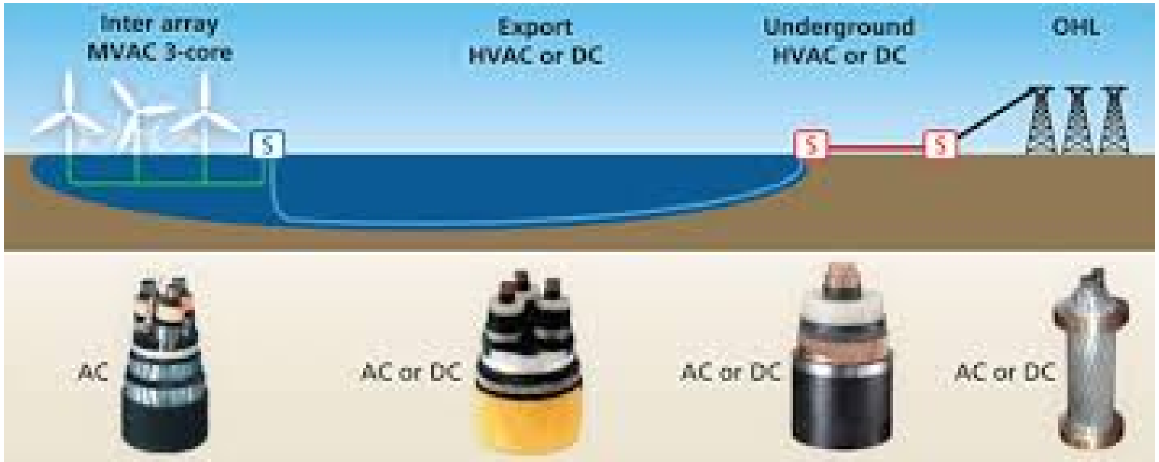
16th November 2017

Holistic Operation and Maintenance for Energy from Offshore Wind Farms

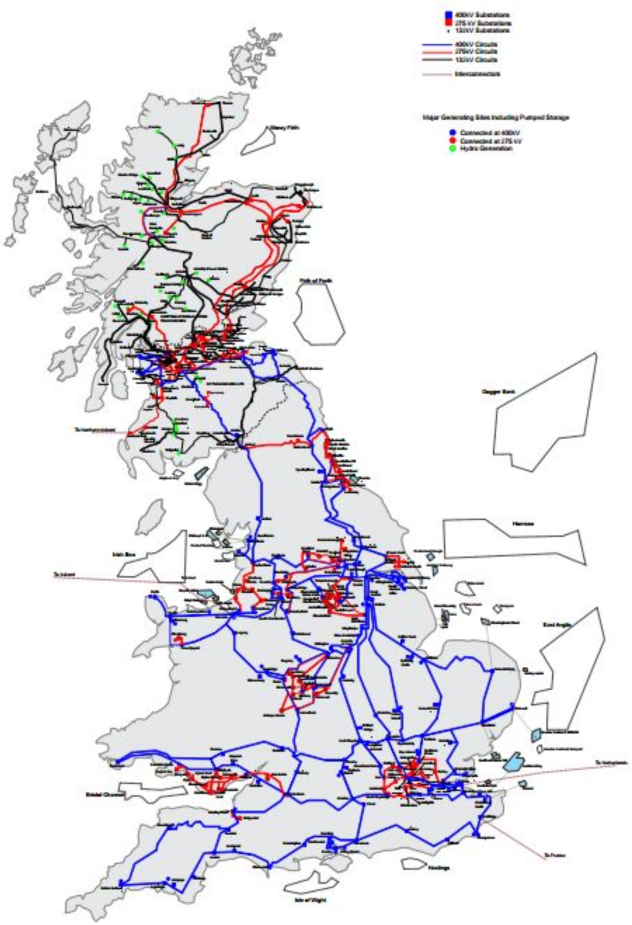
HOME-Offshore

Project Leader: Prof Mike Barnes

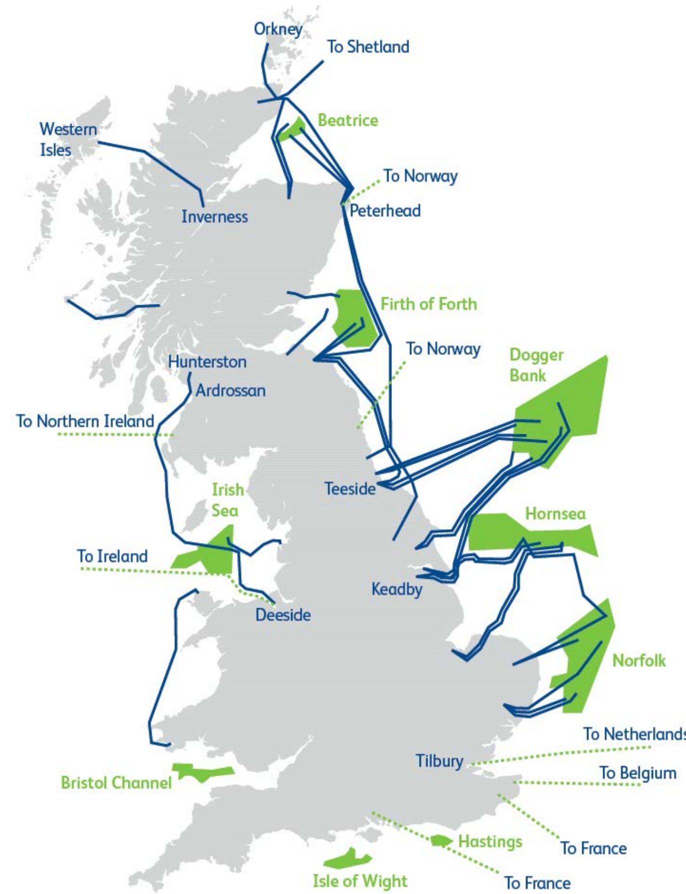
Operation, CM & Management of Major Marine Assets



Rapid Growth Projected for Offshore Wind



UK Electricity Network (largely AC)



Anticipated Round 3 Links

HOME Offshore

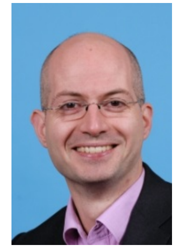
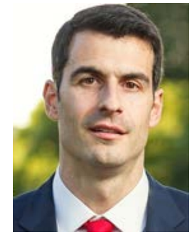
EPSRC
Pioneering research and skills

Maintenance

HOME Offshore

EPSRC
Pioneering research and skills

The Team

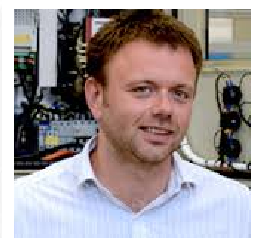




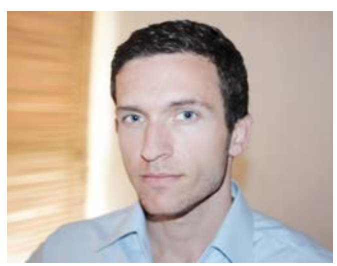






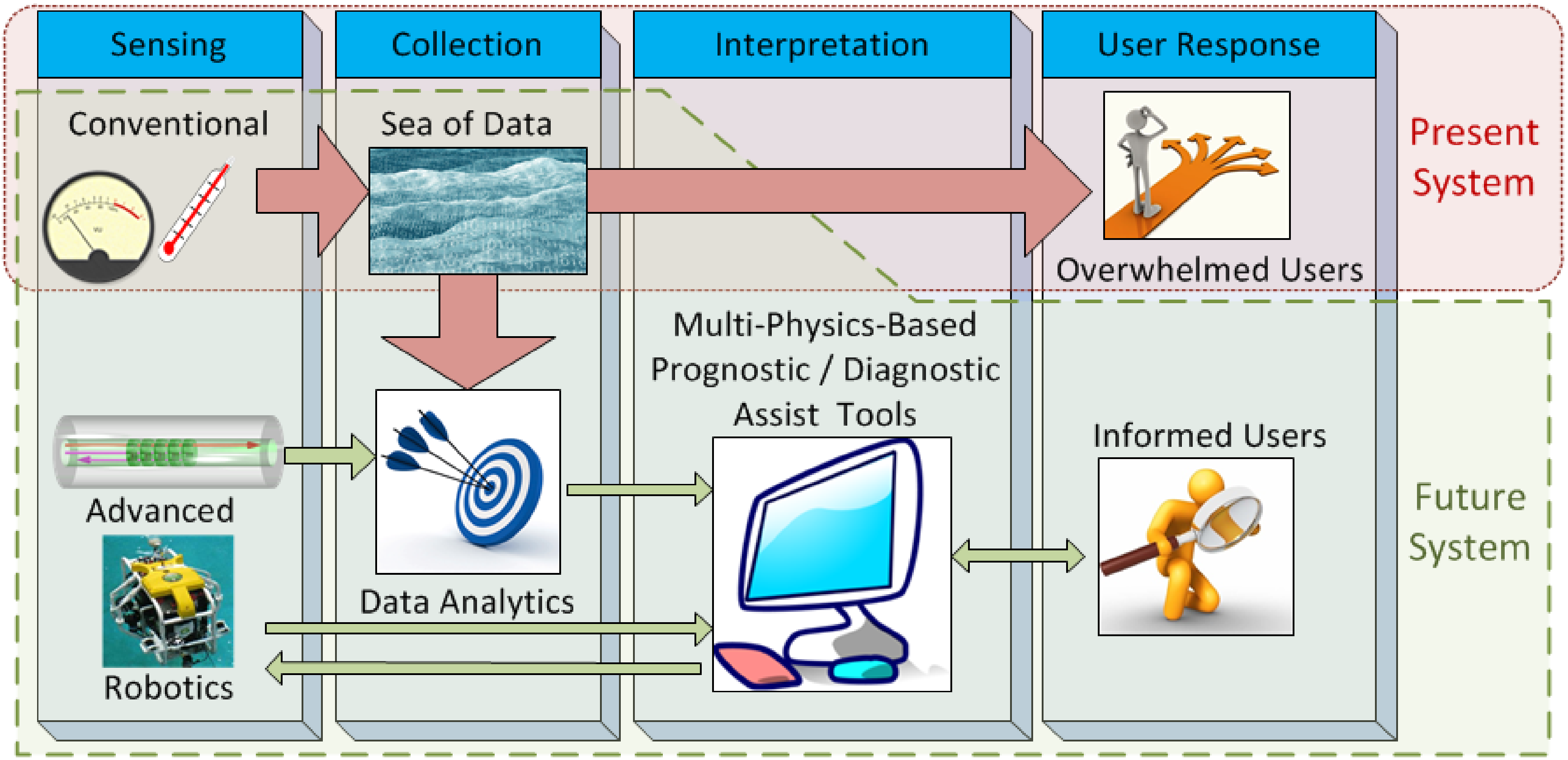





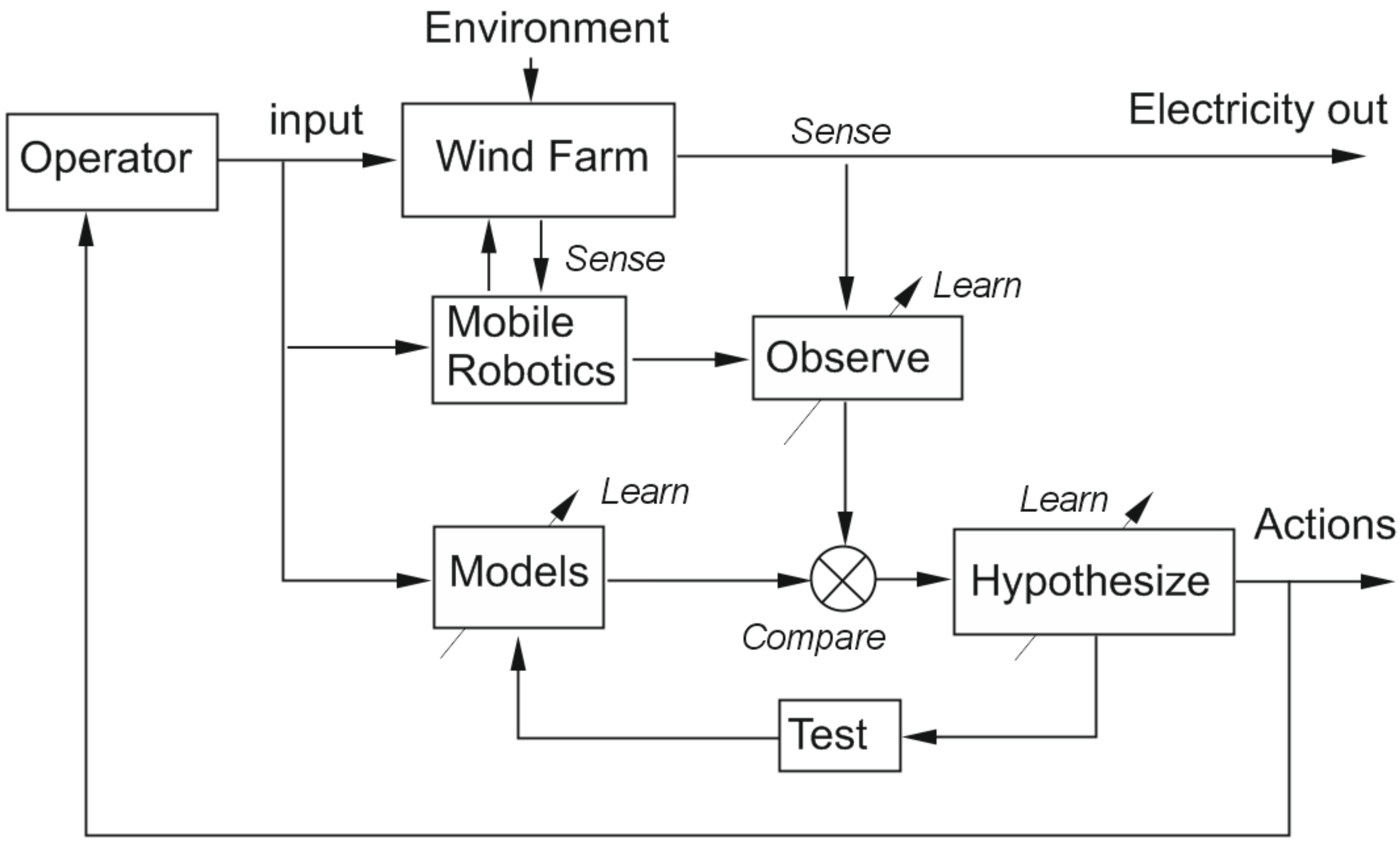


+ 5 PDRAs & 6 PhDs to be recruited

Current State vs. Proposed

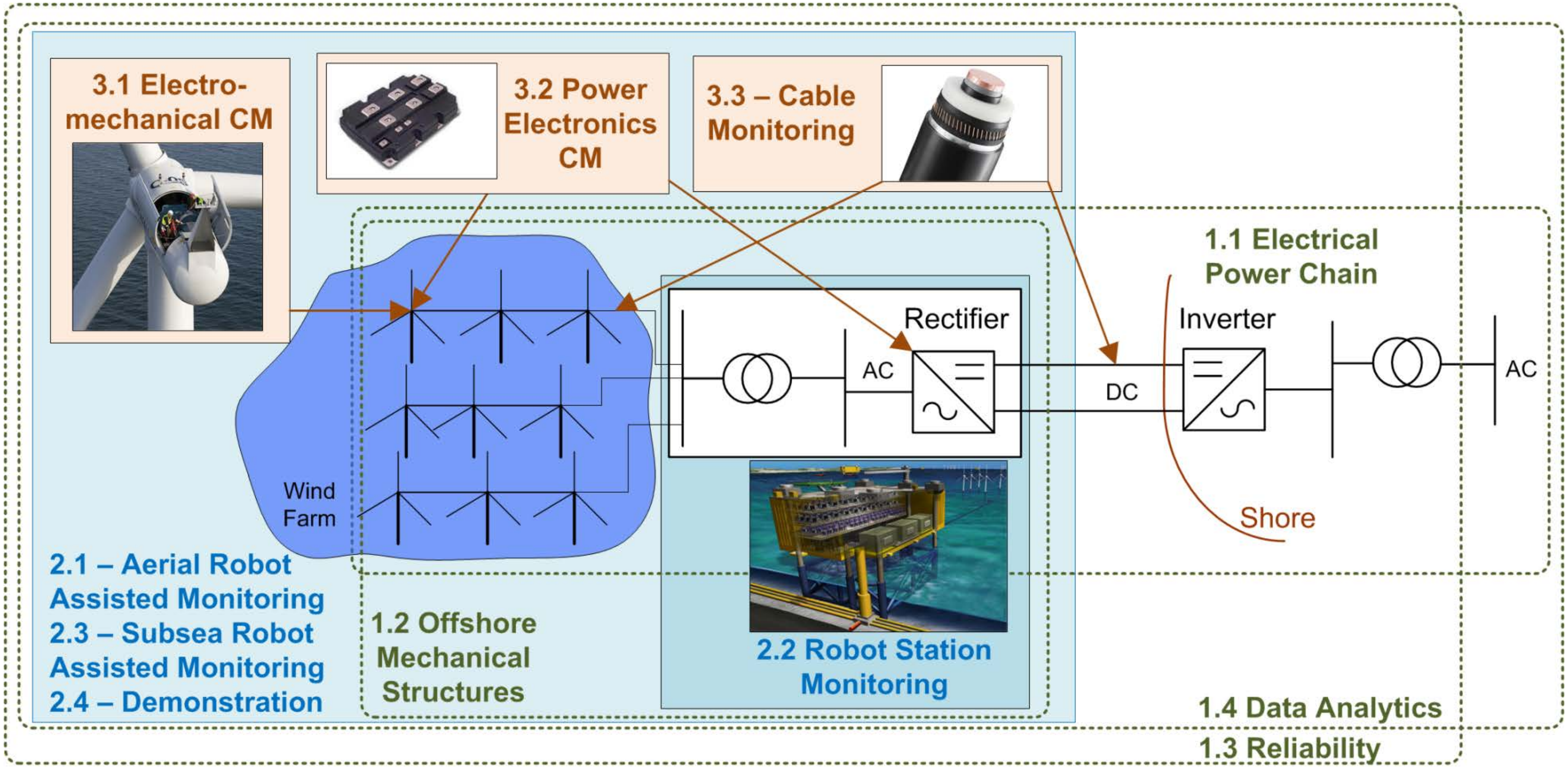


Procedure



Environment
Operator
input
Wind Farm
Sense
Electricity out
Sense
Mobile Robotics
Learn
Observe
Learn
Models
Learn
Hypothesize
Actions
Compare
Test

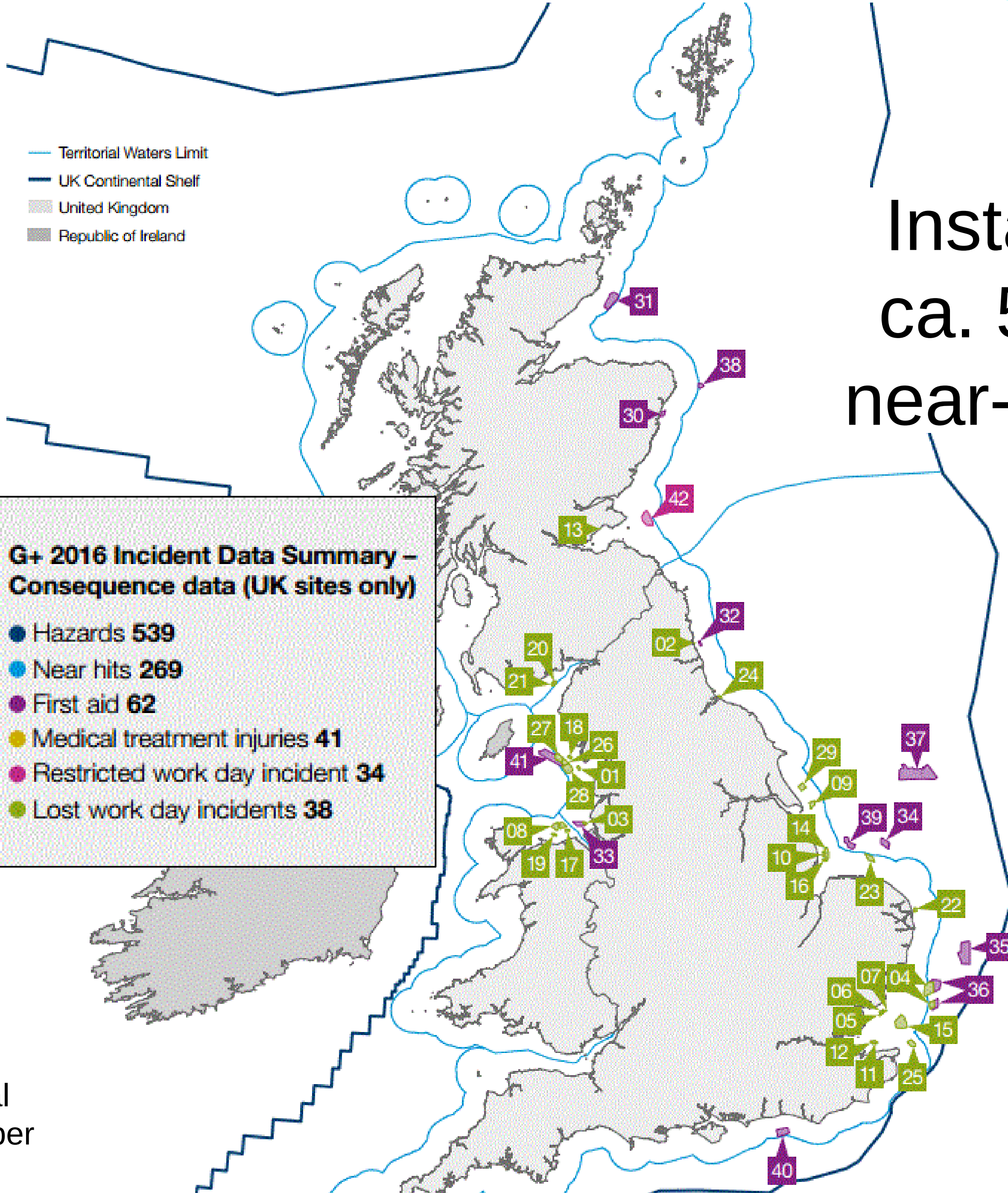
Project Overview



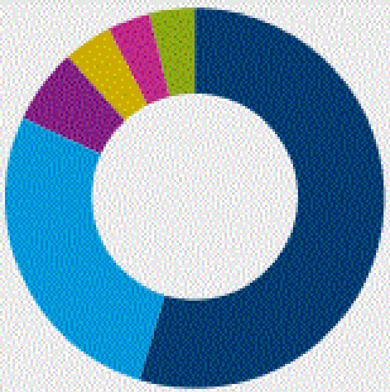
Final Project Demo – 2020

State of the Art

Operational
In construction
Supported



Installed ca. 5GW near-shore



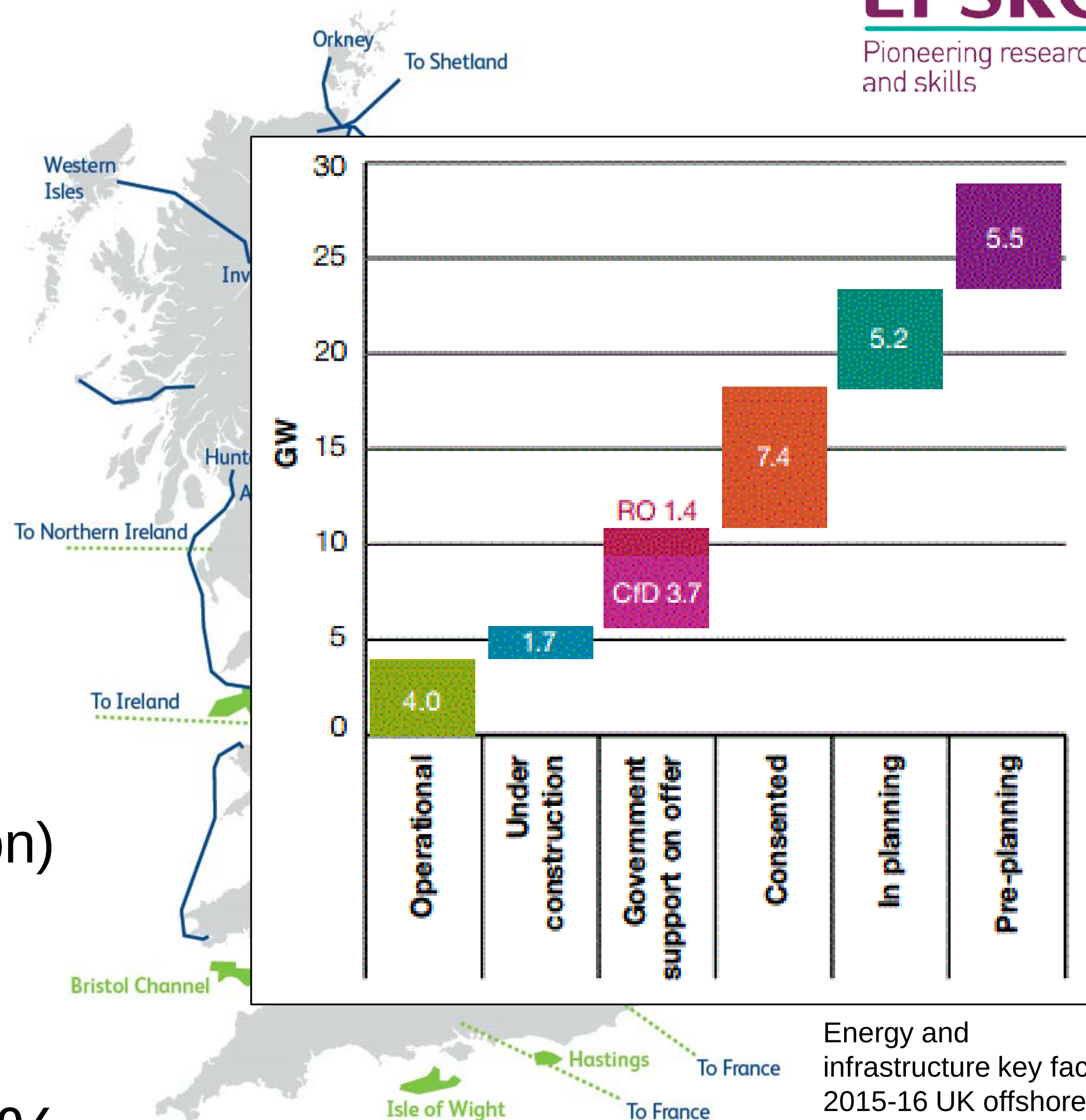
Offshore wind operational report January – December 2016, The Crown Estate

Round 3

- 5 to 25GW
- £2-3/W WT
- £1/W link to shore
- (£15bn to £100bn)

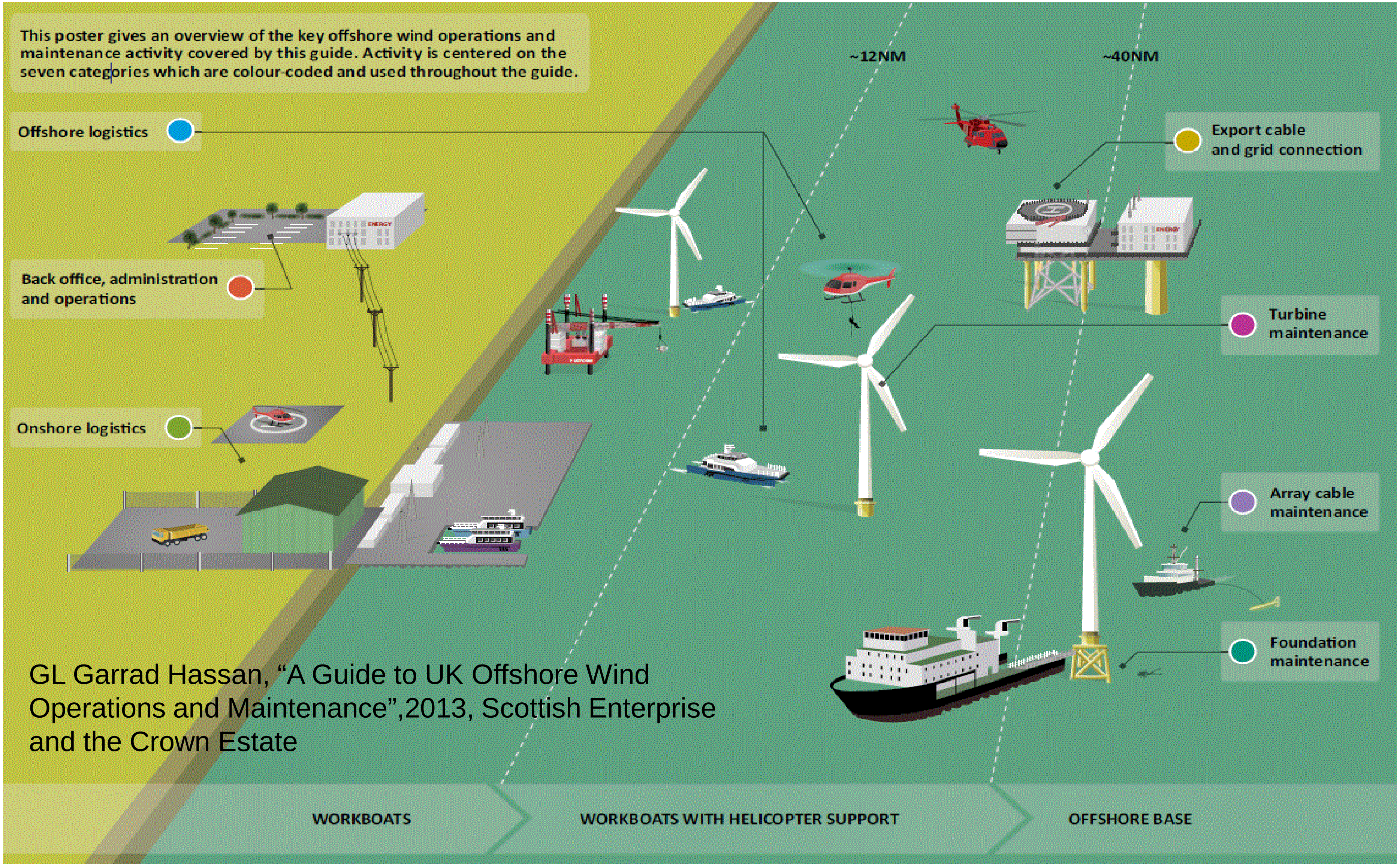
- O&M:

  +25% to 50%



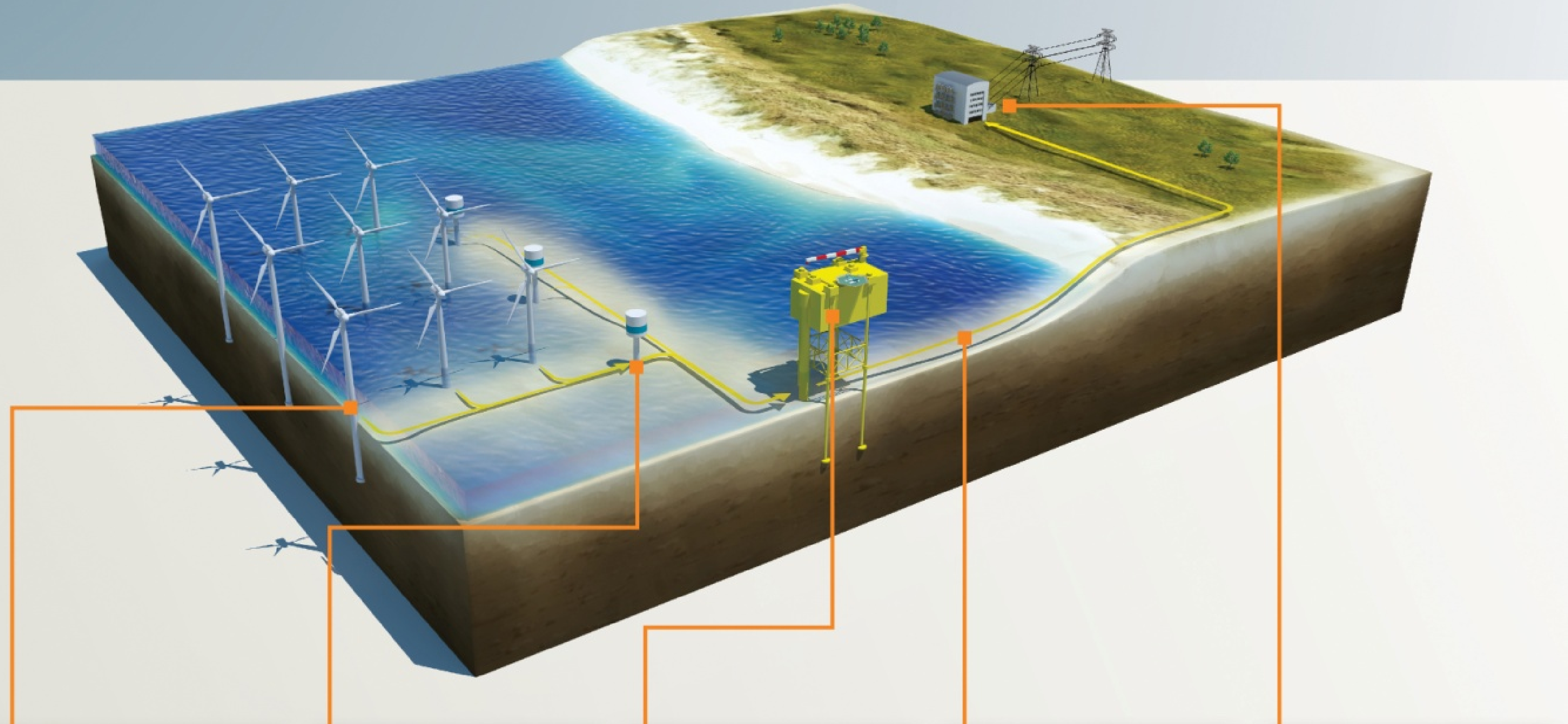
Energy and infrastructure key facts 2015-16 UK offshore wind, The Crown Estate

O&M Offshore



GL Garrad Hassan, "A Guide to UK Offshore Wind Operations and Maintenance",2013, Scottish Enterprise and the Crown Estate

Typical Offshore Systems Layout



1 Offshore wind turbine plants generate medium-voltage AC power

2 Wind energy generated by the wind farm turbines transformed to higher AC power at the substation platform

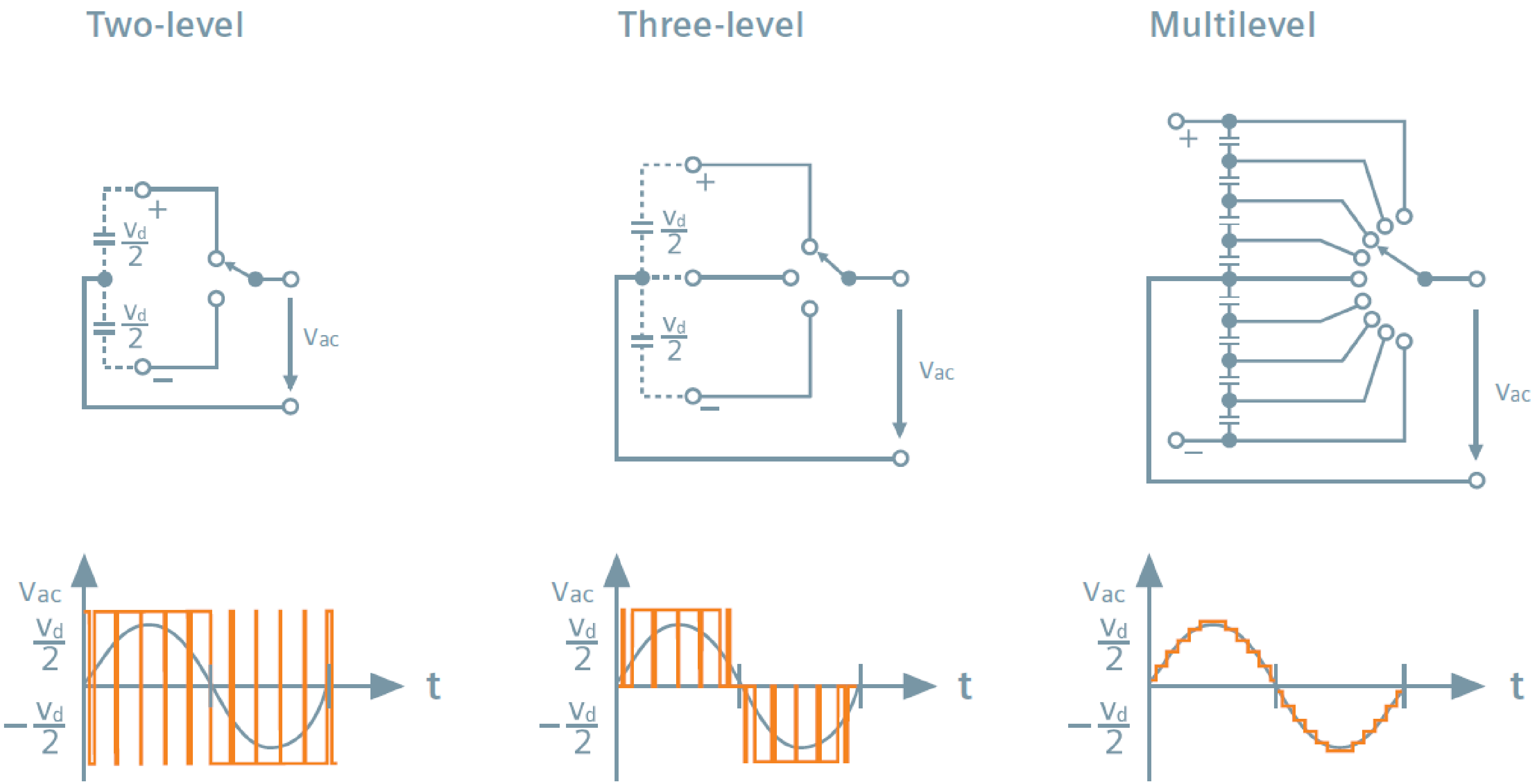
3 HVDC platform converts the alternating current from several substation platforms to direct current for transmission

4 Subsea cables, some more than 100 km in length, transport the low-loss direct current onto land

5 A converter station on land transforms the direct current back into alternating current for feeding into the high-voltage grid and for further transmission

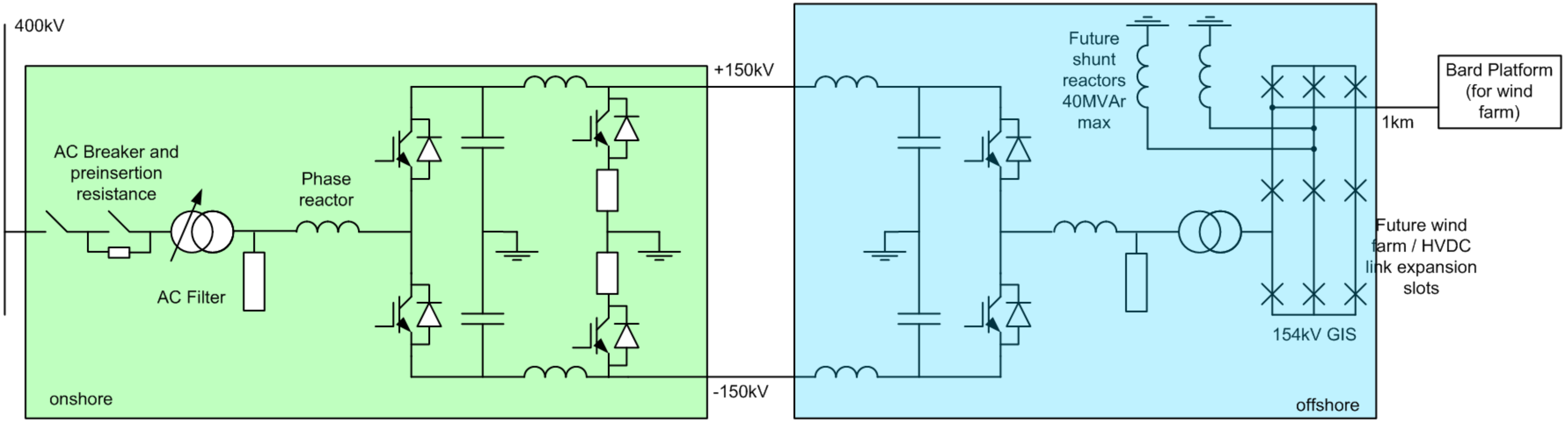
[Siemens VSC HVDC Website, http://www.siemens.com/press/en/presspicture/]

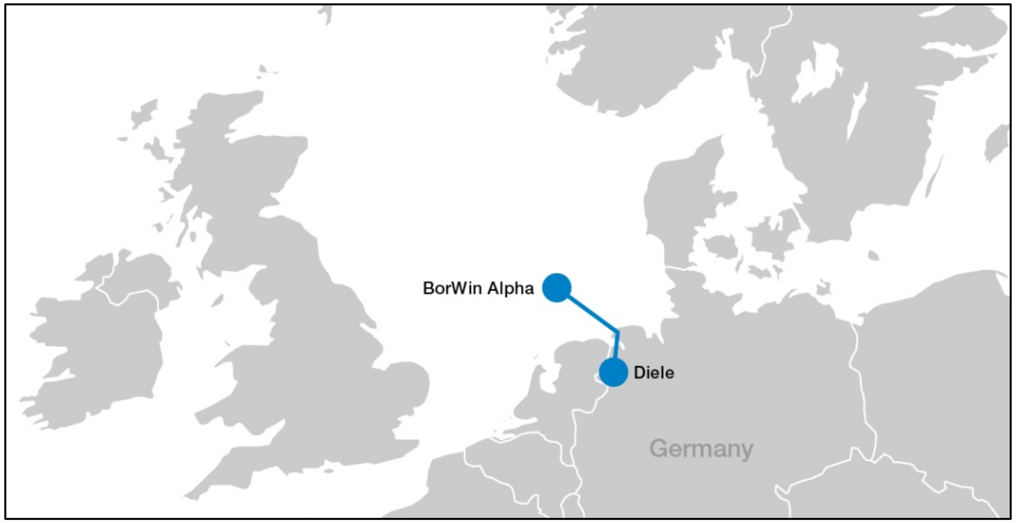
Modular Multi-level Converter



[Siemens VSC HVDC Website, http://www.siemens.com/press/en/presspicture/]

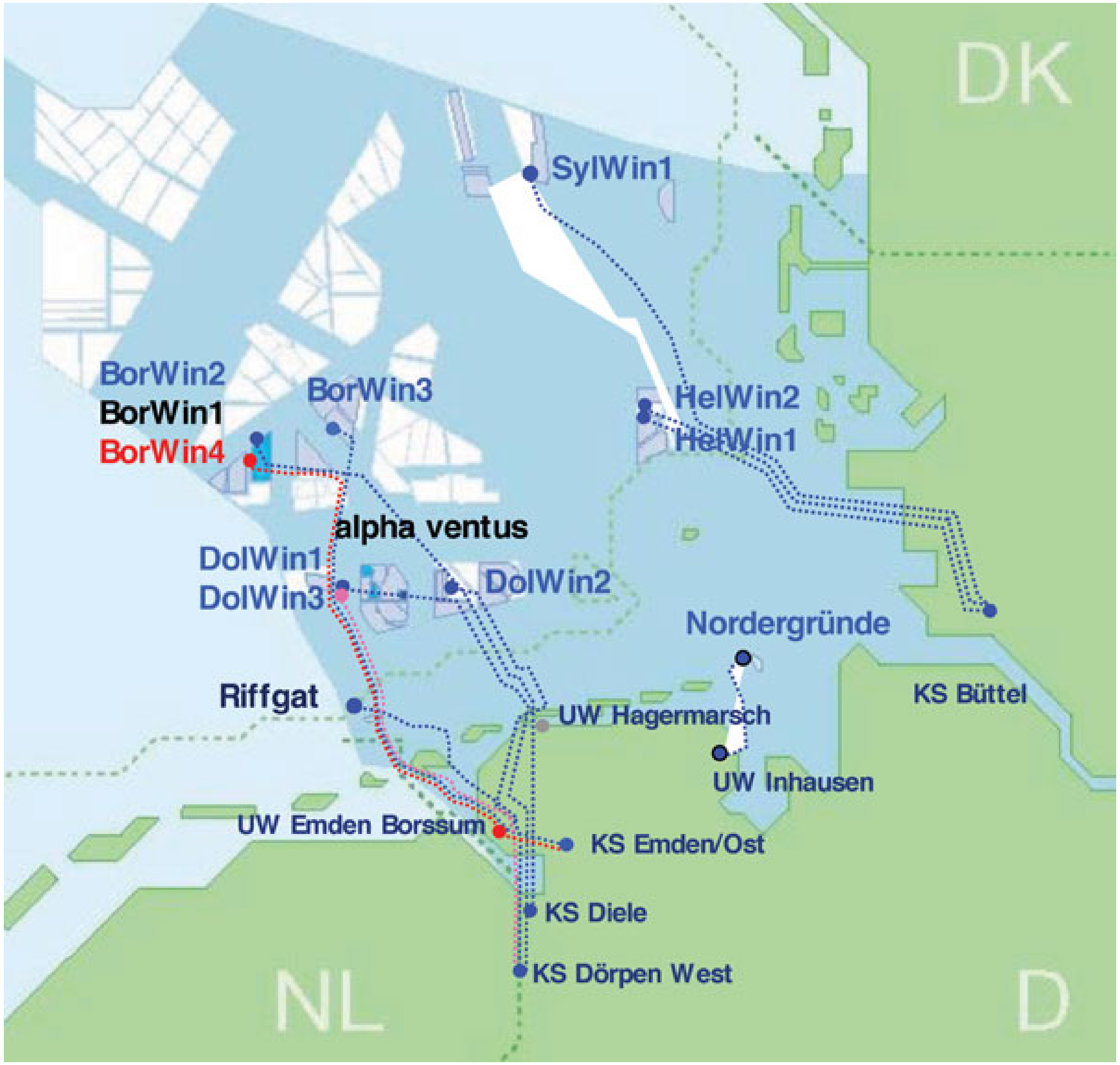
Borwin 1





- Images: ABB, Tennet, University of Manchester

Other X-wins

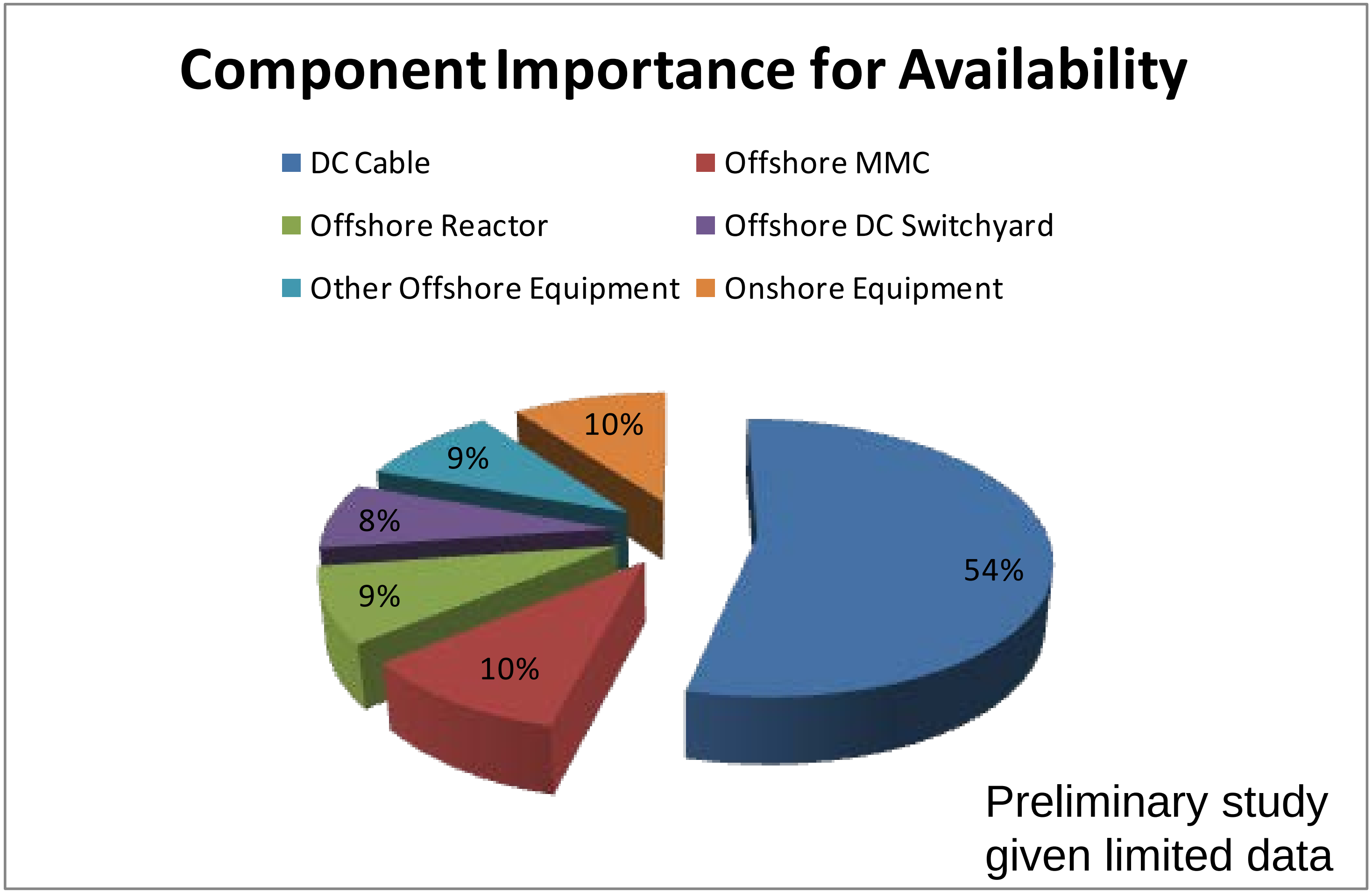


- Images: Modern Power Systems

HVDC Station Interior

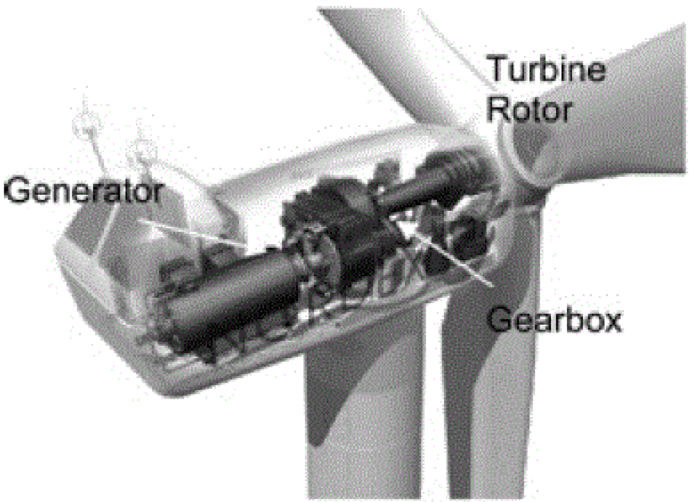
http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2016/energymanagement/pr2016020137emen.htm&content[]=EM

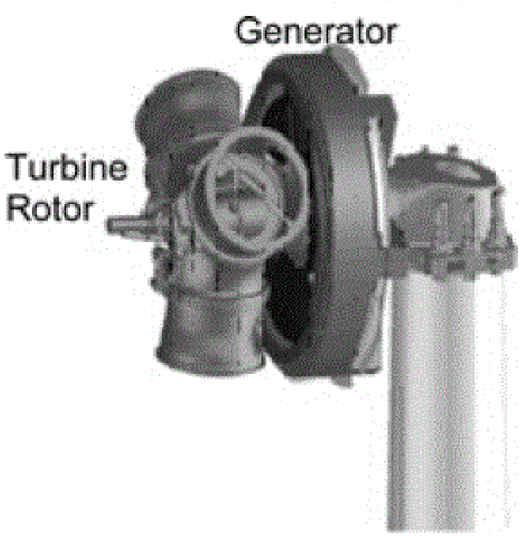
Reliability statistics of offshore connection

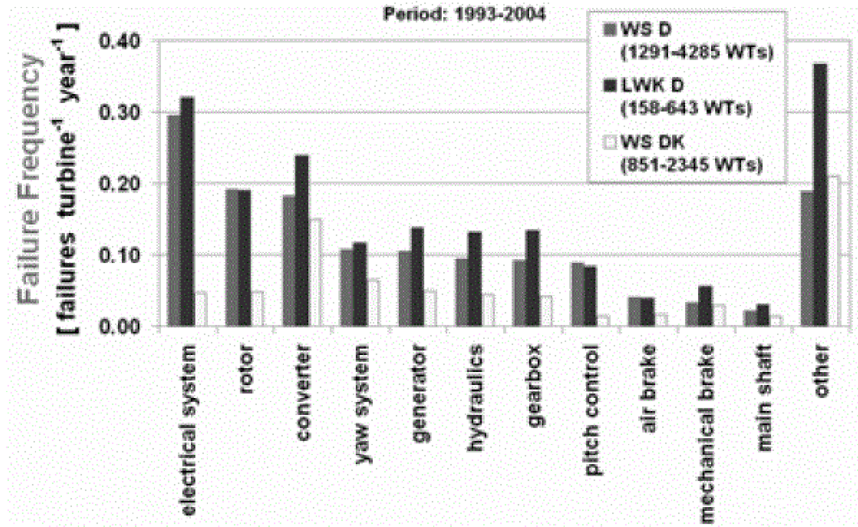


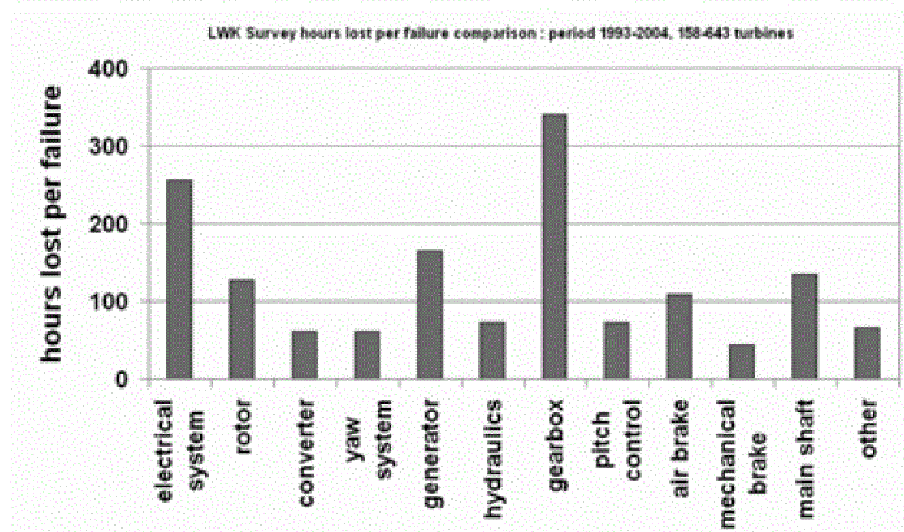
- VSC-HVDC Availability Analysis, Antony Beddard Dr Mike Barnes November 2011 Revision 2.1, http://www.eee.manchester.ac.uk/our-research/research-groups/pc/researchareas/powerelectronics/vsc/

Turbine Reliability Statistics



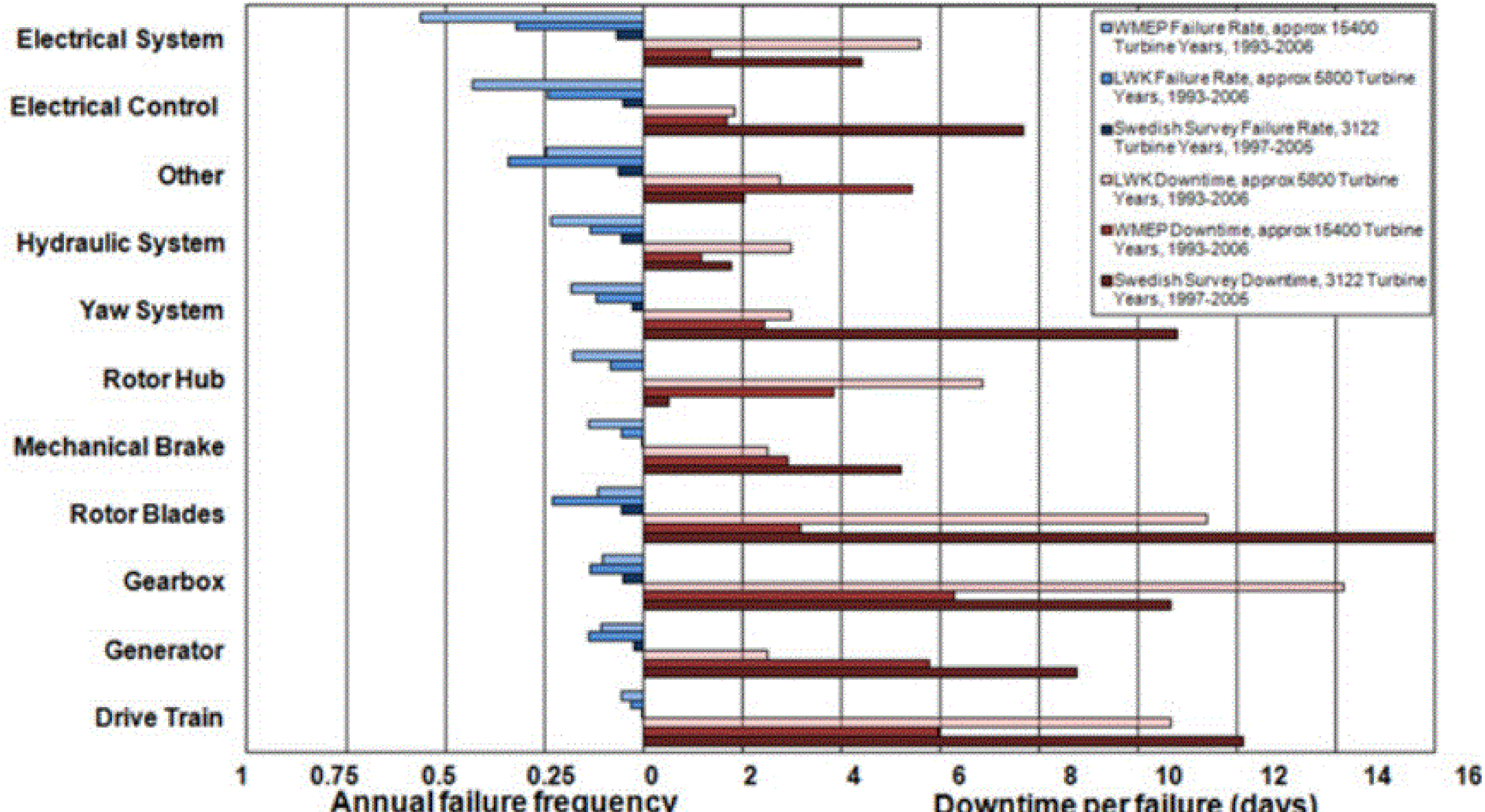






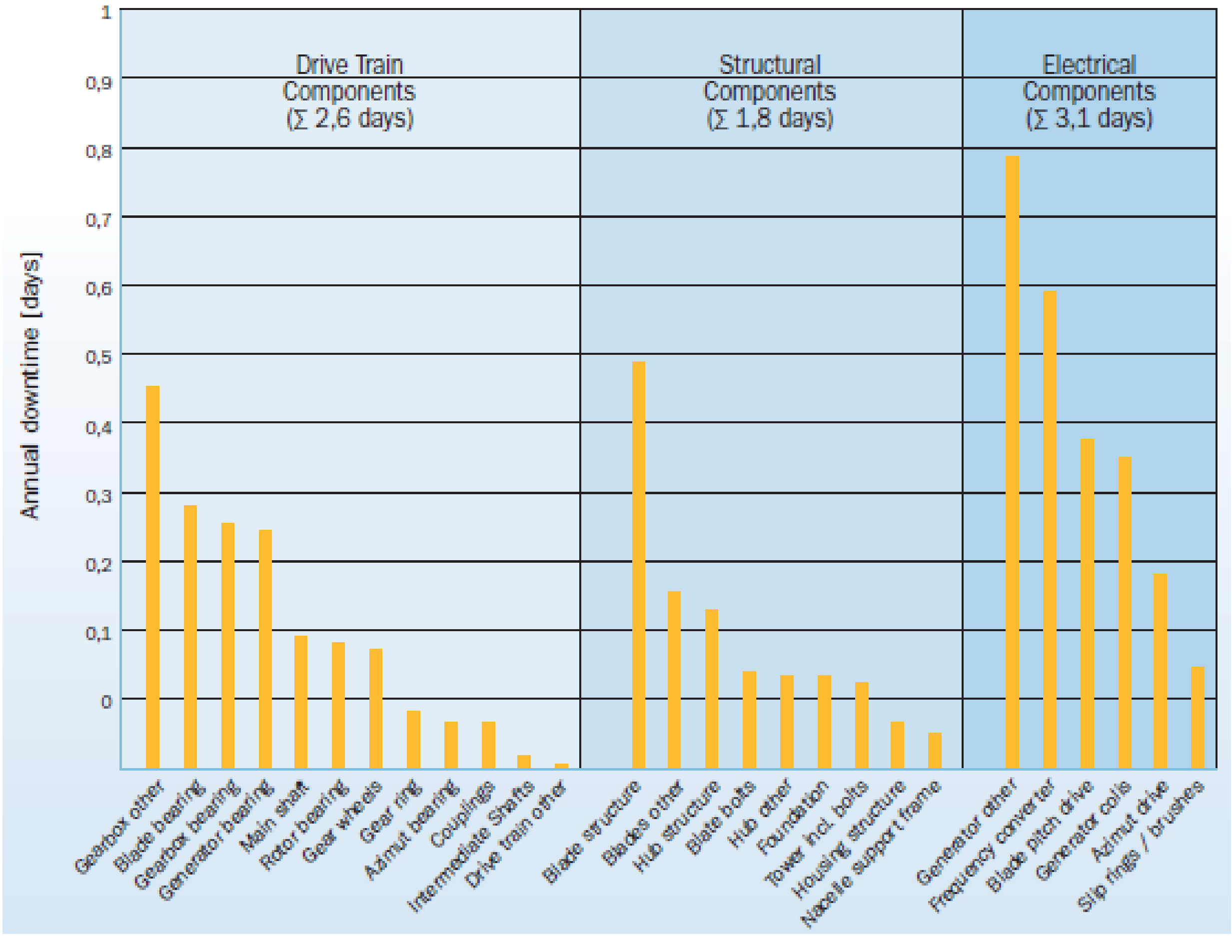
- Reliability of wind turbine subassemblies, F. Spinato, P.J. Tavner, G.J.W. van Bussel & E. Koutoulakos, IET RPG, 2008

Turbine Reliability Statistics 2015



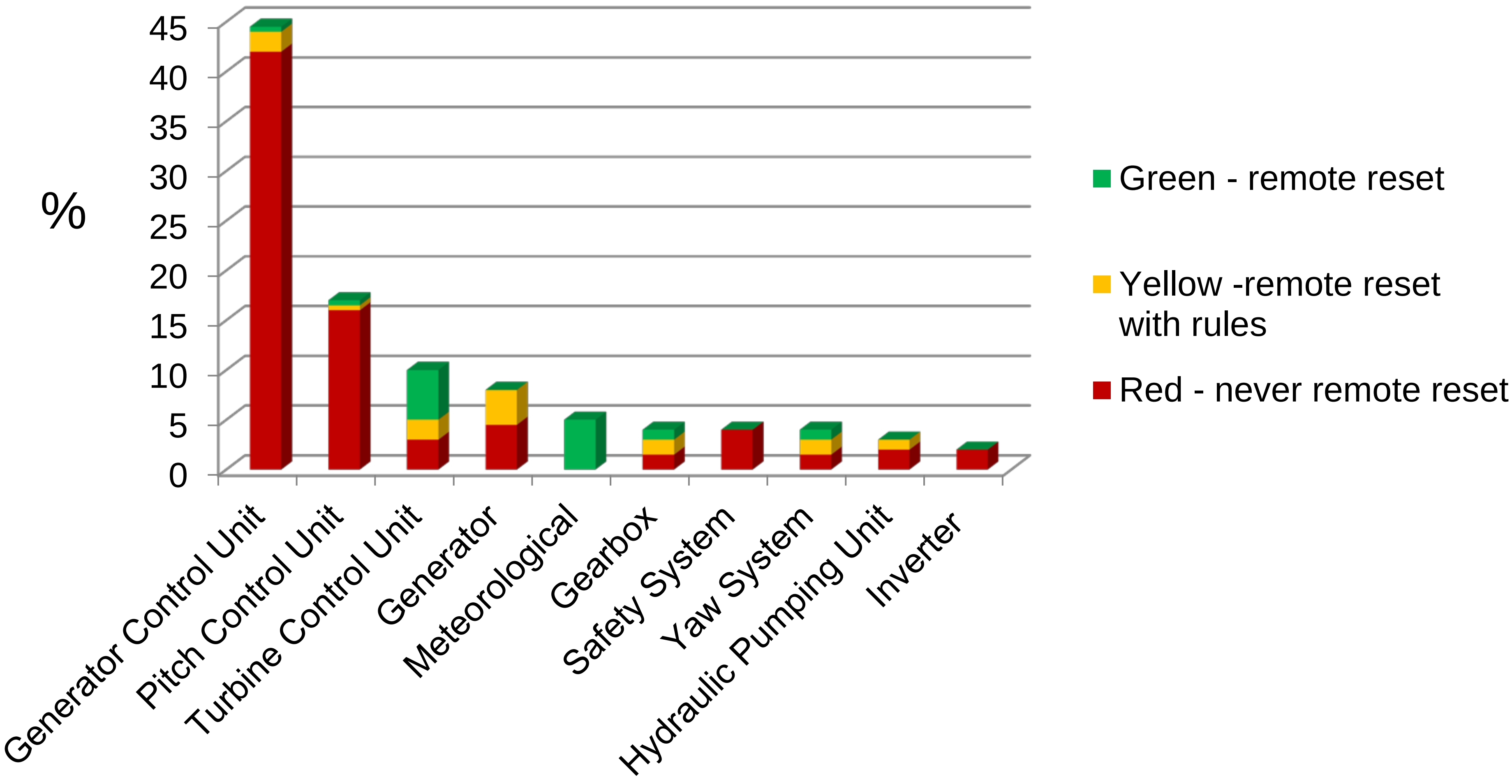
Automated on-line fault prognosis for wind turbine pitch systems using supervisory control and data acquisition, Bindi Chen, Peter C. Matthews, Peter J. Tavner, IET RPG, 2015

Components of variable speed wind turbines and their reliabilities



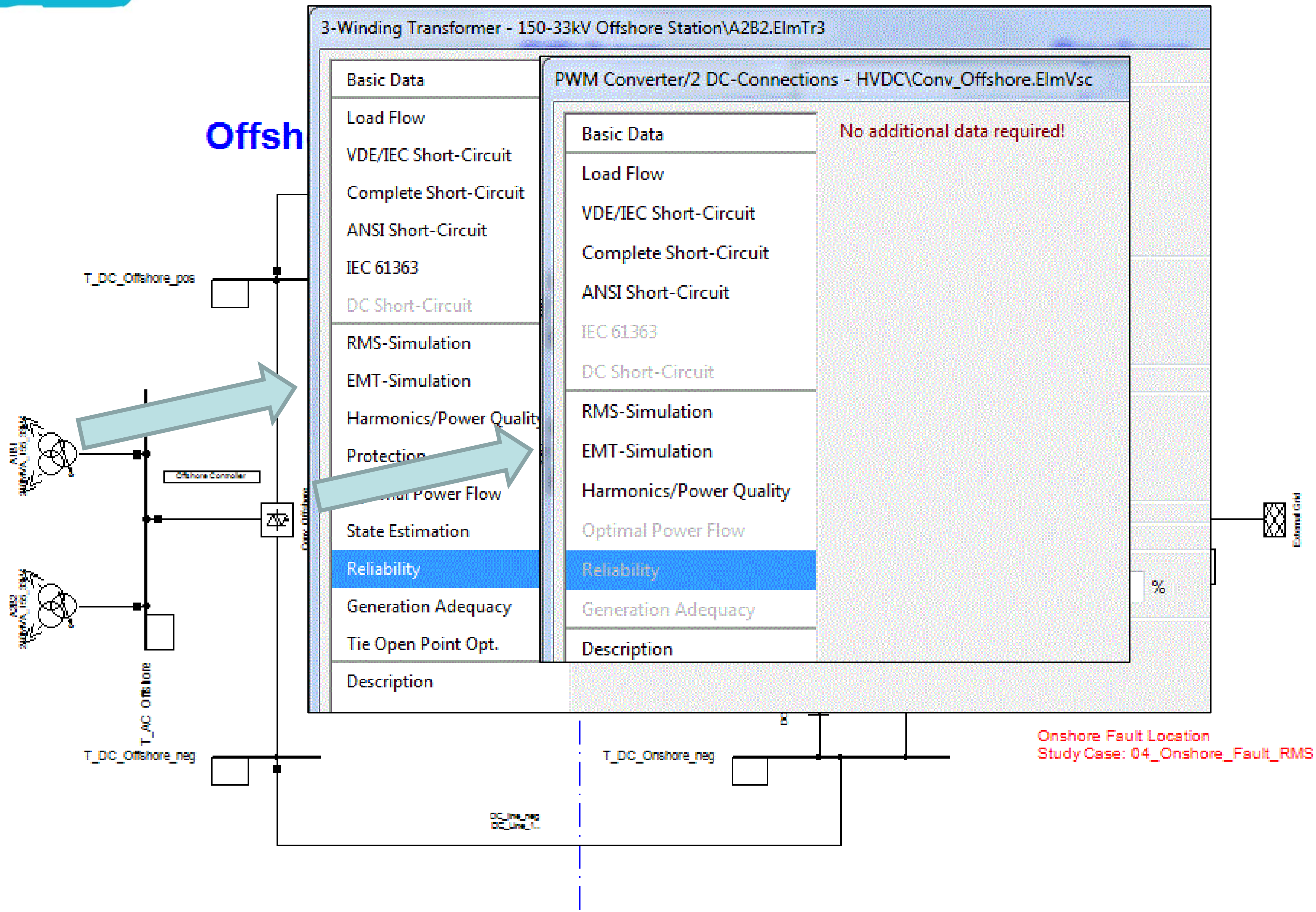
From : Design Limits and Solutions for Very Large Wind Turbines, Mar. 2011. UpWind project.

SCADA Alarms

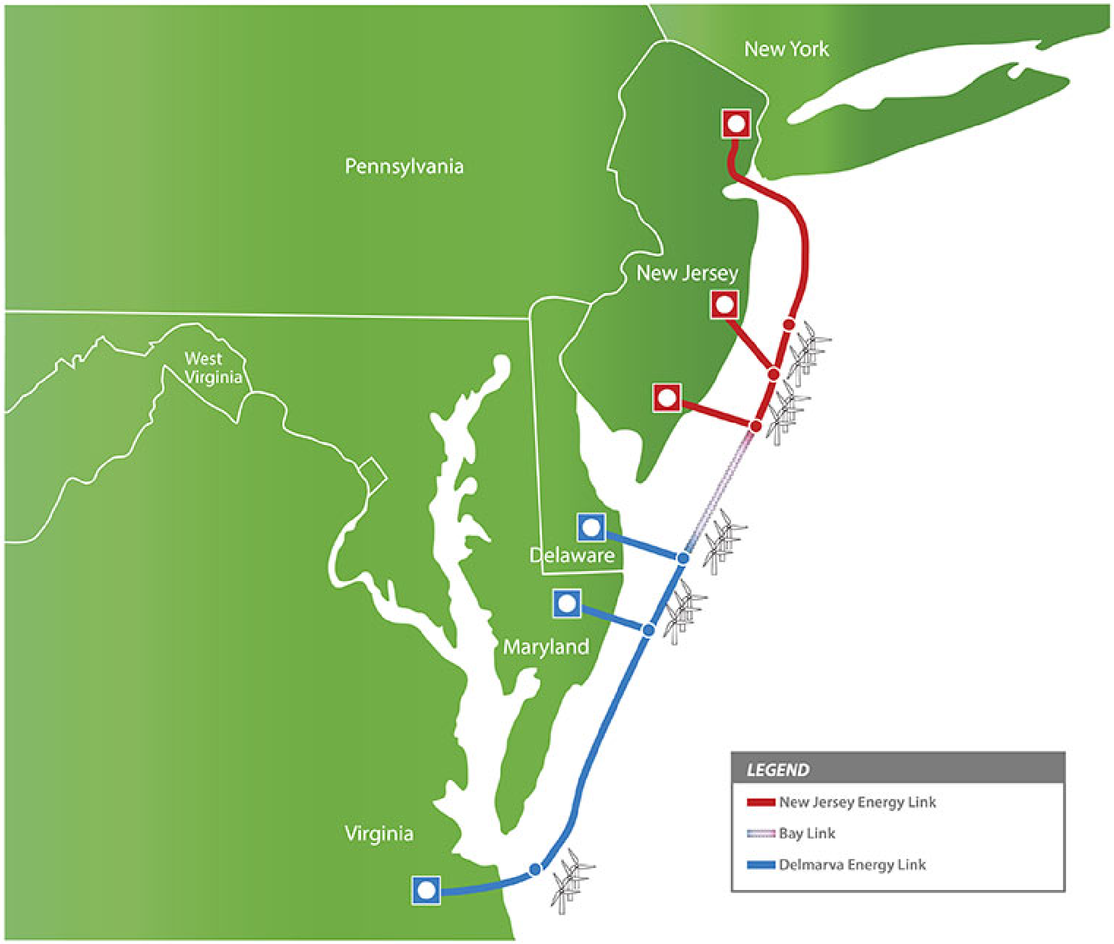


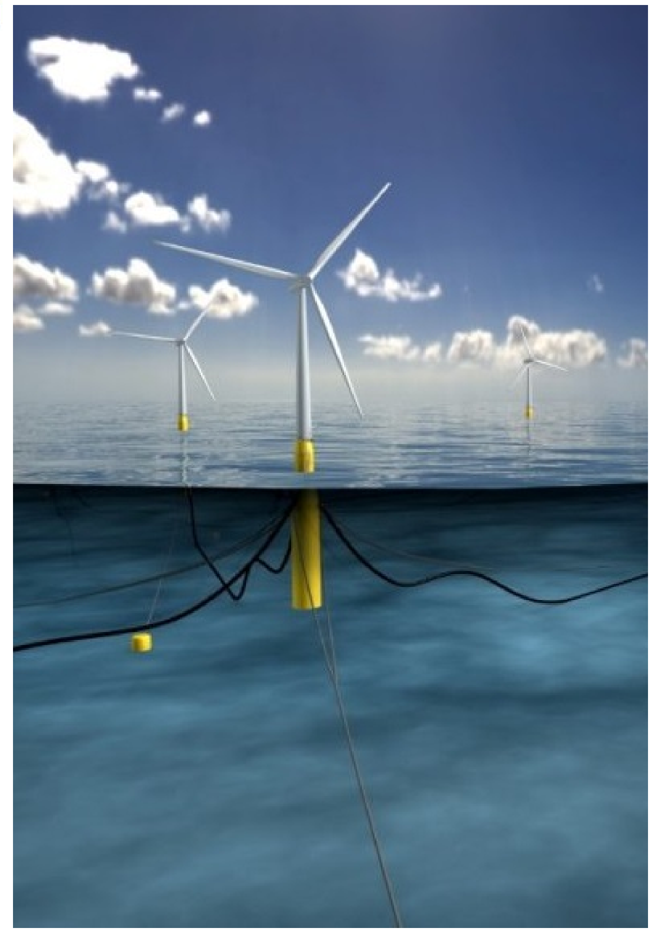
Wind turbine SCADA alarm analysis for improving reliability Yingning Qiu, Yanhui Feng, Peter Tavner, Paul Richardson, Gabor Erdos and Bindi Chen, Wind Energy 2012

Simulation state-of-the-art - DSPF



Challenge Disruptive Technologies





http://atlanticwindconnection.com/projects/

https://www.statoil.com/en/news/hywindscotland.html

HOME Offshore

Project Goal

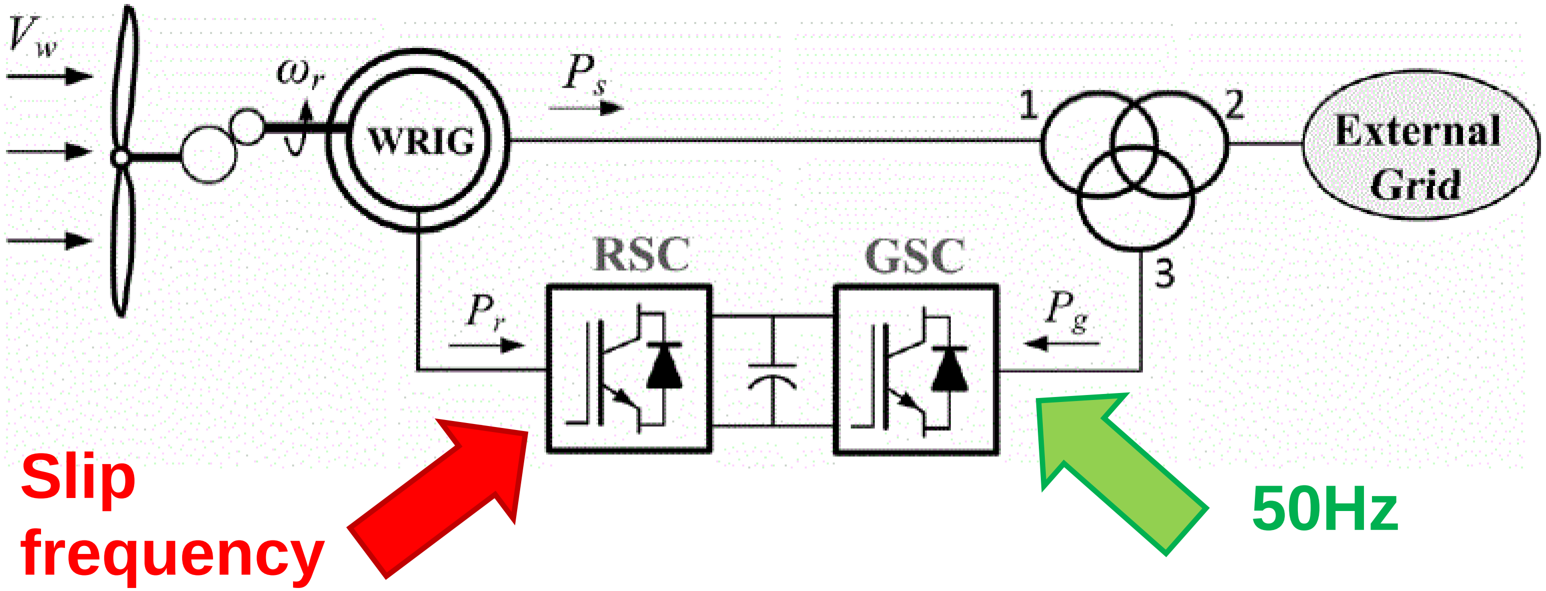
- Improved actionable data for offshore windfarms

Prior Work / Research Avenues

Work based on:

1. Multi-physics modelling
2. Advanced sensing / condition monitoring
3. Reliability analysis
4. Robotics (e.g. subsea cable monitoring)

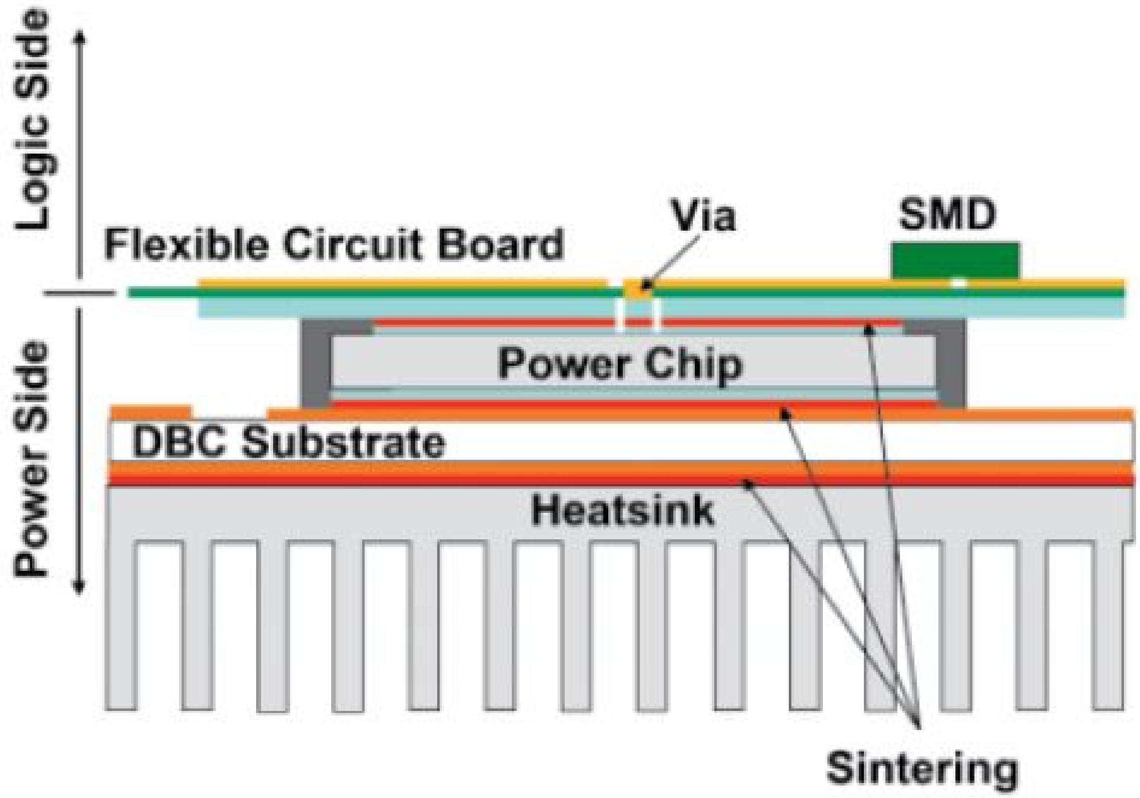
1. Wind Turbine: multi-physics modelling



Issue: RSC fails more frequently than GSC of same rating

Ting Lei, Mike Barnes, Sandy Smith, Sung-ho Hur, Adam Stock, and William Leithead, "Using Improved Power Electronics Modelling and Turbine Control to Improve Wind Turbine Reliability", IEEE Trans. Energy Conversion, vol. 30, no. 3, Sept. **2015**, pp. 1043-51, DOI: 10.1109/TEC.2015.2422792

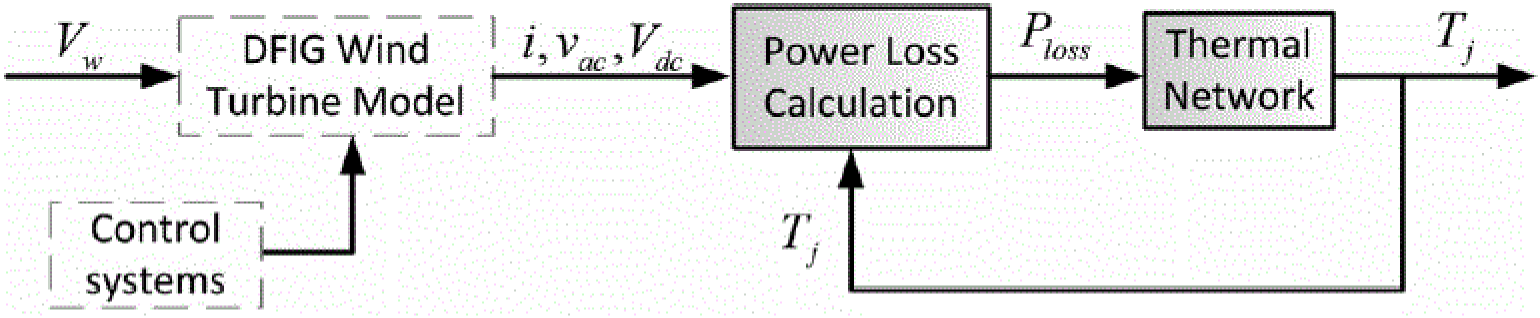
Typical Power Electronic Module



Schematic cross section of the first gen SKiN® module

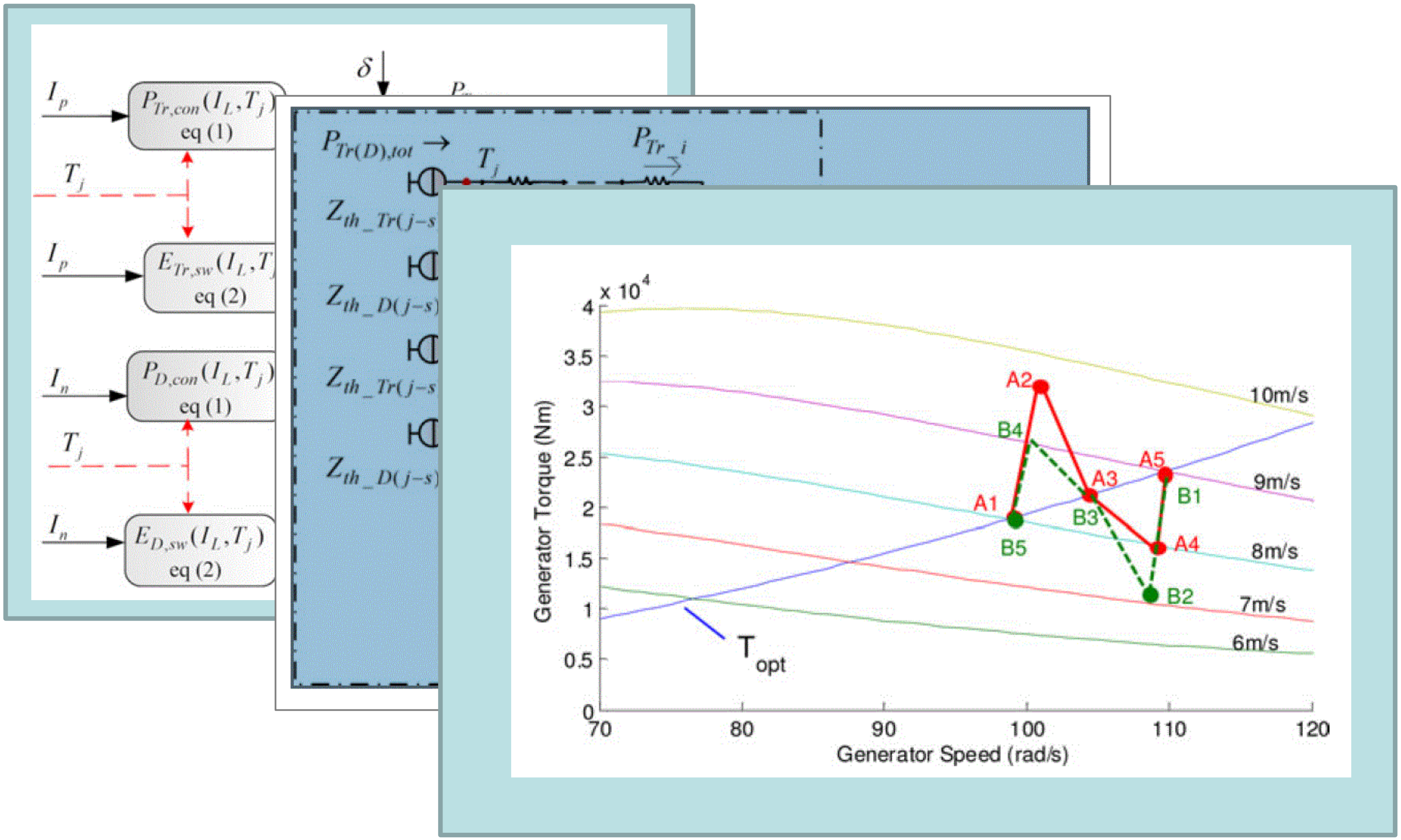
http://www.powerguru.org/new-packaging-technology-enabling-high-density-low-inductance-power-modules/

Model overview



- Investigation: multi-physics model
- Semi-coupled with mechanical model

EMT Model additions

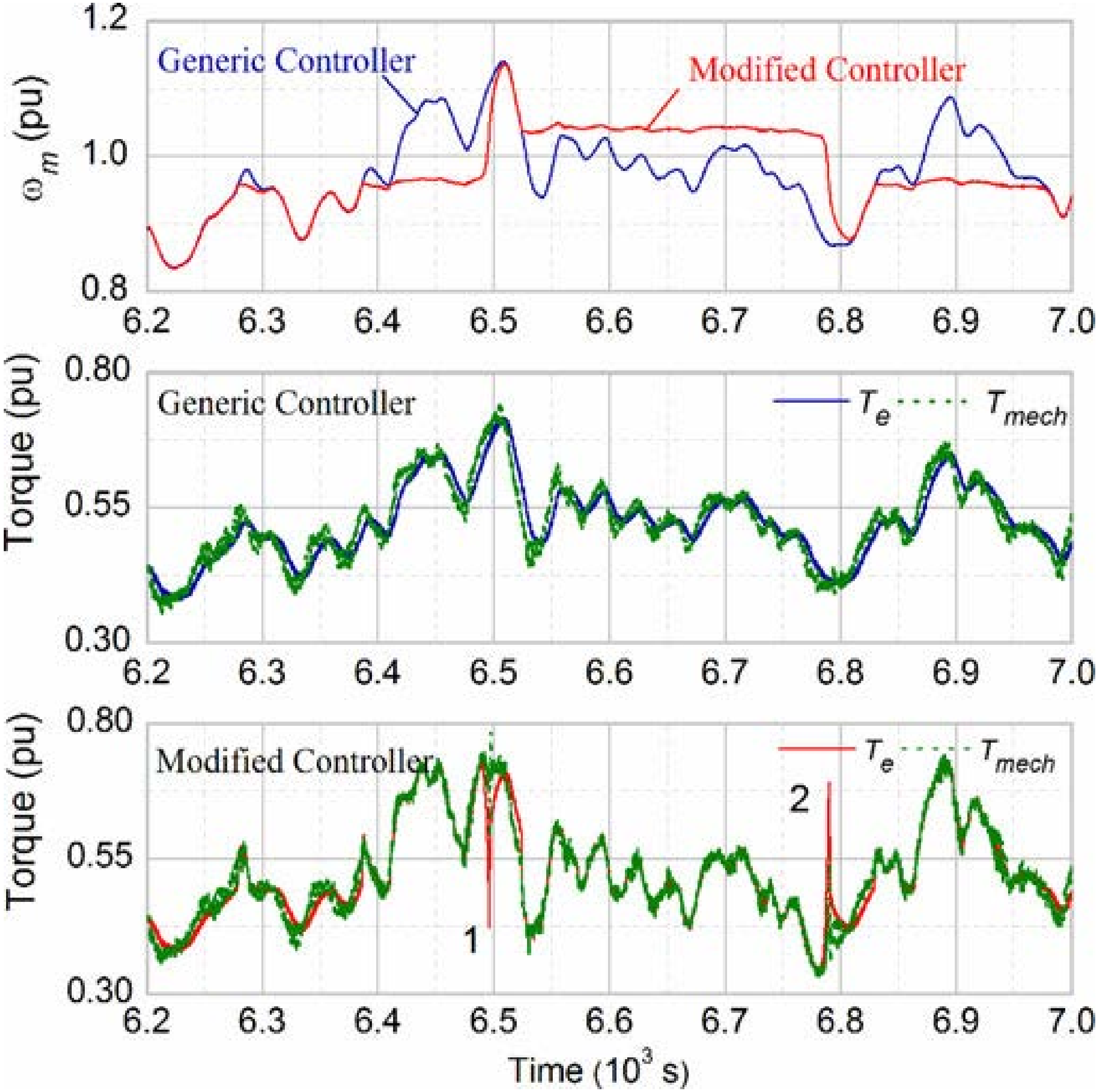


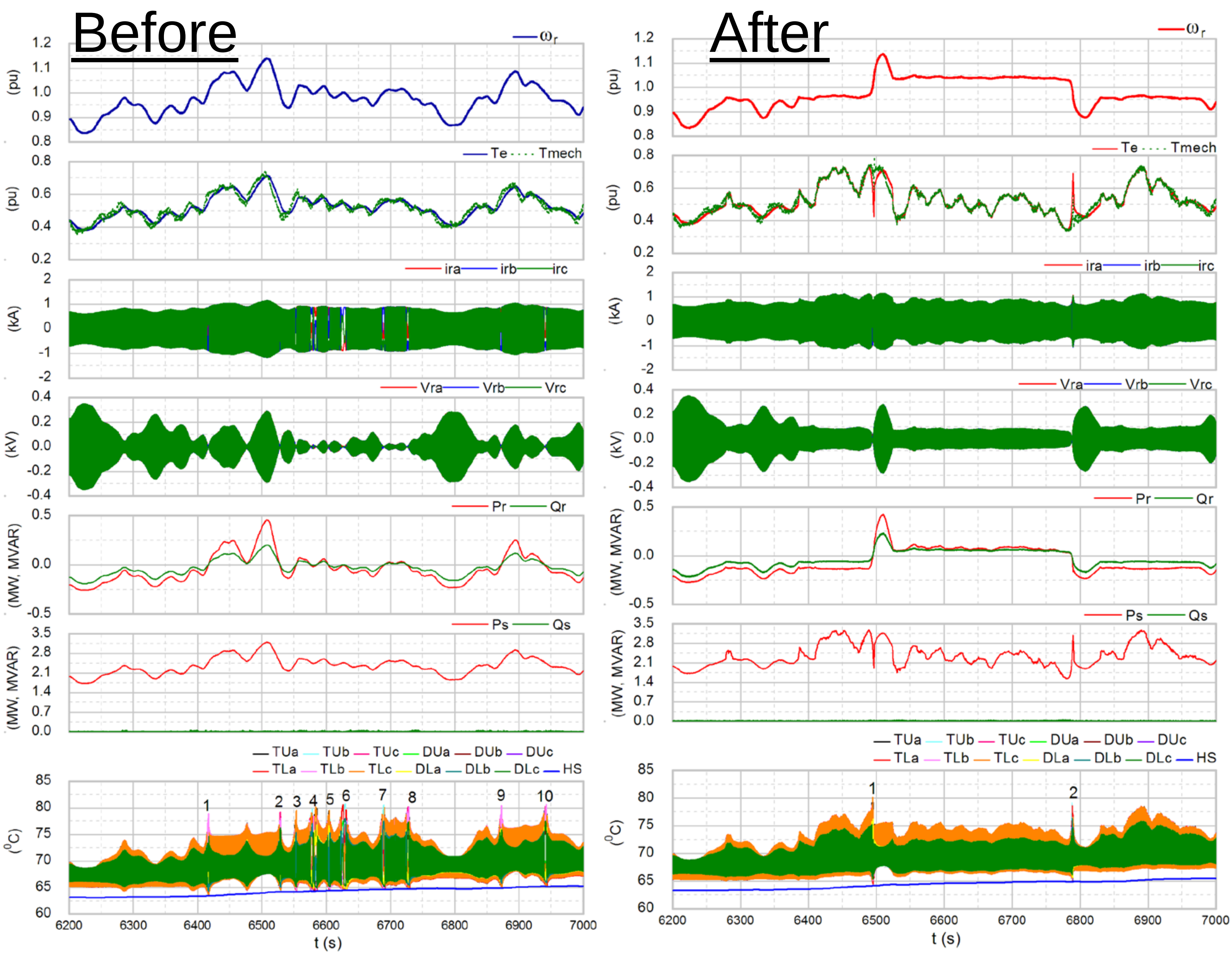
1. Switch averaging

2. Thermal model

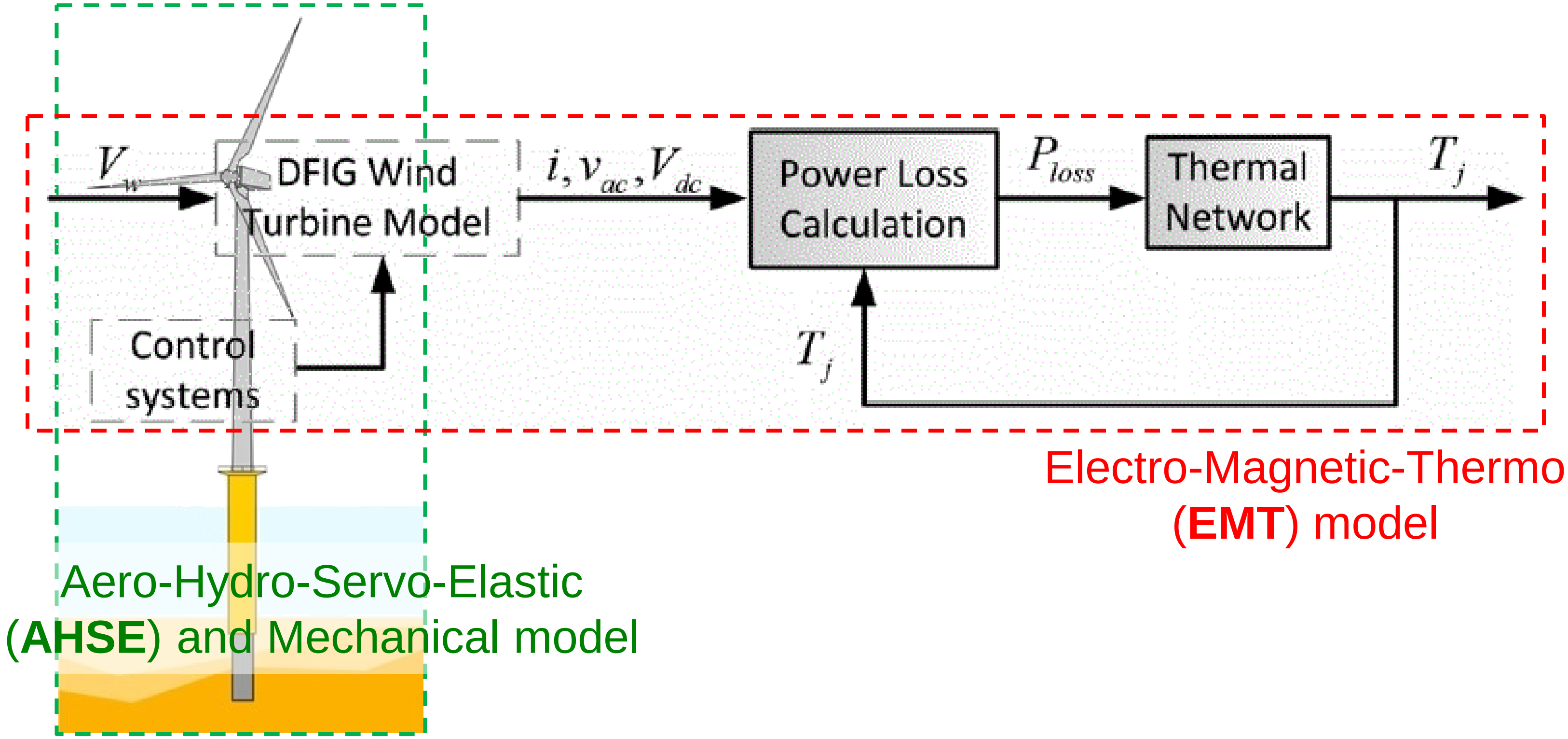
3. Blade control and input

Operation – mitigation strategies




Before
After
ωr
Te Tmech
ira irb irc
Vra Vrb Vrc
Pr Qr
Ps Qs
TUa TUb TUc DUa DUb DUc
TLa TLb TLc DLa DLb DLc HS
(pu)
(kA)
(kV)
(MW, MVAR)
(°C)
t (s)
1
2
3
4
5
6
7
8
9
10

Model overview



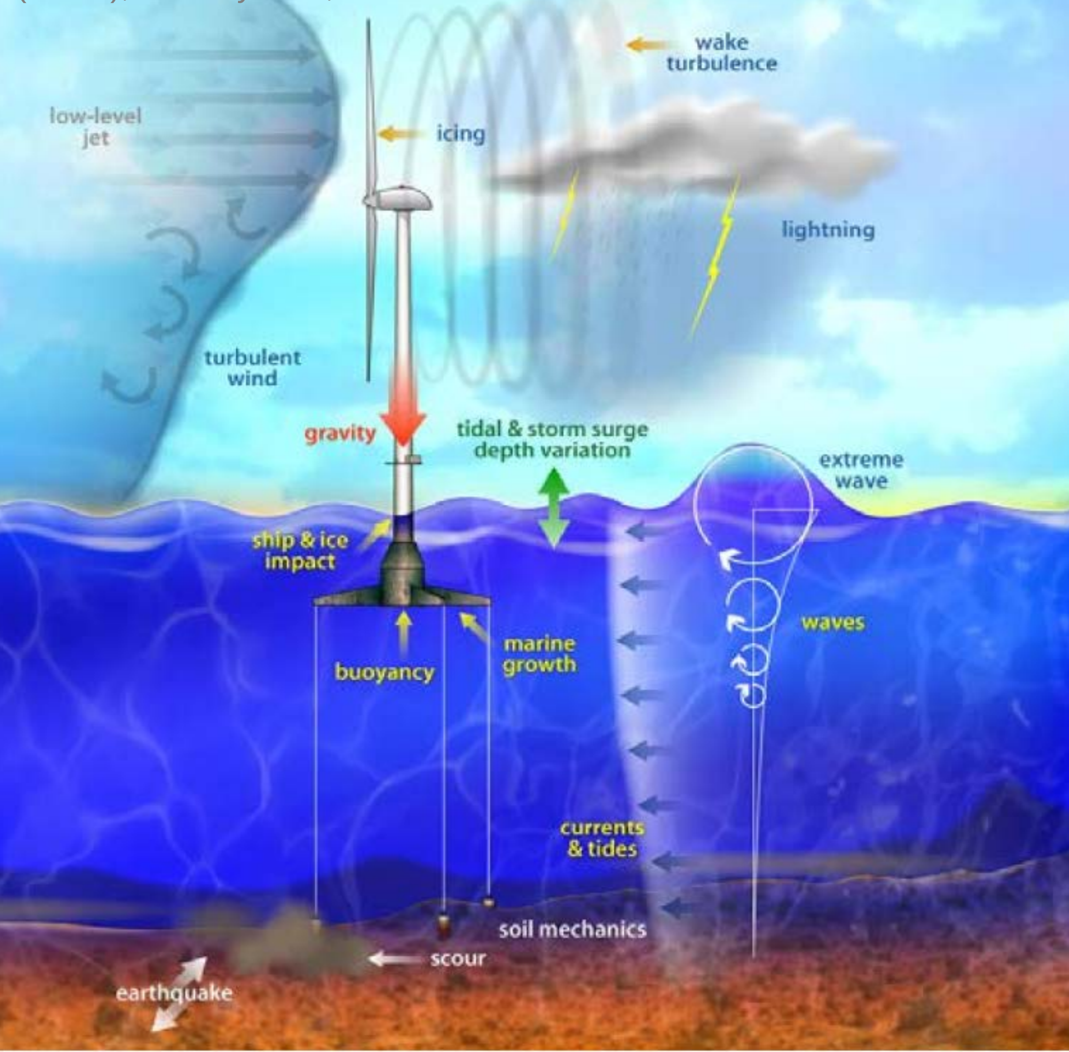
- Investigation: multi-physics model
- Coupled with AHSE and mechanical model

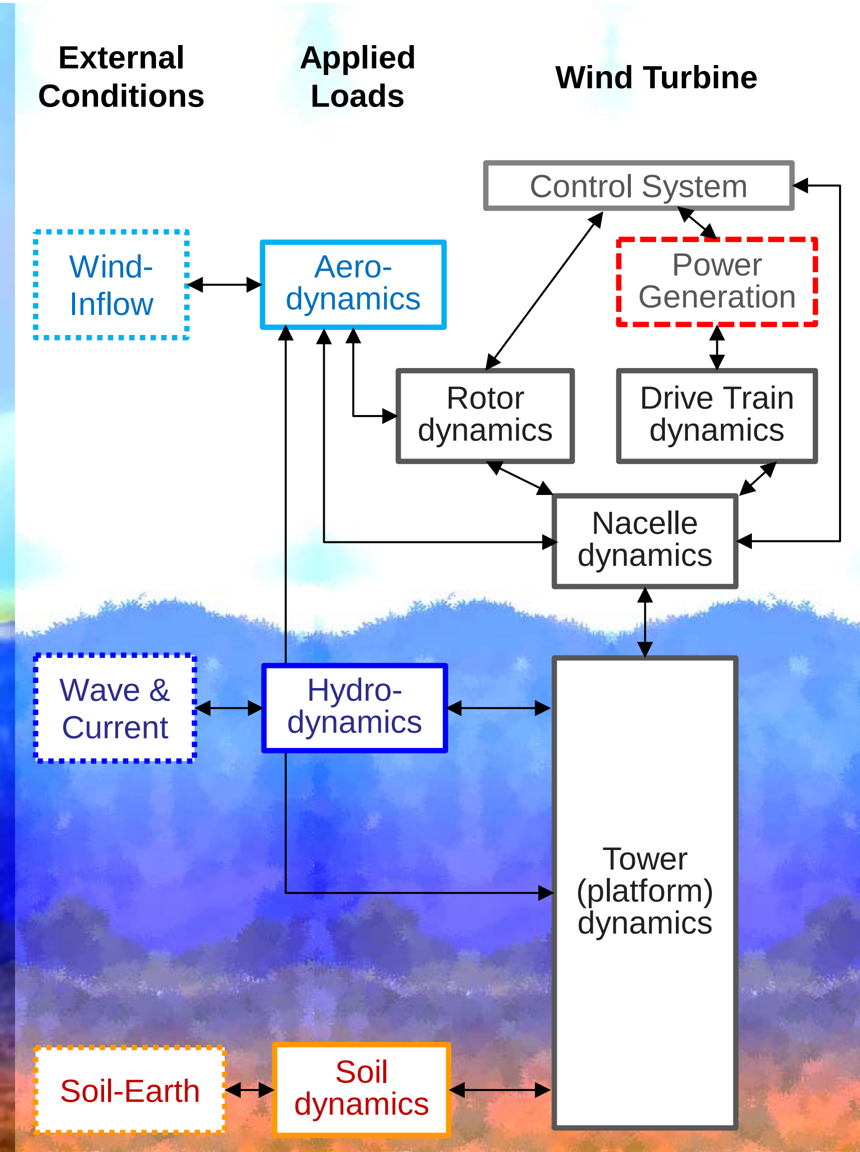
HOME Offshore

EPSRC
Pioneering research and skills

AHSE Model overview

Jonkman Jason, “The New Modularization Framework for the FAST Wind Turbine CAE Tool”, 51st AIAA Aerospace Sciences Meeting, Dallas (Texas), January 7-10, 2013

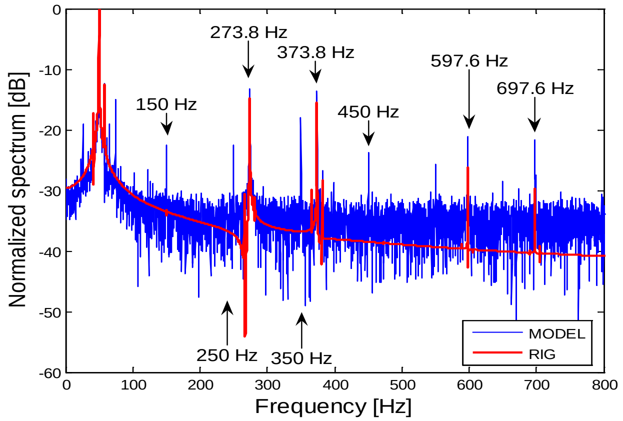




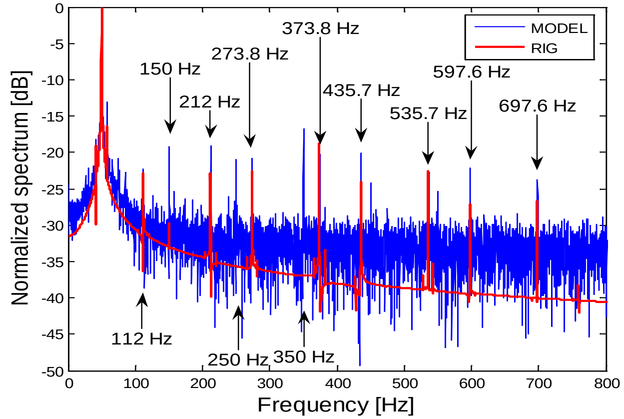
2. Fault detection in WT generators - electro-mechanical signature analysis

Previous/ongoing work

- Detailed numerical/analytical models for electrical and mechanical fault monitoring and analysis on DFIG/PM generators
- Generator bearing fault detection
- Mixed vibration / current signature use for improved fault detection
- Fault analysis in realistic transient conditions



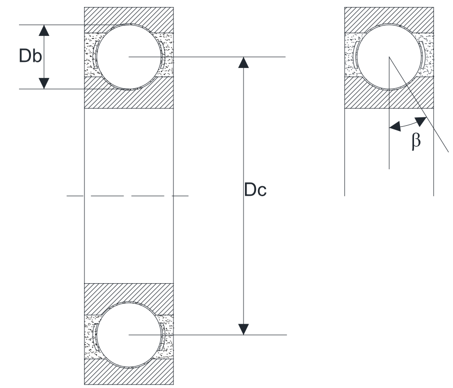
Healthy DFIG current signal

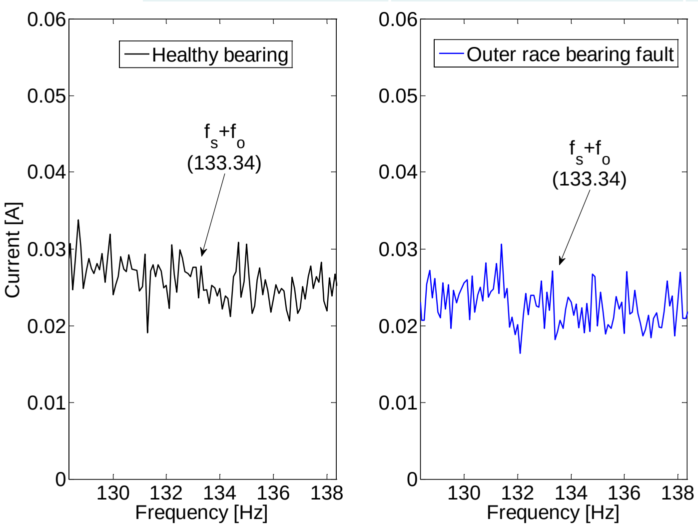


DFIG with a stator winding fault

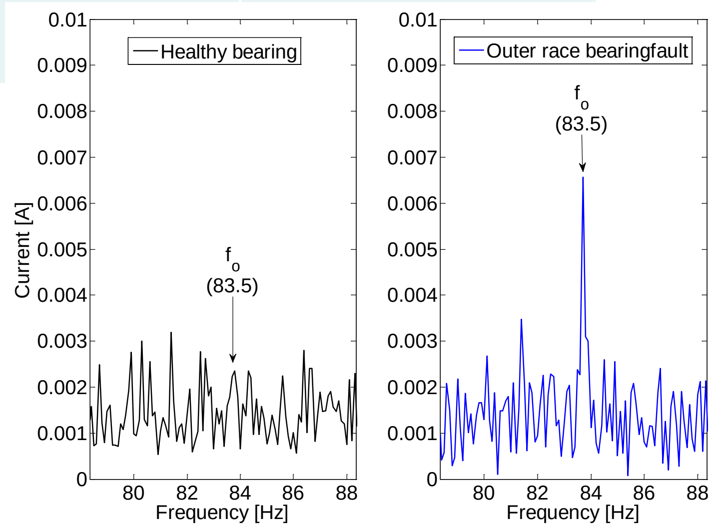
Generator bearing fault detection using instantaneous negative sequence current spectra

Fault	Mechanical frequencies	Current frequencies	Negative seq. frequencies
Inner race	$G_o = \frac{N_b}{2}\left(1 - \frac{D_b}{D_c}\cos\beta\right)$	$f_{oc} = f_s \pm k f_r G_o$	$f_o = k f_r G_o$
Outer race	$G_i = \frac{N_b}{2}\left(1 + \frac{D_b}{D_c}\cos\beta\right)$	$f_{ic} = f_s \pm k f_r G_i$	$f_i = k f_r G_i$
Ball	$G_b = \frac{D_c}{D_b}\left(1 + \frac{D_b^2}{D_c^2}\cos\beta\right)$	$f_{oc} = f_s \pm k f_r G_o$	$f_b = k f_r G_b$





Normal stator current spectrum: no clear signal to indicate bearing problem

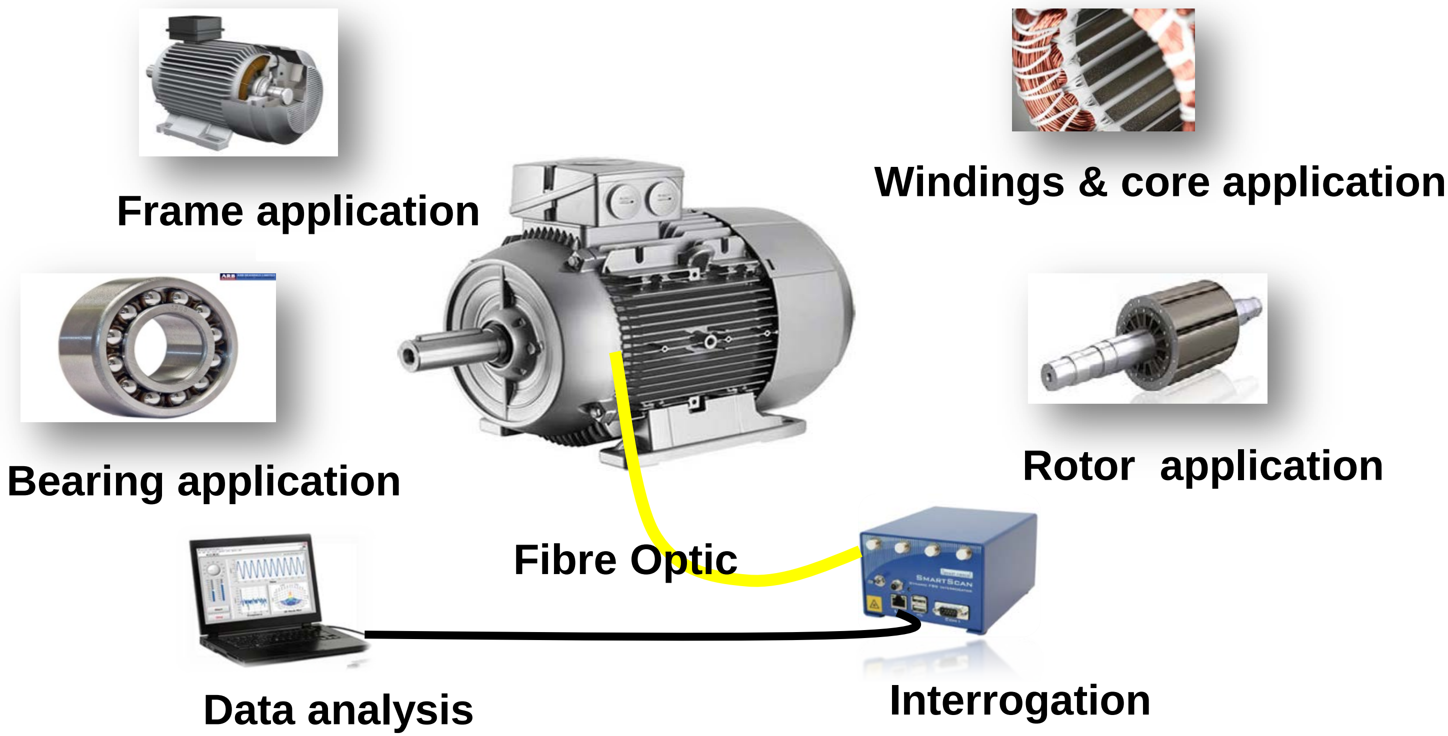


Instantaneous negative sequence current spectrum: clear frequency signal relating to bearing fault.

Generator outer race bearing fault - test rig

Going forward: Embedded monitoring for improved drivetrain diagnostics

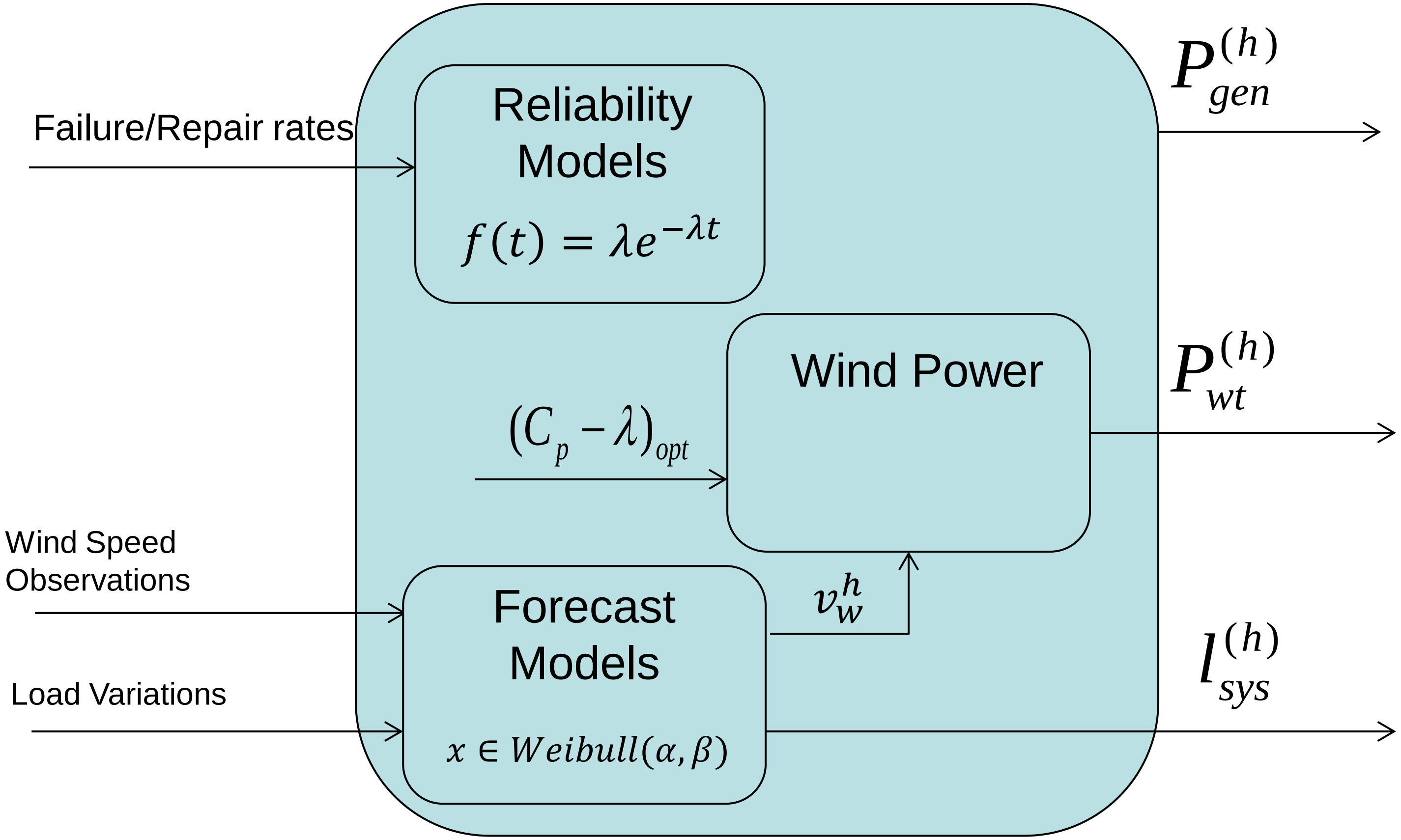
- Current diagnostics performance largely limited by sensing access to critical failure points
- Research on embedded FBG sensing solutions for generator/drivetrain thermal and mechanical measurements
- In close proximity to known failure points to enhance diagnostic efficiency
- Fusion of embedded and conventional CM indices for improved diagnostics



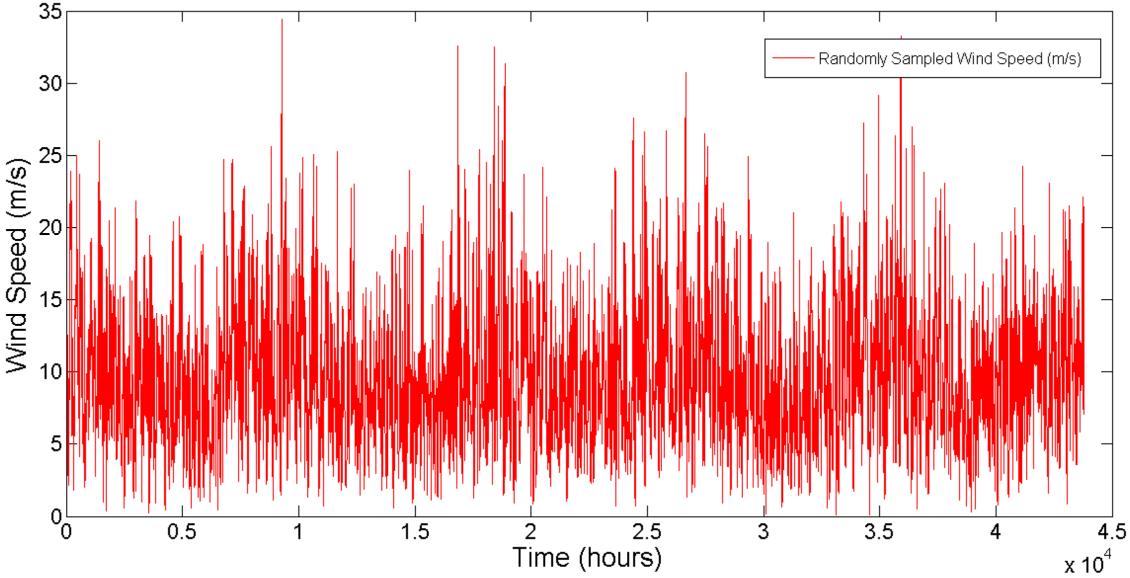
3. Evaluation of risk and reliability of various offshore wind farm connection designs

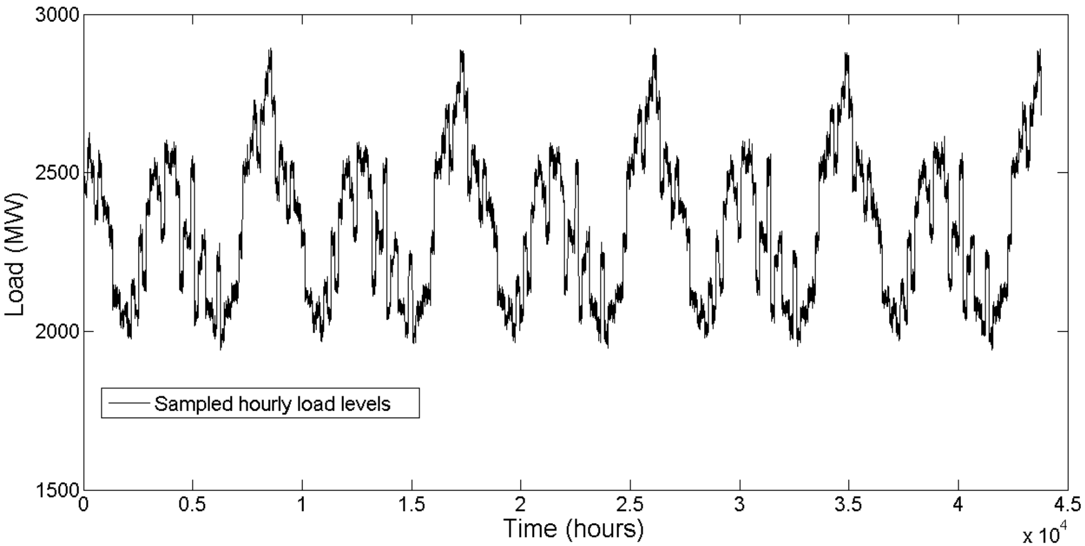
- Offshore network selection based on lowest risk of energy loss/power outage
  - Wind Farm Location
  - Weather Factors
  - State of onshore grid

System Simulation Overview

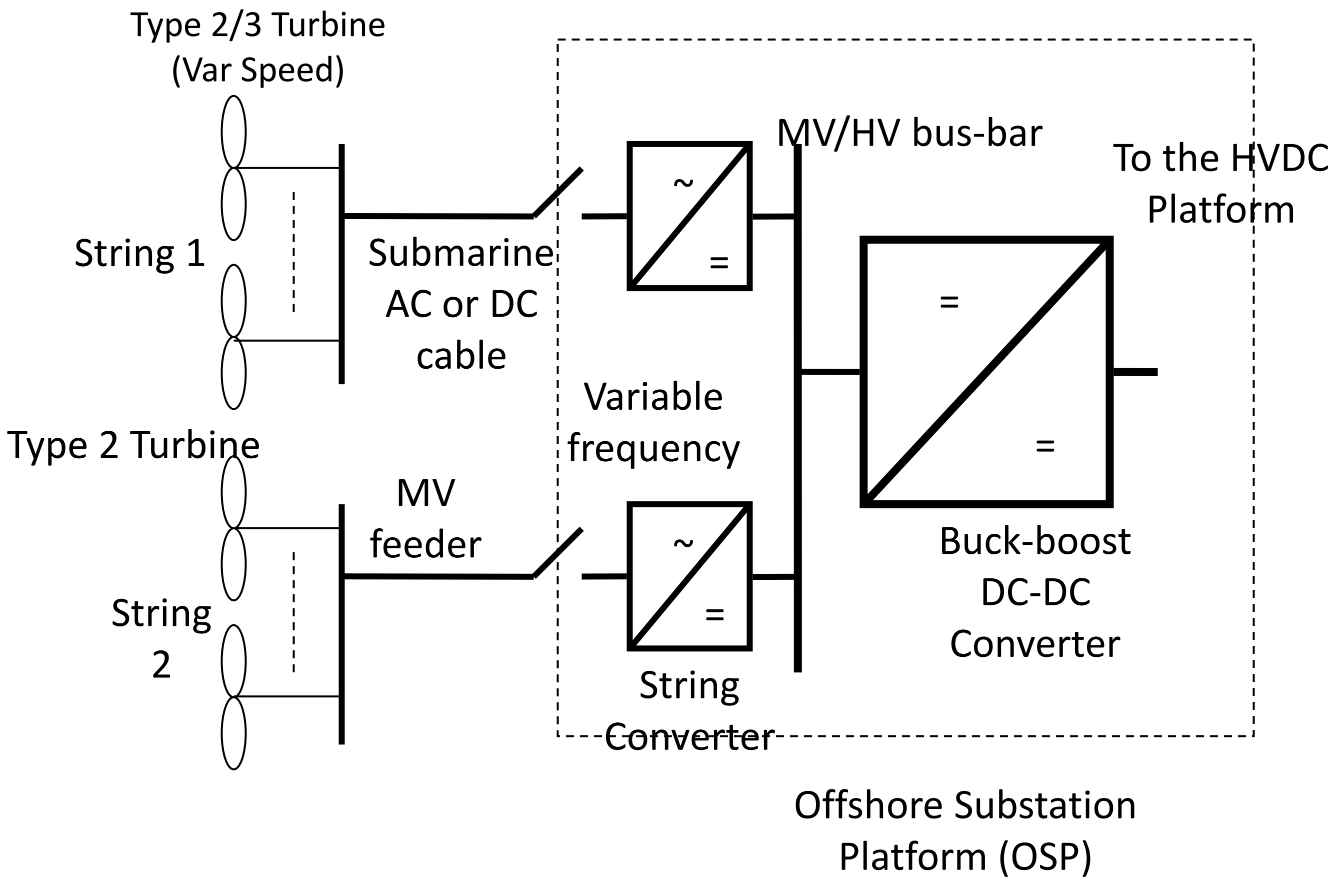


Wind Speed and Load Forecast Model





Offshore Connection Type (B/C)



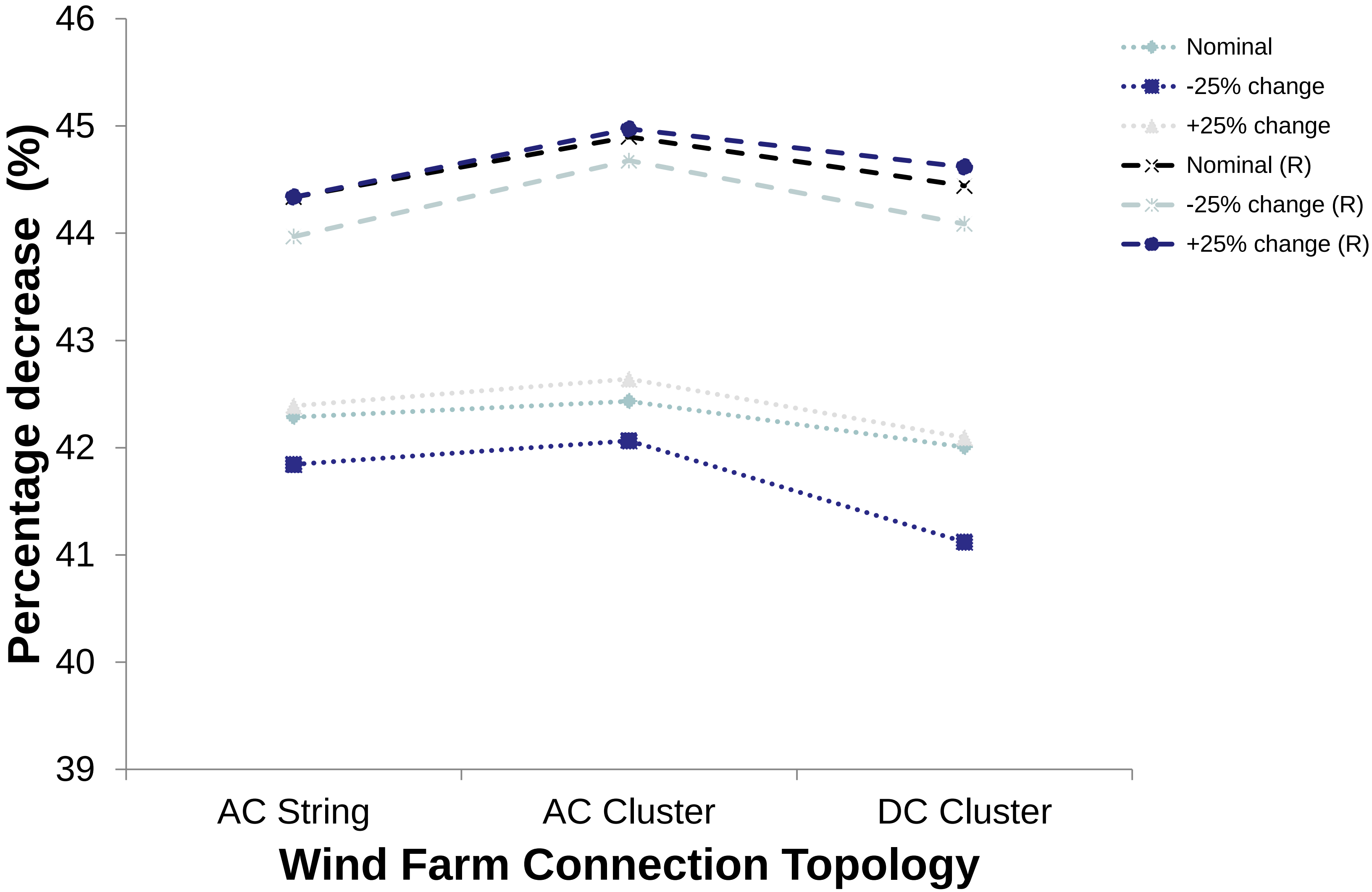
Wind Farm		Onshore System (IEEE-RTS)		Annual Peak Load
No. Turbines	100	No. Gens	32	2850 MW
Rated Power	600 MW	Rated Power	3405 MW	

System Performance Evaluation

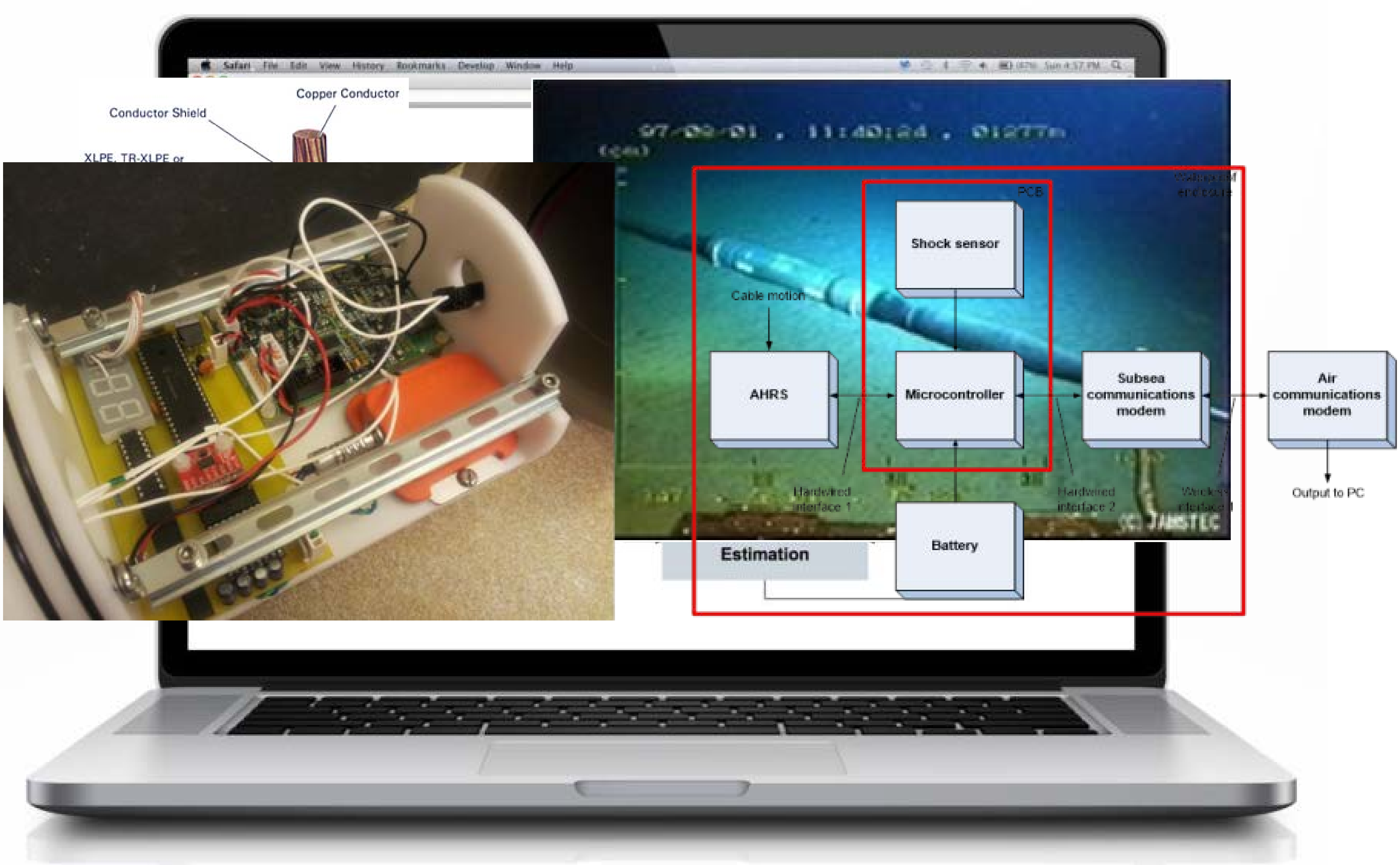
Performance Index	Definition
Availability (%)	Average time that the system was available and producing power
Capacity Factor (%)	System's productivity
EDLC (time/year)	The total amount of time that system's power was exceeded by demand
EENS (MWh/year)	The total amount of energy loss due to a mismatch between output power and demand

EDLC ➔ Expected Duration of Load Curtailment
EENS ➔ Expected Energy Not Supplied

EDLC Variation with additional Wind Power



4. Subsea Power Cable Asset Management



Fusion of Datasets

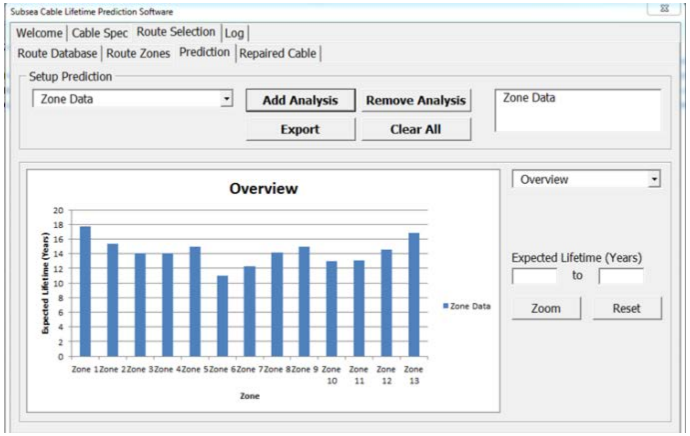
Desktop Analysis Tool
- Predict both MTBF and TTF
- Database for data capture

Random Failures
- Mean Time Between Failure (MTBF)
- Based on field data
- Function of fishing activity

Wear Out Failures
- Total Time to Failure (TTF)
- Based on abrasion/corrosion
- Based on tidal flow

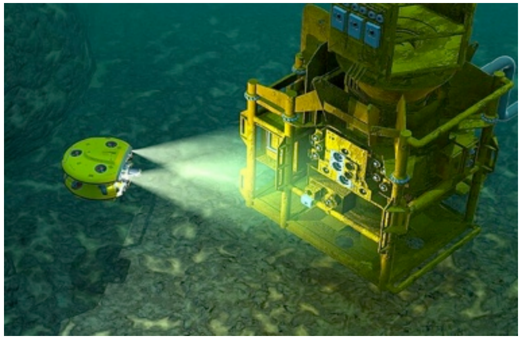
Field Data
- Impacts on cable
- Fishing activity
- Data from PHM Sensors

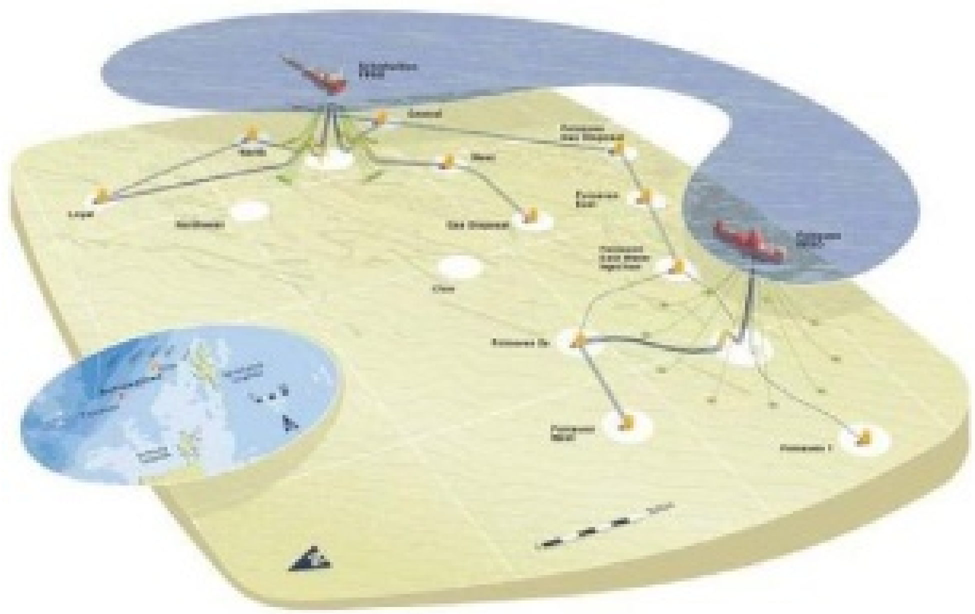
Tests
- Wear rates
- Corrosion Rates
- Accelerated ageing



Subsea as a Smart Space

Robots are the arms, legs and sensors of Big Data





Interaction between people, data, robots.

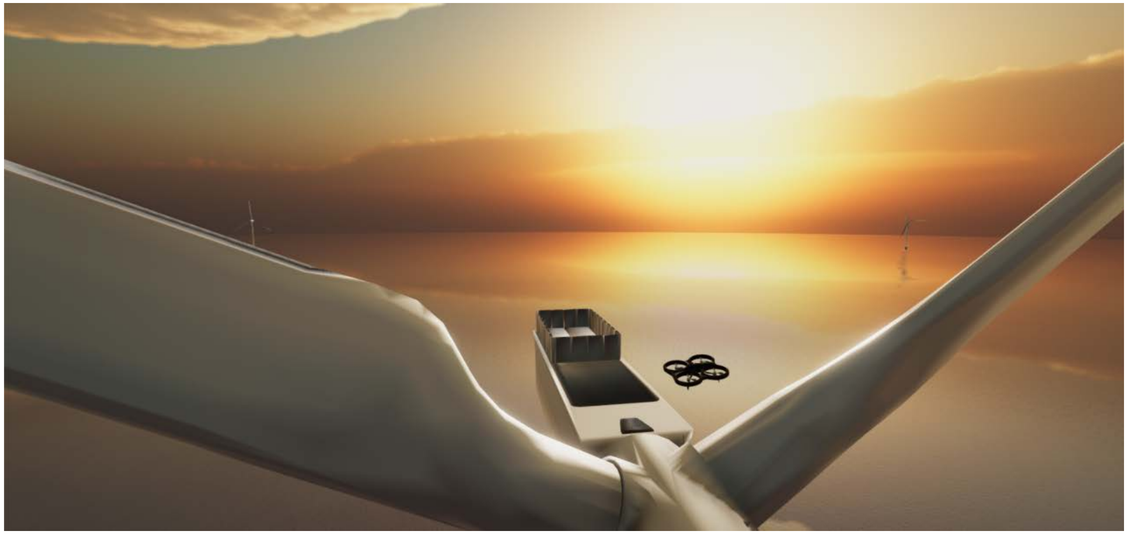
Condition monitoring as part of Life of Field asset integrity

Robotics Inspection

It is proven that robotics are useful for performing task which are classed as dirty, dull and/or dangerous.


VS


3D Visualisation



In conclusion

- Combining and extend different specialisms to offer a ‘holistic’ approach to offshore O&M and CM

- Target actionable data and interventions

Thank you!

Questions?