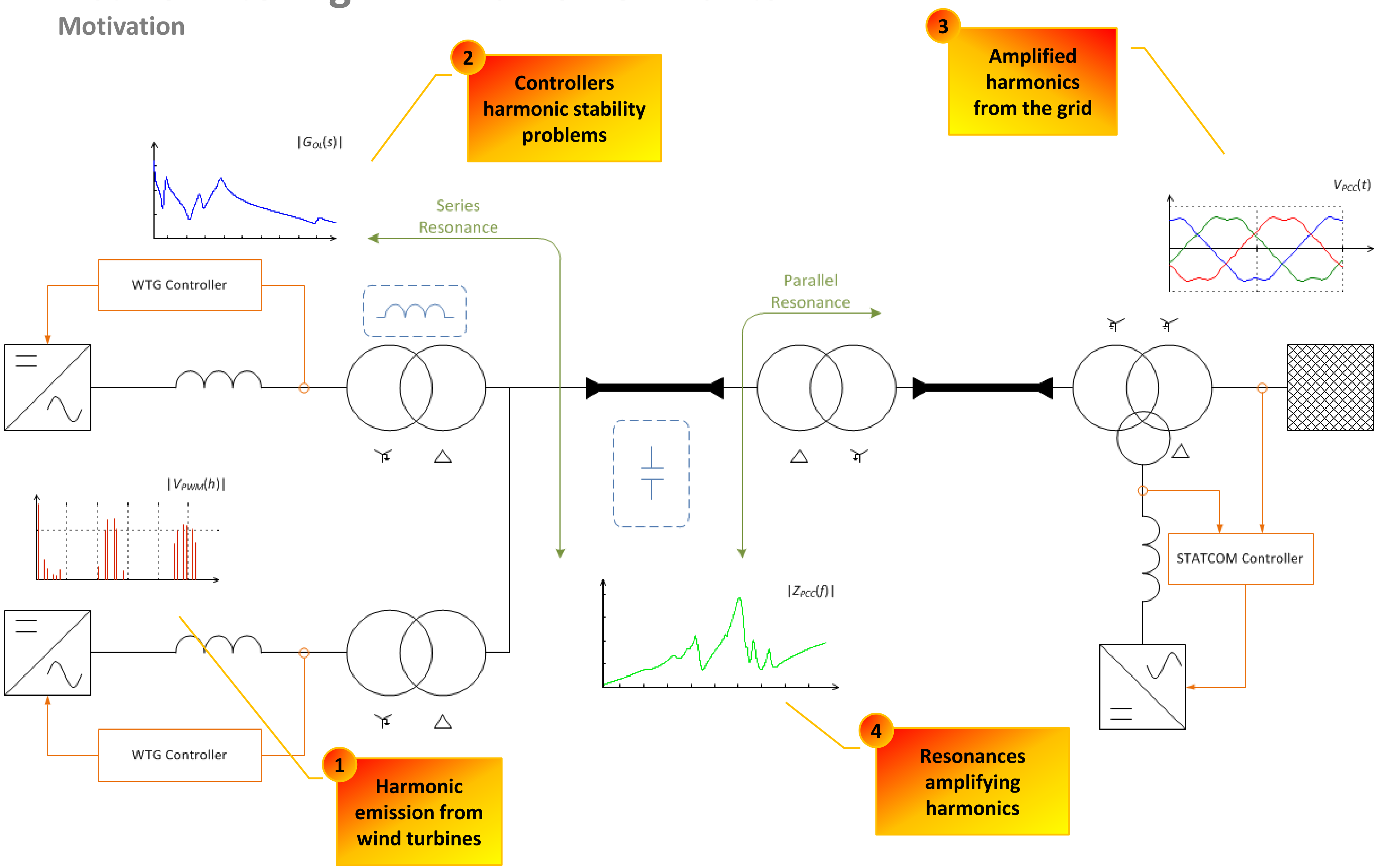
Active Filtering in Wind Power Plants

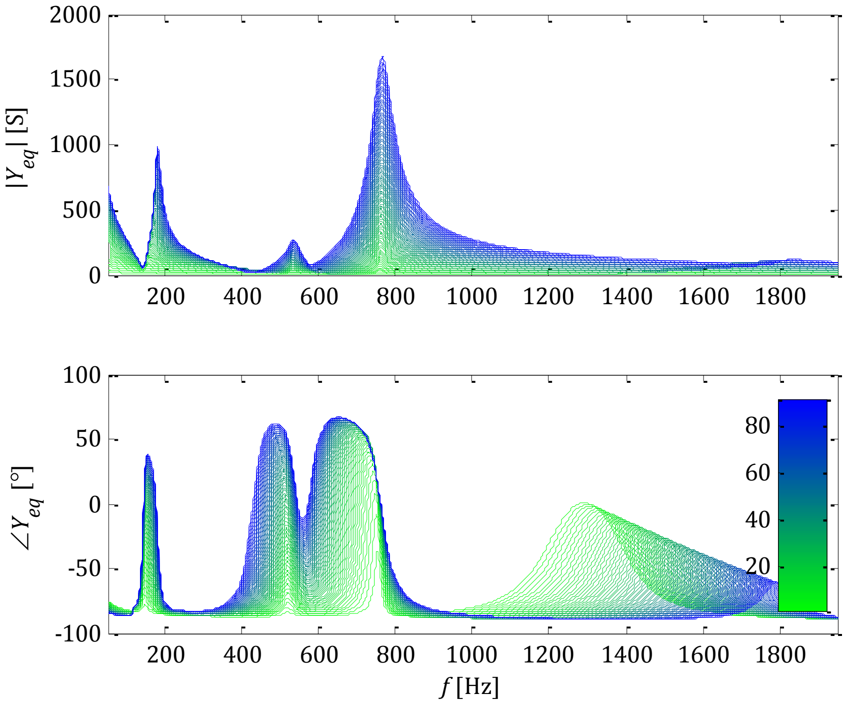
Motivation



Wind Farm Structures

resonance phenomena

Horns Rev 2



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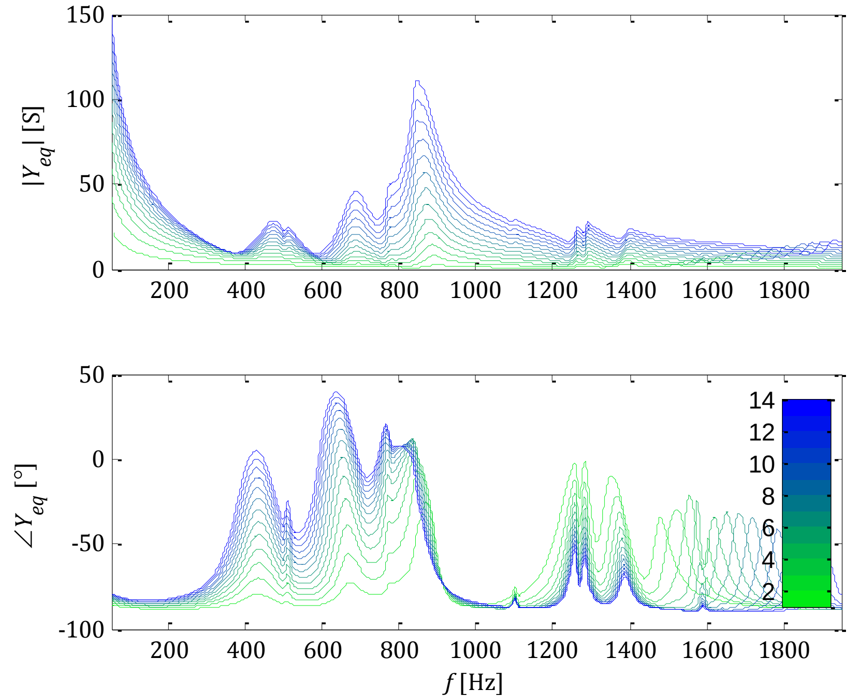
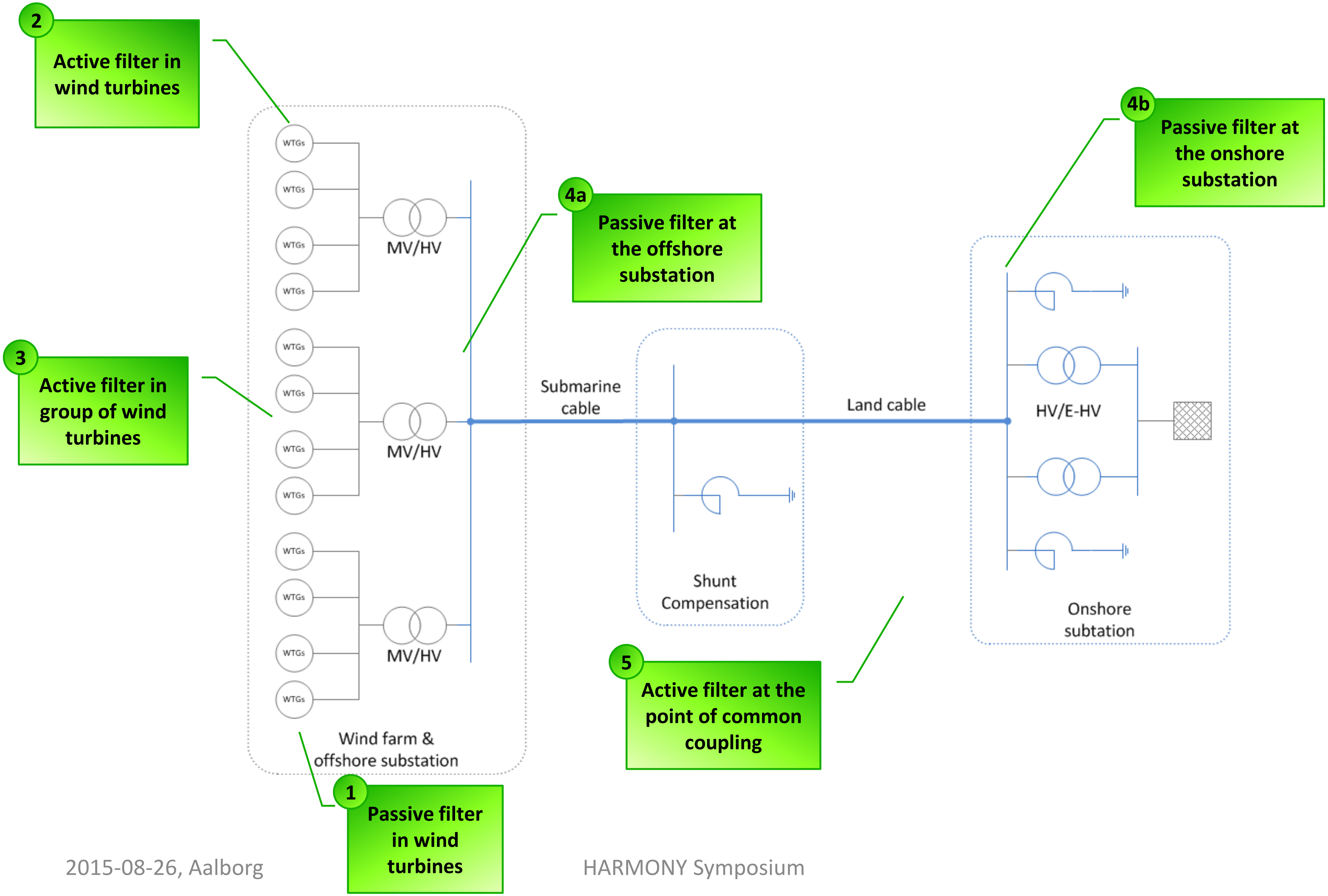


Conclusions

- Long HVAC cables can affect significant series resonances
- Wind farm aggregated for different number of connected wind turbines
- Different wind turbines can operate differently with wind farms
- Distribution network introduces higher impedance in comparison to the transmission system

Active Filtering in Wind Power Plants

Mitigation



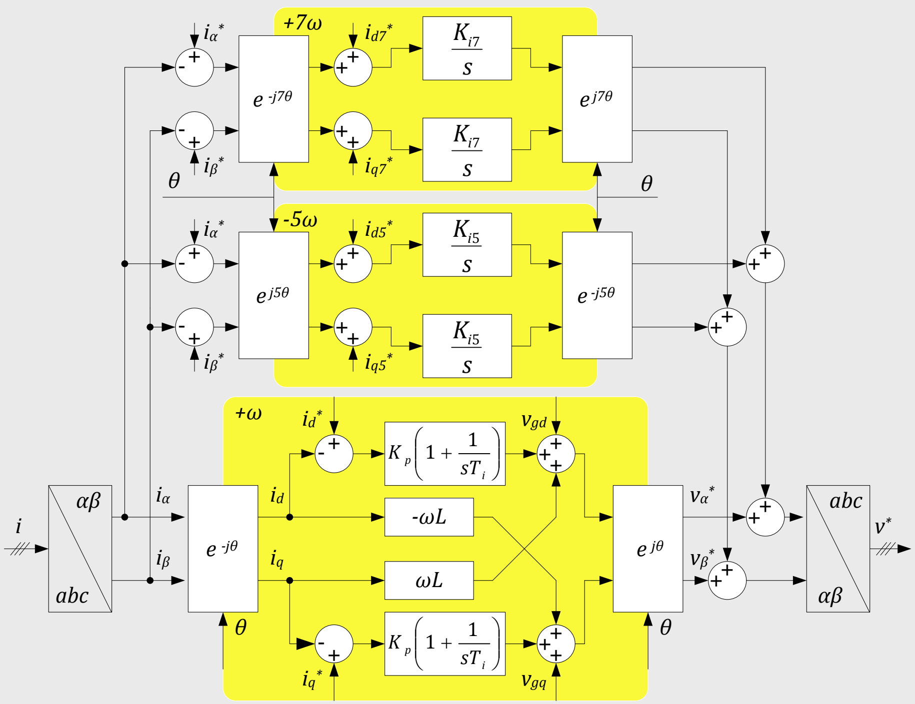
Active Filtering

pros and cons

Pros	Cons
– Already existing technologies such as STATCOMs can be utilised for it active filtering at the connection point	– Improving technology not commonly applied in wind farms
– Possibility of online retuning or with a short downtime and thus reduced risk of design uncertainties	– Extra effort in terms of harmonic stability is needed
– Wide control potential (e.g. selective harmonic compensation, wide band high-pass active filtering, etc.)	– Limited harmonic range due to hardware constraints and thus hybrid solutions might be preferable
– Network impedance changes during operation can be addressed	– Component sizing issues and limited DC-link voltage utilisation
– Control method can be tuned for each of wind farms independently taking into consideration grid code issues as well as wind farm structure	
– Negligible losses for series connected active filters such as wind turbines	

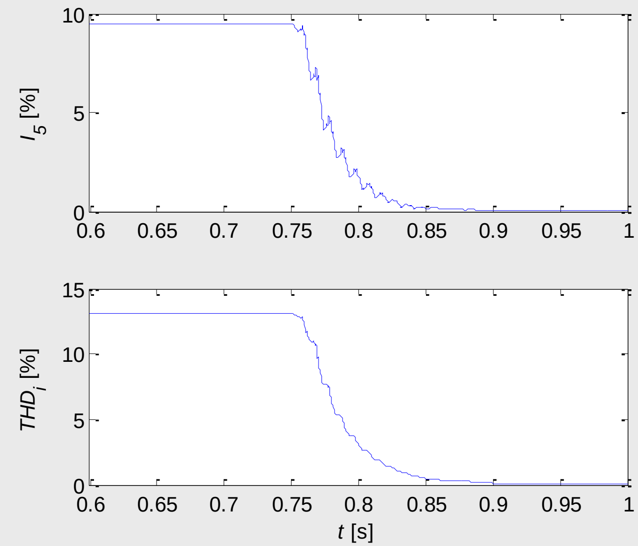
Active Filtering in Wind Turbines

harmonic current control



Case: Control in rotating reference frame

Control: Harmonic compensation needed if background distortions are present (i.e. 5th, 7th, ...)



Conclusions:

- Harmonic current dependent on background and selective harmonic control
- Command signal distorted to compensate current
- Current quality improved due to the control
- Converter output voltage more distorted

Active Filter Functionalities

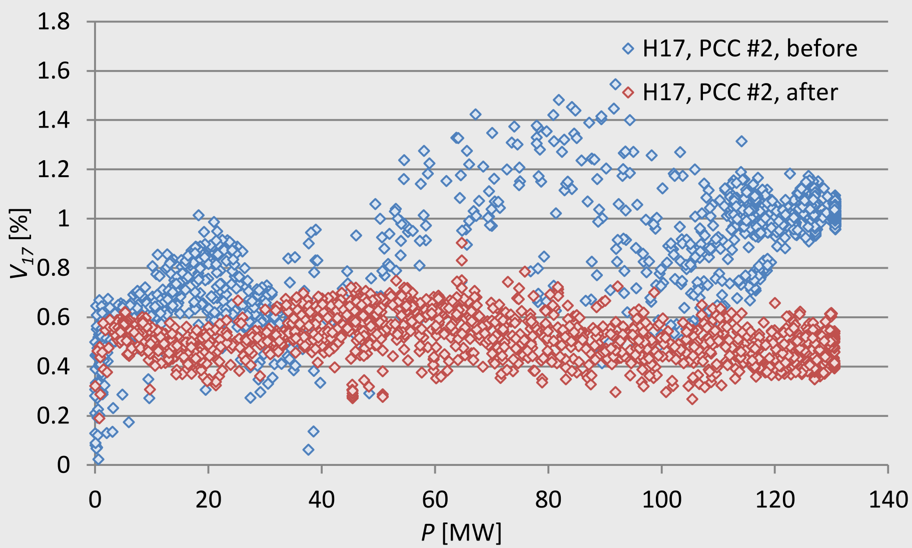
experience from Anholt Offshore Wind Farm

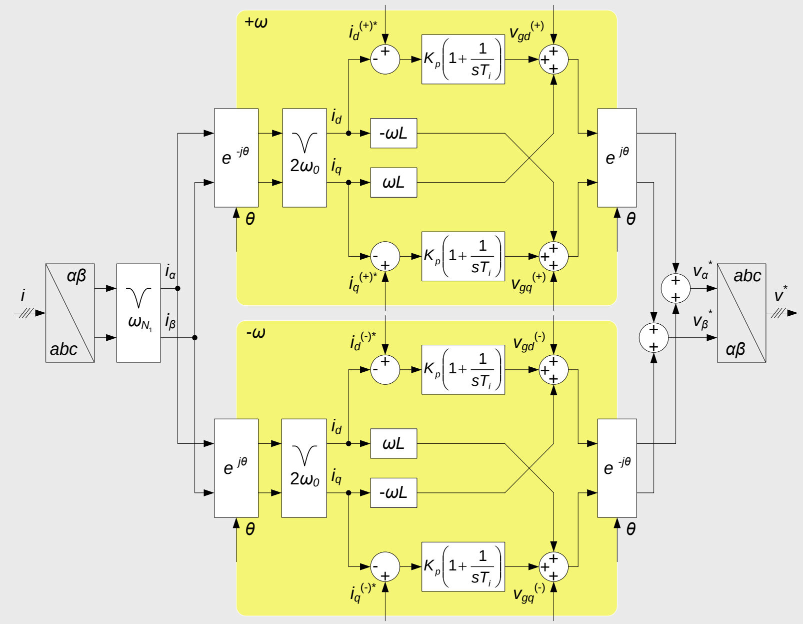
Conclusions

- Changes in the converter internal impedance can affect harmonic emission
- Emission can be reduced without loss of stability and converter oversizing
- Harmonic rejection capability improved

Benefits

- Harmonic mitigation measure without extra passive components,
- Flexibility,
- Reduced cost of electricity.

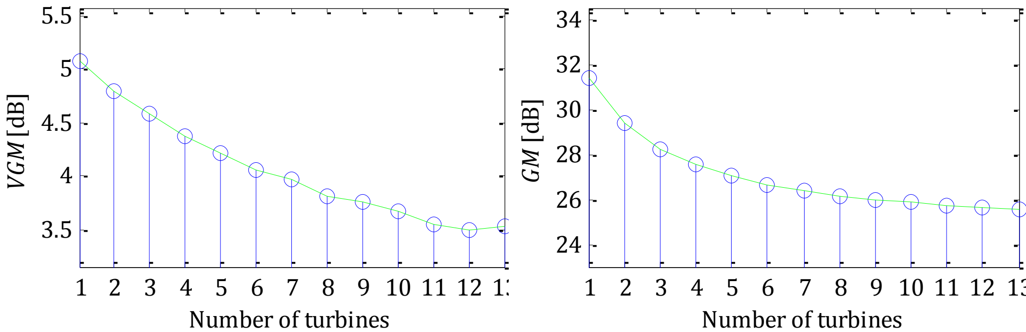




Wind Farm Stability Assessment

Nyquist criteria and stability margins

Karnice



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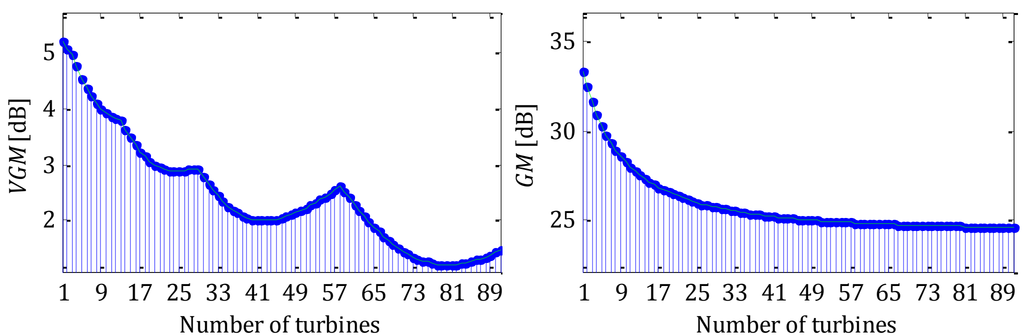
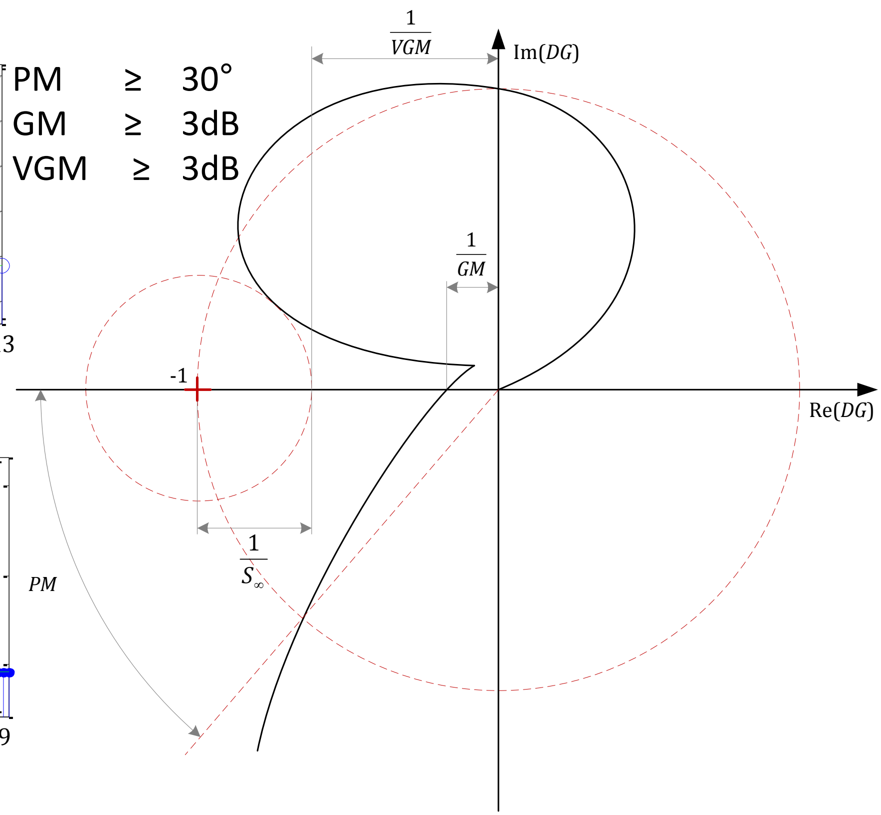


PM	≥	30°
GM	≥	3dB
VGM	≥	3dB



Conclusions

- Gain margin does not show stability issues for low frequencies
- Vector gain margin gives supplementary information about the stability
- Vector gain margin can detect low-frequency resonance
- Vector gain margin and gain margin are equal when in case of boundary stability

Uncertainties

to be addressed by R&D activities

Cables

- The underground export cable is typically physically installed in flat formation which introduces asymmetry in positive and negative sequence impedance between phases. Therefore of the whole three-phase system would be more sophisticated.

Sequence

- It is assumed that positive and negative sequence control of the grid-side converter in the WTs are the same and thus the Nyquist plot is symmetrical. Typically for steady-state operation this assumption can be valid for the sake of simplification.

Coupling

- It was assumed that the positive and negative sequence controller are decoupled and thus the WT for harmonic and stability studies can be expressed as a simplified single-phase equivalent system.

Tolerances

- WPP components tolerances is also difficult to incorporate into the model. Fortunately such parameters as transformers copper losses are typically available from test reports and cable capacitance tolerances are provided by the suppliers and adjusted in order to find the best match between simulations and measurements.

Data

- WPP components such as transformers or cables frequency-dependent characteristics were not available during the studies. Thus commonly accepted by the industry modelling approach was assumed.

Operation

- The sequence of WTs disconnection was assumed based on the most probable wind direction however it does not necessarily reflect the reality.

Methods

- The proposed harmonic analysis methods are based on linearity assumptions and such issues as frequency coupling in harmonic load flow or non-linearities (e.g. controller saturation, transformer saturation curve, etc.) were not included in the system representation.

Active Filtering in Wind Power Plants

benefits in relation to the cost of electricity reduction

DEVEX (DEVelopment EXpenditure)

- Lower risk during WPP development, e.g. reducing uncertainties during filter design thereby reducing the needed contingency reserves,
- Shorter development (design and implementation) period,
- Simplified procurement process and technical requirements of harmonic filters,
- Simplified design reduce need for coordination within the project and with stakeholders.

CAPEX (CAPital EXpenditure)

- Better risk management, e.g. reduced contingency reserve,
- Less passive components in the WPP system (e.g. shunt reactors, passive filters),
- Smaller reactive power compensation need (in most cases only cable system compensation) and smaller STATCOM size,
- Active filtering can be included in already existing components such as WTG converters or STATCOMs causing no significant additional costs,
- Reduced onshore substation size,
- Reduced risk of curtailment due to insufficient filter design and resulting with grid-code compliance issues,
- Reduced issues with passive components lead time,
- More optimized onshore substation layout,
- Additional space for potential future changes at the substation due to e.g. changes in the external network,
- Facilitate connection to neighboring WPPs within extended offshore clusters without significant electrical infrastructure topology change,
- Reduced passive filter size implying possibility of compensation by dynamic reactive power compensation plants during the energization,
- Smaller passive filter and avoidance of static shunt compensation can help avoid severe zero-miss phenomena,
- Reduced problems with air core reactor electromagnetic field exposure.

OPEX (OPerational EXpenditure)

- Reduced downtime due to filter failure,
- Adaptive harmonic mitigation in case of changes in the external network,
- Reduced risk of curtailment due to passive filter failure,
- Application of active filtering can help eliminate the risk of G5/4-1 and G5/5 non-compliance during the WPP energization process,
- Reduction of power losses in the infrastructure components.

Active Filter Functionalities

for Power Converters in Wind Power Plants (R&D Activities)

Type of collaboration

- PSO- financed public research programme.
- ELFORSK research and development programme under the Danish Energy Association.

Technical scope

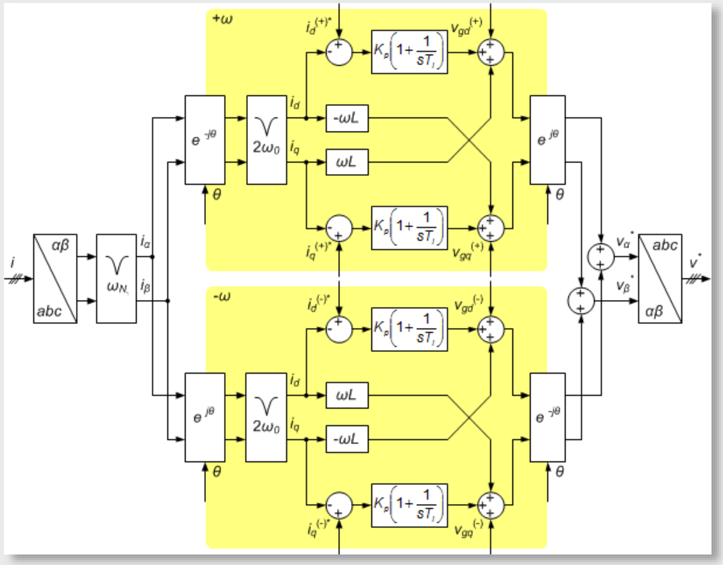
- Analyse and develop advanced filter solutions based on combinations of passive filters and active filters.
- Develop active filter solutions applicable for large commercial wind power plant projects.

Partners

- Aalborg University, Denmark (University),
- DONG Energy Wind Power, Denmark (Wind Power Plant Developer),
- Vestas Wind Systems A/S, Denmark (Wind Turbine Manufacturer),
- ABB AB – FACTS/RT (Transmission System Components Manufacturer),
- Energinet.dk, Denmark (Transmission System Operator).

Benefits

- Wind power plant optimization,
- Uncertainties and risk management,
- Flexibility,
- Reduced cost of electricity.



Research Directions
valuable to the industry

Models
- Improvement of models, e.g. wind farm components for time and frequency analysis

Methods
- Better harmonic emission and stability assessment techniques applicable to waveforms affected by power electronics

Mitigation
- More sophisticated harmonic mitigation methods such as active filtering

Design
- More optimized overall electrical infrastructure design as well as robust control solutions

Interdisciplinary approach
- Harmonic analysis/optimization should be introduced in other areas of electrical engineering, e.g. power system, control, power electronics engineering, etc.

Questions?

Gunfleet Sands Offshore Wind Farm

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