An Introduction to Floating Wind Turbines

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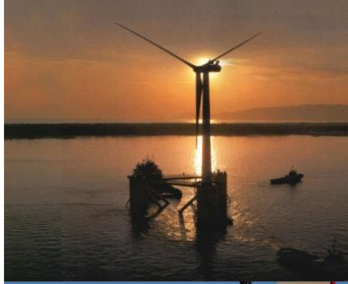
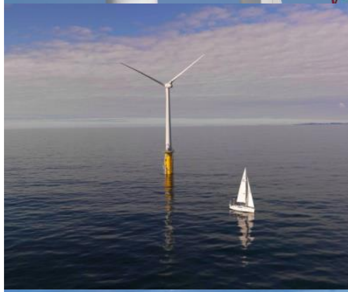
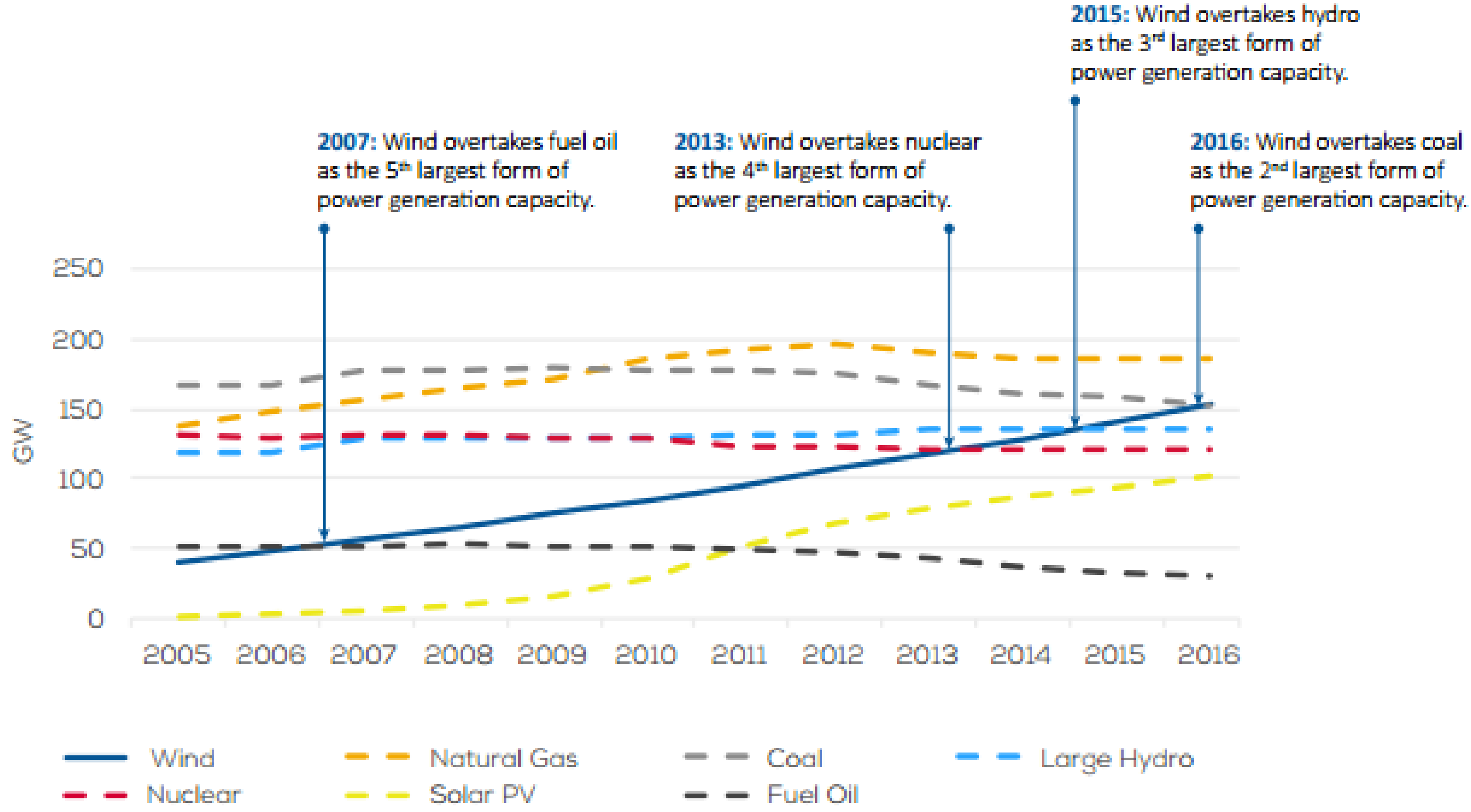




INTRODUCTION

Motivation (1)

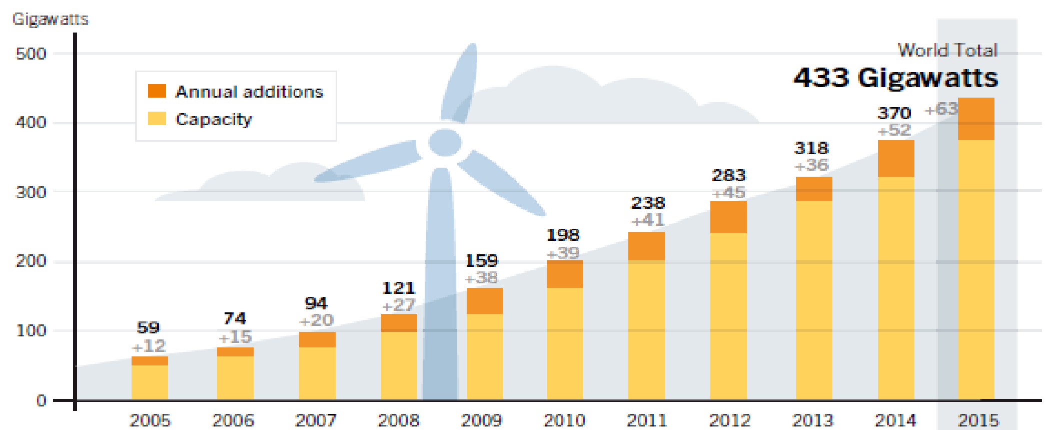
Cenário: fontes de geração elétrica - Europa



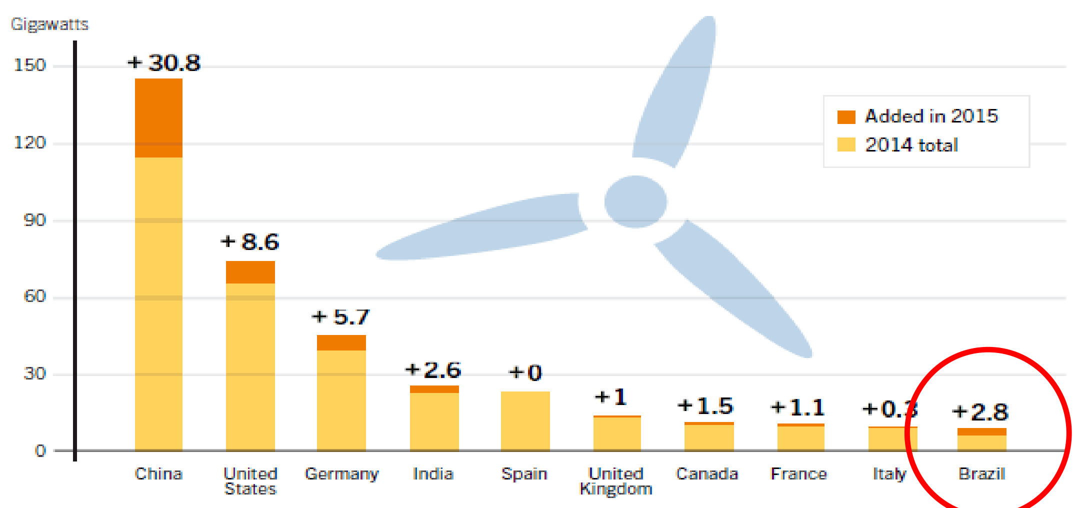
Source: WindEurope

Motivation (1)

Wind Power Global Capacity and Annual Additions, 2005–2015



Wind Power Capacity and Additions, Top 10 Countries, 2015



Source: Renewables 2015 Global Status Report

BRAZIL

10.6 GW (installed)

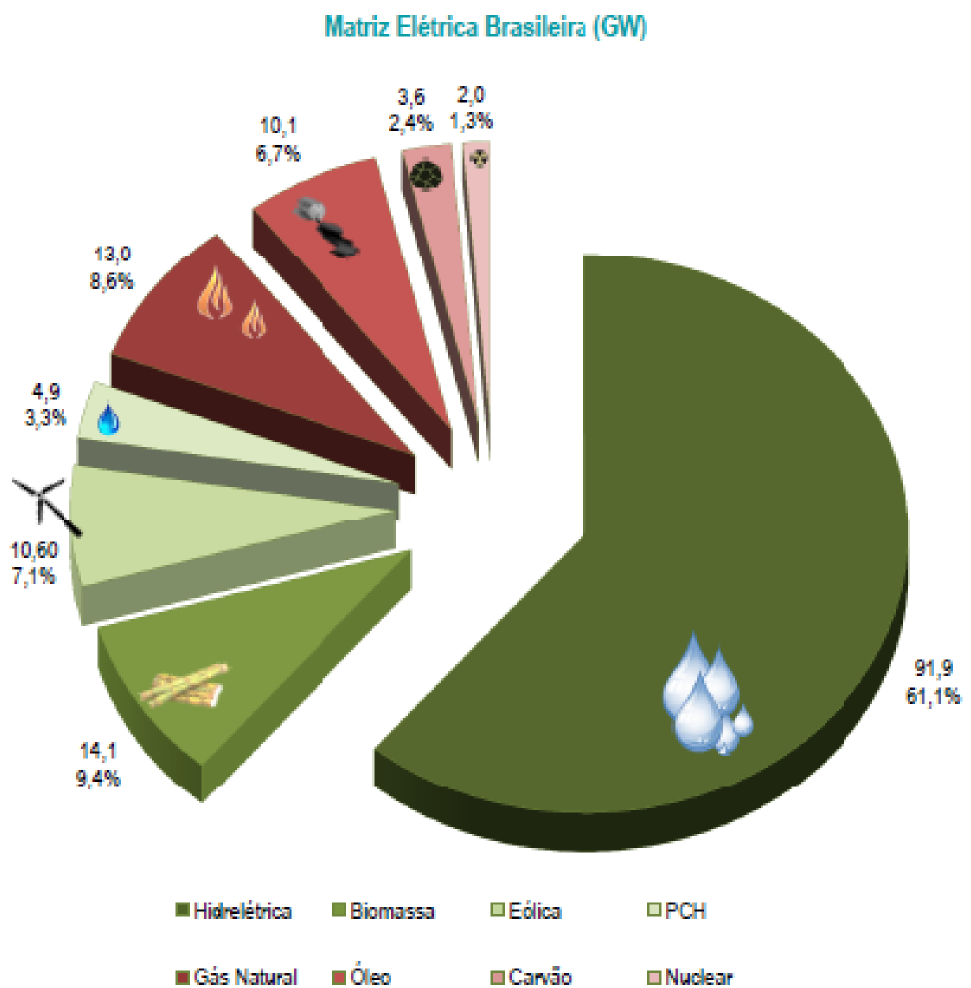
+

7.4 GW (contracted)

Onshore Potential ~500GW

Source: FAPESP 2016

Motivation (1)



Fonte: ABEEólica - Dados mensais de Dezembro 2016

BRAZIL

10.6 GW (installed)

+

7.4 GW (contracted)

Onshore Potential ~500GW

Source: FAPESP 2016

Motivation (1)

OFFSHORE WIND: MAIN ADVANTAGES*

- greater area available for siting large projects;
- proximity to cities and other load centers;
- generally higher wind speeds compared with onshore locations;
- lower intrinsic turbulence intensities;
- lower wind shear.

*Manwell, McGowan, Rogers
Wind Energy Explained

siemens.com

Motivation (1)

vox.com

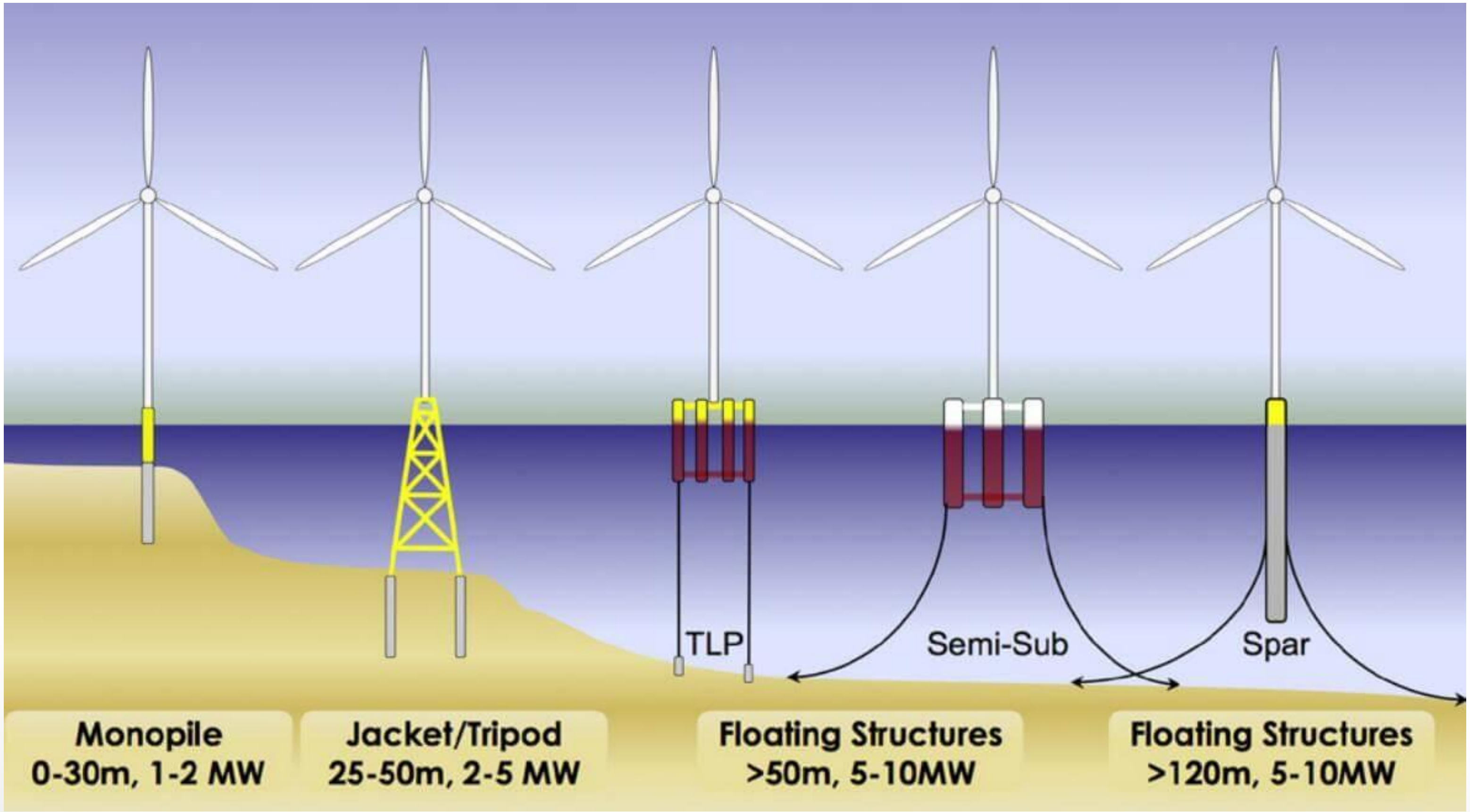
*Manwell, McGowan, Rogers
Wind Energy Explained

OFFSHORE WIND: MAIN CHALLENGES*

- higher project costs due to a necessity for specialized installation and service vessels and equipment and more expensive support structures;
- more difficult working conditions;
- more difficult and expensive installation procedures;
- decreased availability due to limited accessibility for maintenance;
- necessity for special corrosion prevention measures

Motivation (1)

Moving further offshore: Floating Offshore Wind Turbines



Source: windpowerengineering.com

Motivation (1)

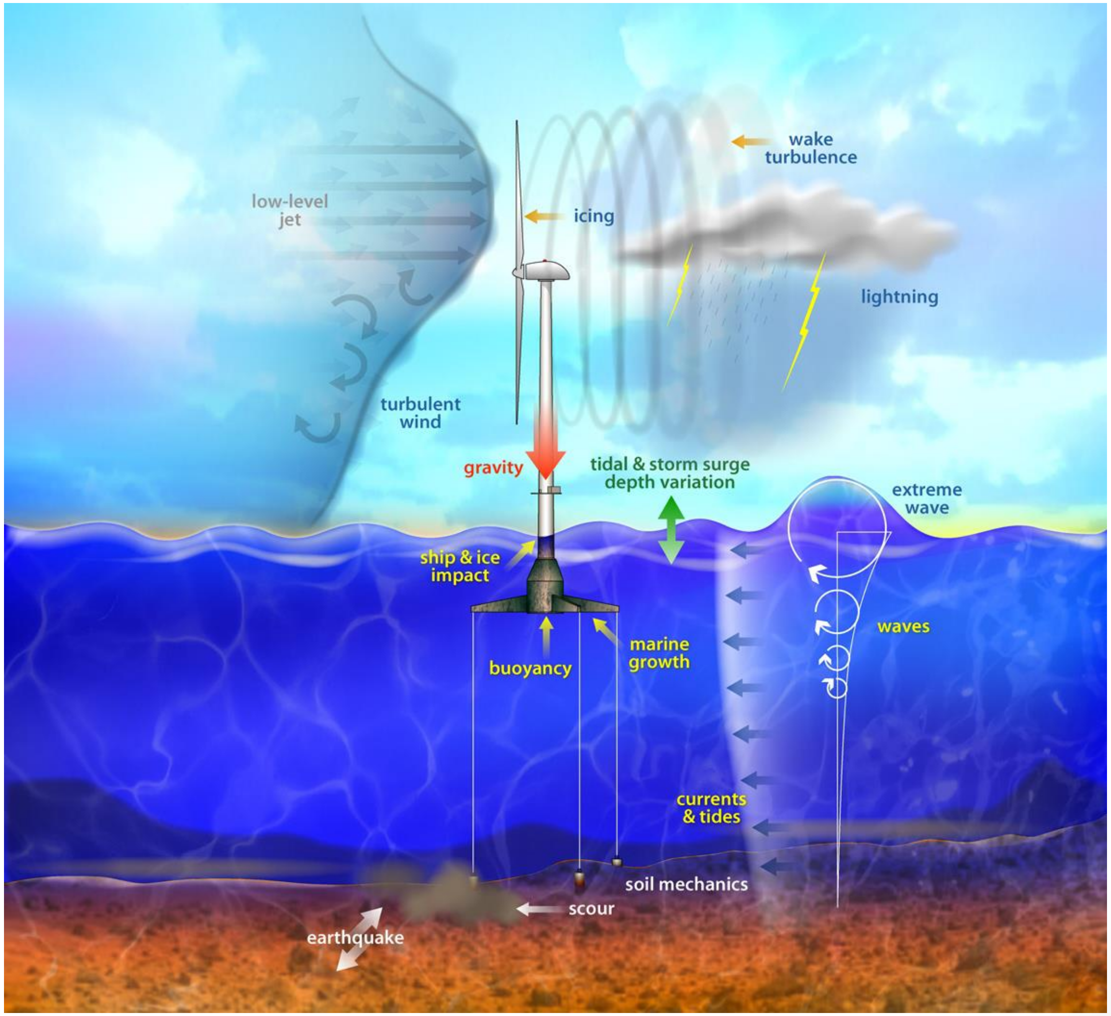
Fixed (jaquets or monopiles)

Floating

Motivation (1)

Design: New Concerns

- Seakeeping
- Effects of floater motions on the turbine performance
- Mooring design



Motivation (2)

Concepts adopted for the FWTs come from the offshore oil&gas industry. Brazil is one of the leaders in R&D for the analysis and design of deep water offshore systems;

WindFloat (Portugal)

Motivation (2)

FWT concepts: from oil&gas to wind power extraction

semi-submersible

Fukushima's demonstration project Japan
(mitshubishicorp.com)

Motivation (2)

FWT concepts: from oil&gas to wind power extraction

TLP

Motivation (2)

FWT concepts: from oil&gas to wind power extraction

SPAR

Statoil's *Hywind* (Norway)

Motivation (2)

Hywind Scotland

1st floating wind farm

5 spar-type FWTs

30MW (5x6MW)

nationalgeographic.com

video

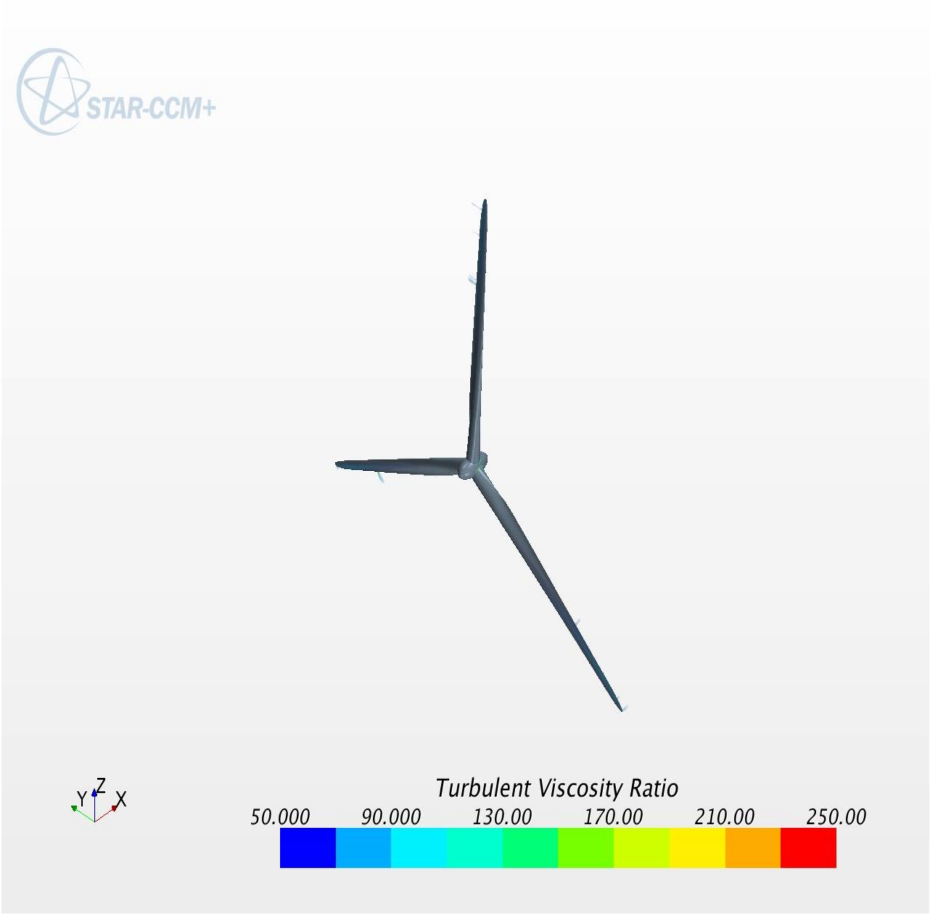
AERODYNAMICS

Aerodynamics

Aerodynamic models

FWT design:
Blade Element Momentum theory

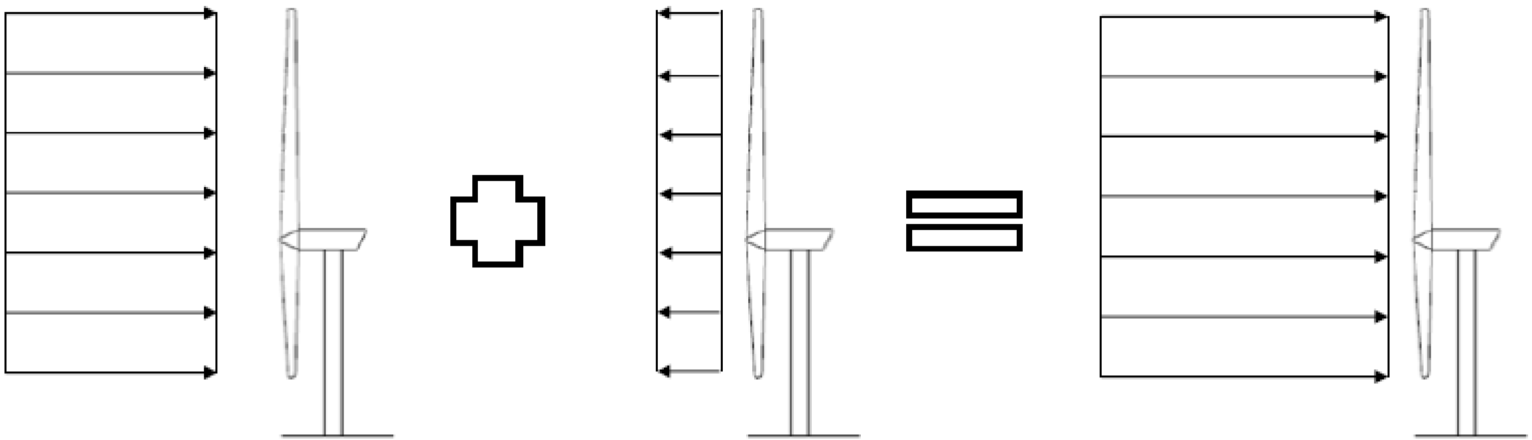
Refined R&D analysis :
CFD simulations



Mariana Lopes Pinto: Analyzing scale effects on NREL’s 5MW turbine

Aerodynamics

Tower motions (6dof) *must be considered*: relative instantaneous wind velocities along the blades

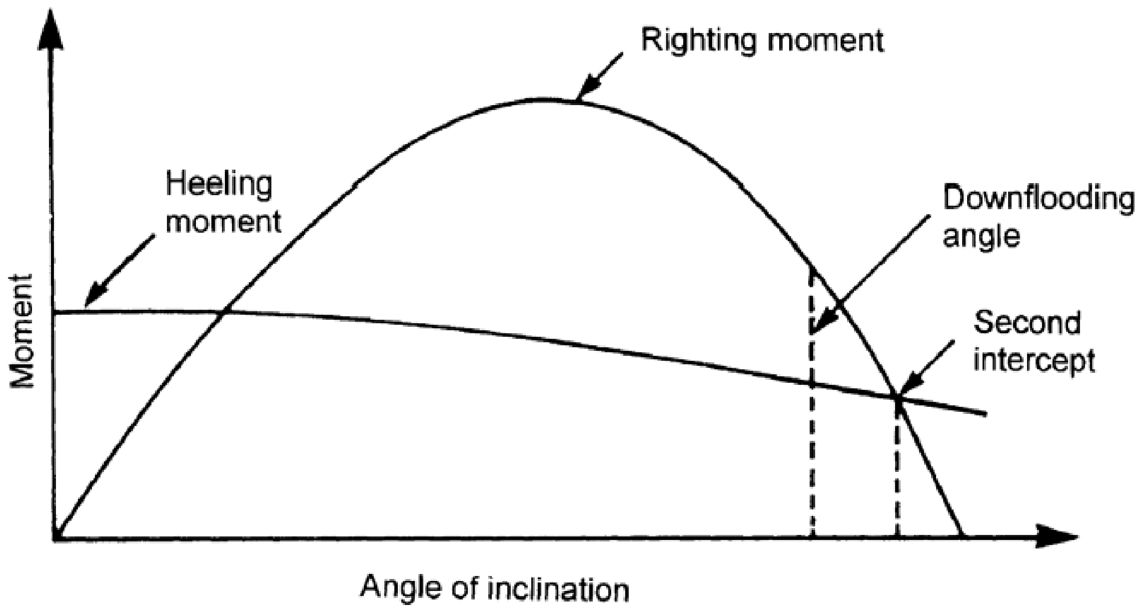


SEAKEEPING

Intact and Damaged Stability

Criteria usually applied to floating offshore units.

Class. Soc. Rules, e.g.:
DNV OS-J103 – *Design of Floating Wind Turbine Structures* (2013)



Wave Frequency Motions

Assessment of:

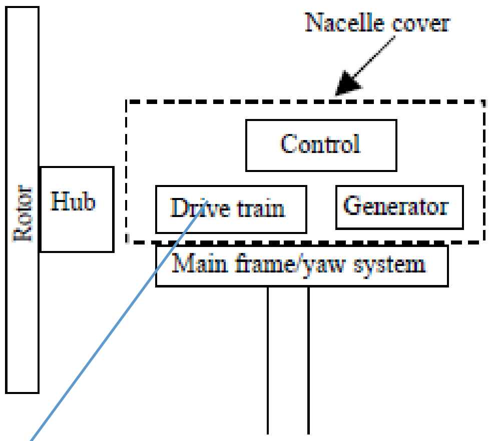
Limiting motions and accelerations on tower-top

Structural loadings

Operation uptime/downtime

Example of industry common practice:

Max axial accel. nacelle: 0.2g – 0.3g



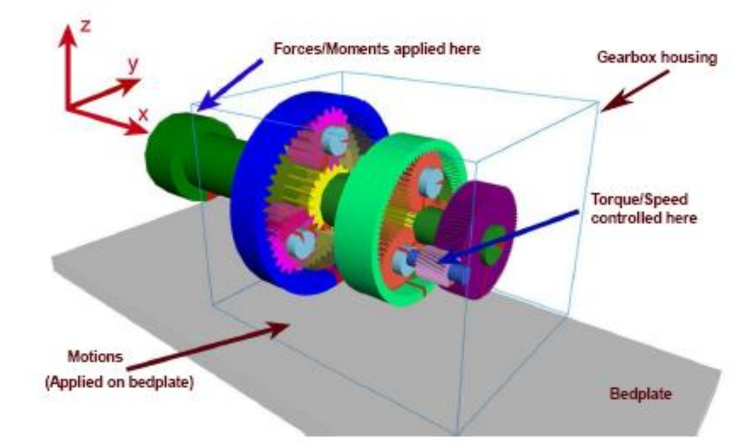


FIGURE 3. MBS MODEL OF 5-MW REF. GEARBOX [8].

Nejad et al. (2017) OMAE2017-62314

Wave Frequency Motions

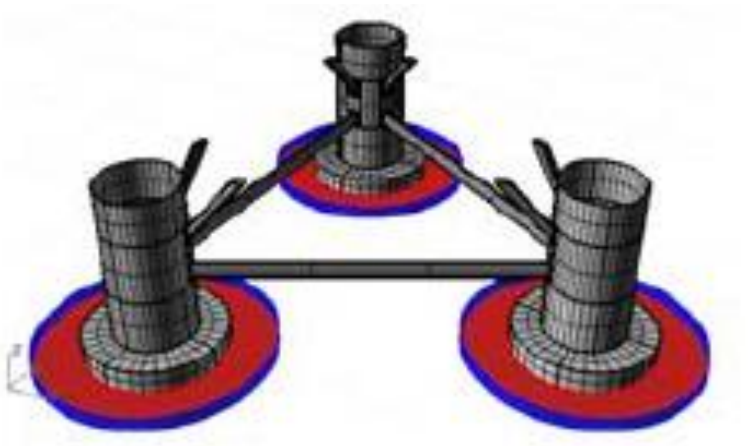
Methods:

Frequency-domain analysis

- Radiation-Diffraction codes

Time-domain analysis

- Radiation-Diffraction codes
- Morison Equation



Wave Frequency Motions

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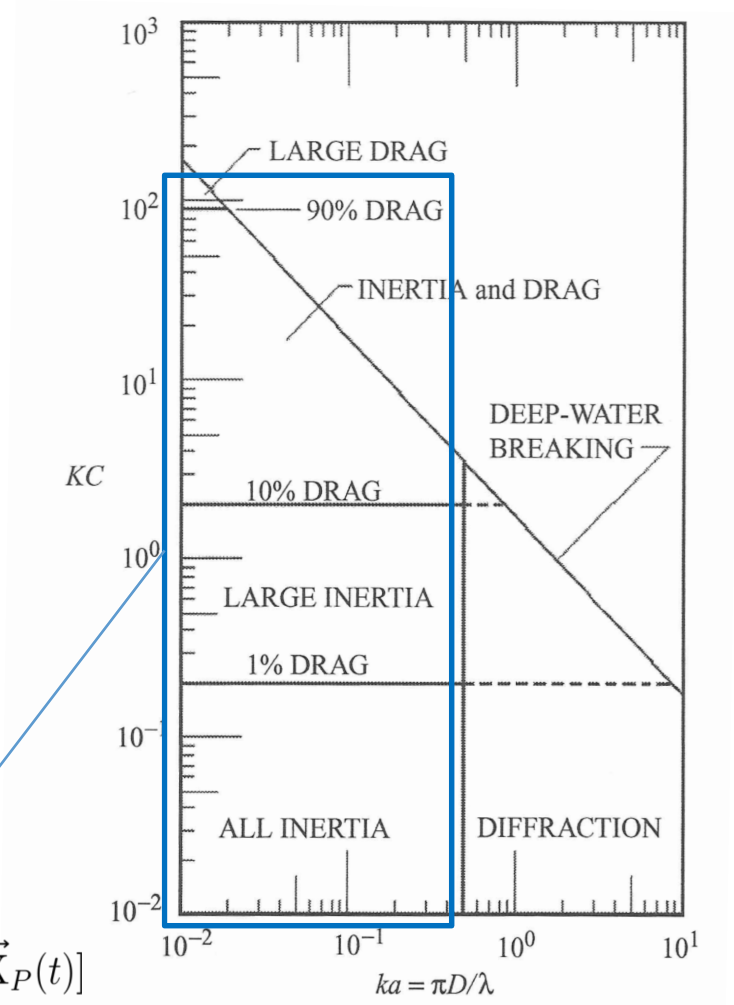
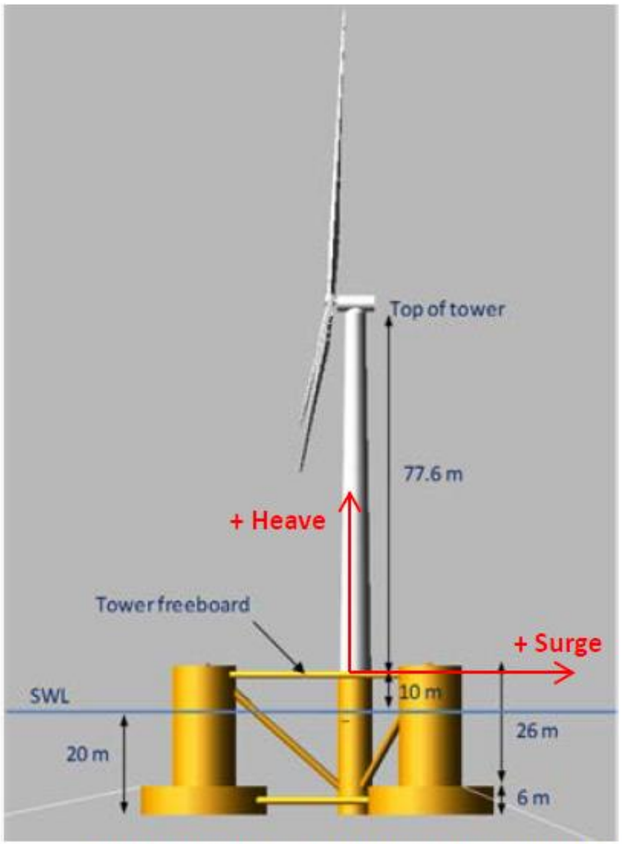


$$\mathrm{d}\vec{F}_m(t) = \frac{1}{2}\rho C_D\, D\, ||\vec{u}_P(z,t) - \dot{\vec{\mathrm{X}}}_P(t)|| \cdot [\vec{u}_P(z,t) - \dot{\vec{\mathrm{X}}}_P(t)]$$
$$+ C_M\, \rho\, \frac{\pi\, D^2}{4}\, \vec{a}_P(z,t) - C_a\, \rho\, \frac{\pi\, D^2}{4}\, \ddot{\vec{\mathrm{X}}}_P$$

Source: McCormick, M. E. – Ocean Eng. Mech

Wave Frequency Motions

- CASE-STUDY: NREL's OC4



OC4-DeepCwind floating wind system design

Summary of semisubmersible properties

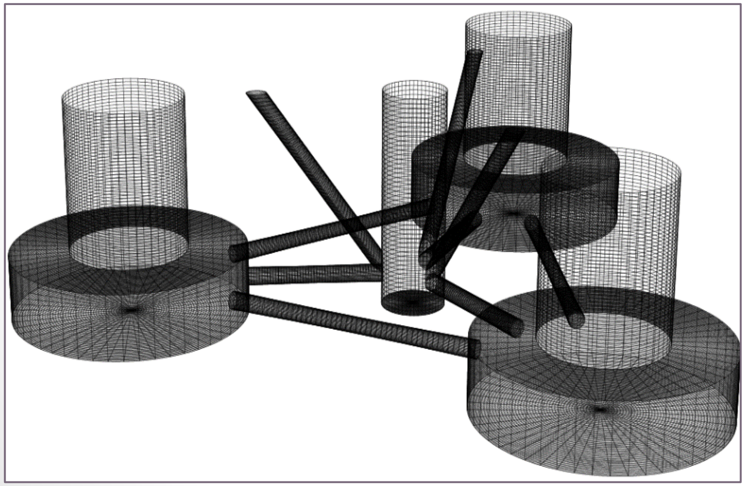
Depth of platform base below SWL (total draft)	20 m
Elevation of main column (tower base) above SWL	10 m
Elevation of offset columns above SWL	12 m
Length of upper columns	26 m
Length of base columns	6 m
Depth to top of base columns below SWL	14 m
Diameter of main column	6.5 m
Diameter of offset (upper) columns	12 m
Diameter of base columns	24 m
Diameter of pontoons and cross braces	1.6 m
Platform mass, including ballast	1.3473E+7 kg
Platform CM location below SWL	13.46 m
Platform roll inertia about CM	6.827E+9 kg-m^2
Platform pitch inertia about CM	6.827E+9 kg-m^2
Platform yaw inertia about CM	1.226E+10 kg-m^2
Number of mooring lines	3
Angle between adjacent lines	120°
Depth to anchors below SWL (water depth)	200 m
Depth to fairleads below SWL	14 m
Radius to anchors from platform centerline	837.6 m
Radius to fairleads from platform centerline	40.868 m
Unstretched mooring line length	835.5 m
Mooring line diameter	0.0766 m
Equivalent mooring line mass density	113.35 kg/m
Equivalent mooring line mass in water	108.63 kg/m
Equivalent mooring line extensional stiffness	7.536E+8 N

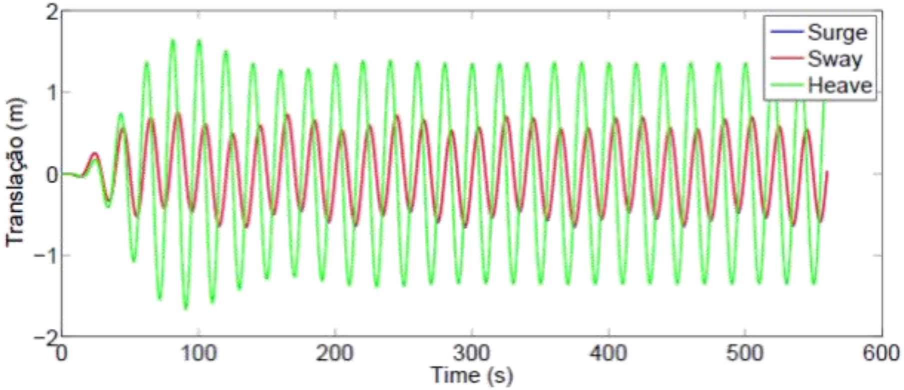
Source: Definition of the Semisubmersible Floating System for Phase II of OC4 (NREL)

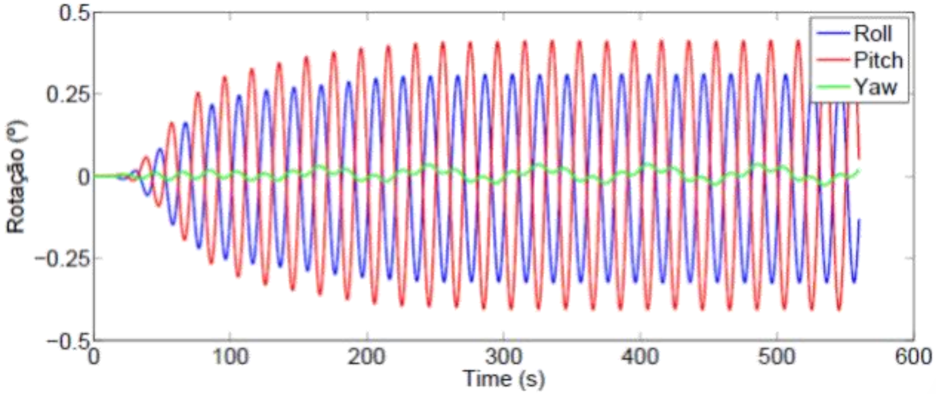
Wave Frequency Motions

- USP **METiS**

CARMO, L.H.S., Application of Morison's Equation to the Hydrodynamic Modelling of FWT, Final Project in Naval Eng., EPUSP, 2016 (in portuguese)







Wave Frequency Motions

- USP **METiS** x WAMIT®

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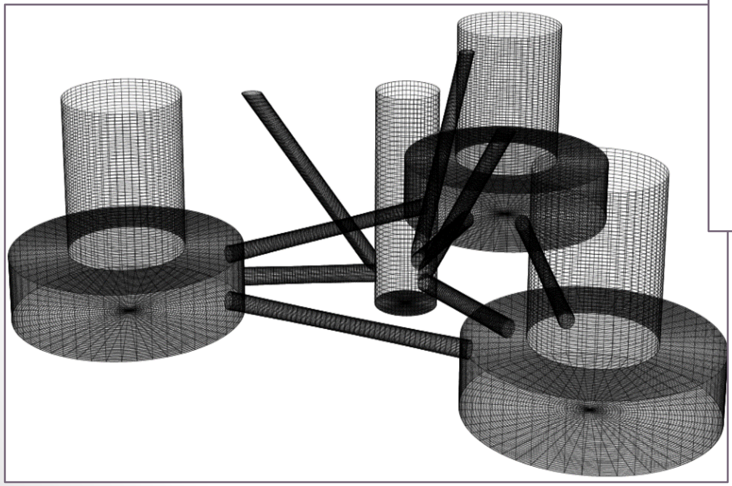
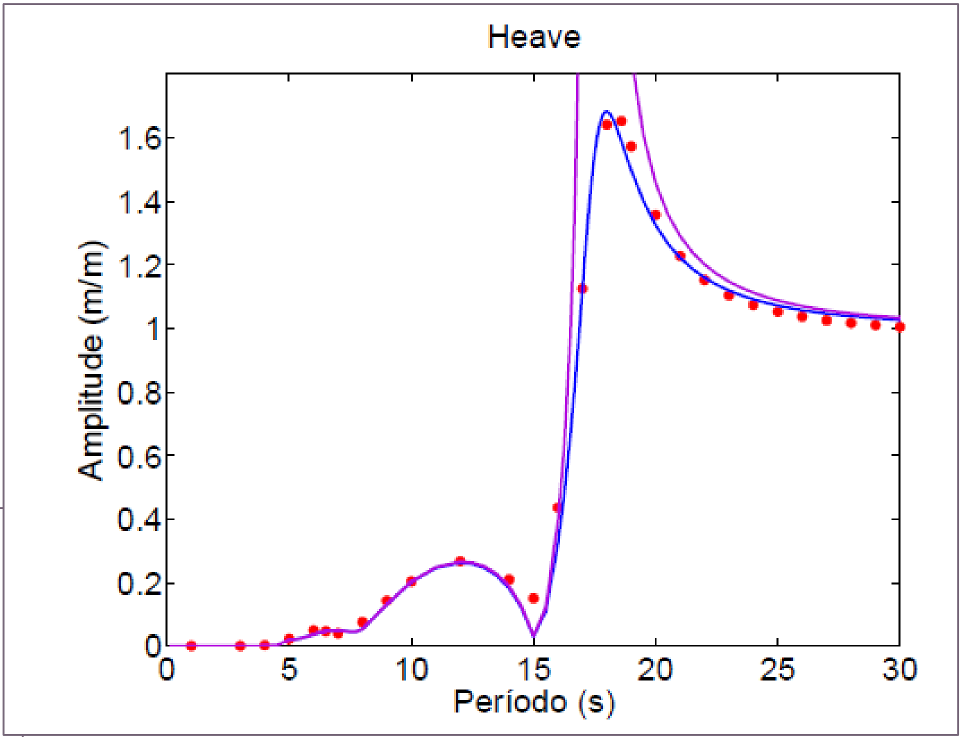




Low Frequency Motions (slow drifts)

Slow-drift forces: non-linear (second-order) forces induced by waves with low frequencies of oscillation

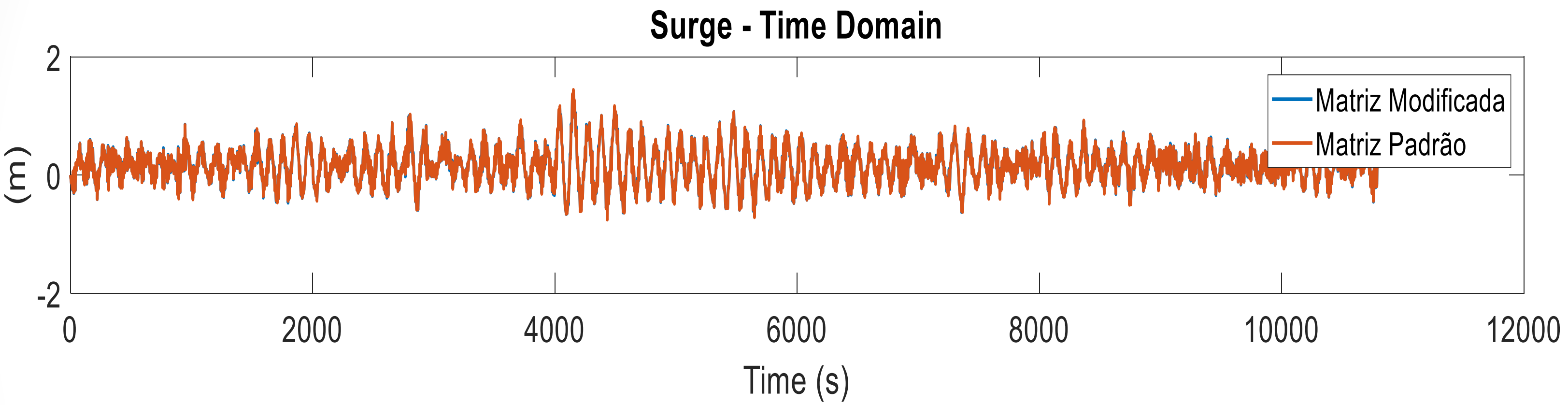
Small magnitudes if compared to the 1st order (wave frequency) loads, but induce resonant responses of the moored system

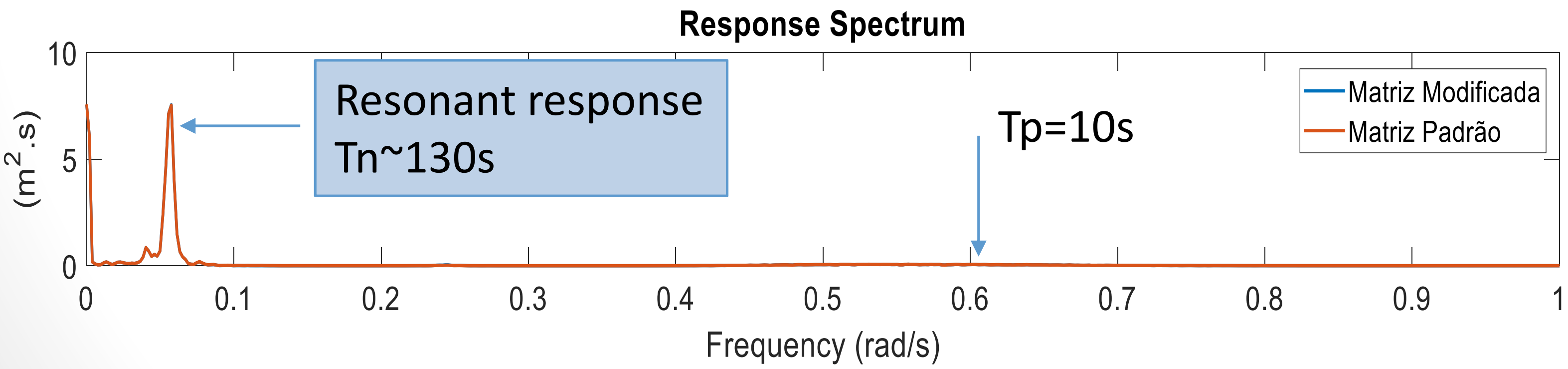
Dynamic offset in waves: mean-drift + slow-drifts

Must be considered in the mooring system design

Low Frequency Motions (slow drifts)

- Example of surge response in irregular waves (Hs=2m; Tp=10s)





Low Frequency Motions (slow drifts)

Previous joint R&D project:

Investigation on the wave drift forces on a FWT semi-submersible floater and applications to mooring system design

POLITÉCNICA

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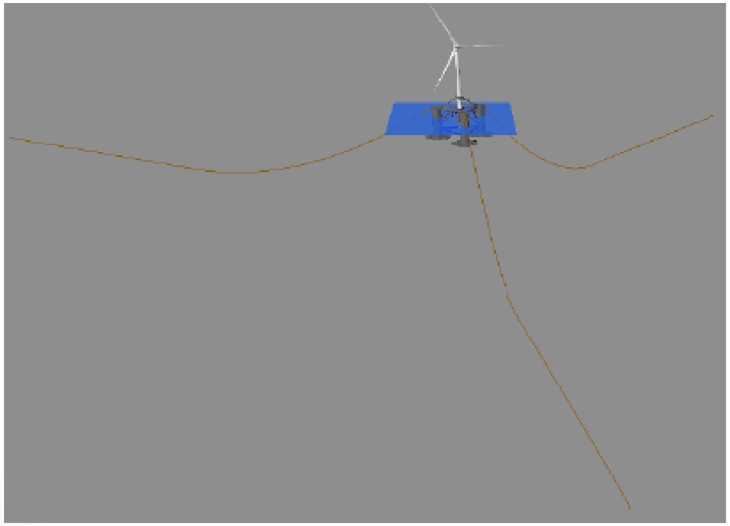
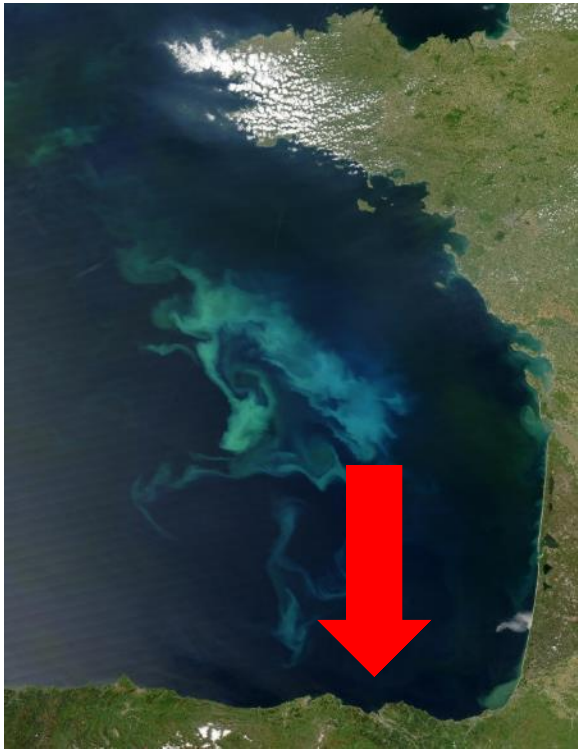
acciona Energy

(1) Hydrodynamics

- Semi-submersible floater for a 1.5MW wind turbine under design as part of AZIMUT project (Spanish CENIT R&D program)
- To be installed in Spanish North Coast, in a water depth of 100m
- Mooring system composed of 3 catenary chain lines





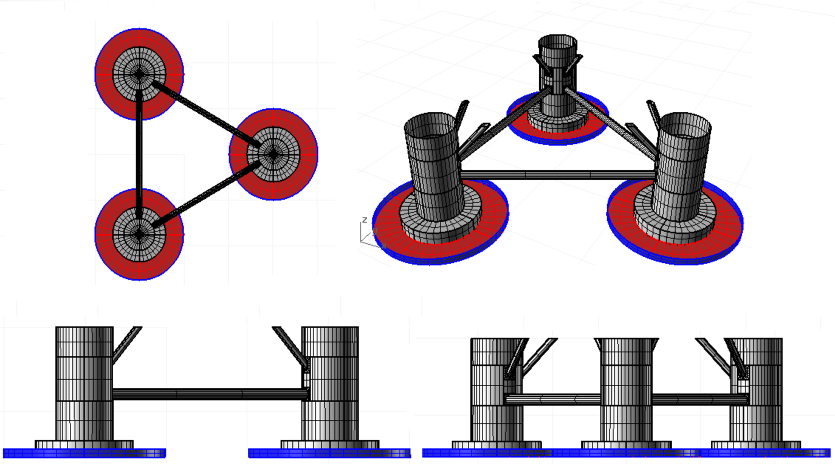
- Extreme sea states
  - Wave Hs up to 13,4m
  - Current up to 1.2 m/s

(1) Hydrodynamics

Experimental verification campaigns:

- CEHIPAR *El Pardo* (fixed model)
- EC Nantes (moored model)

USP team responsible for the hydrodynamic modelling of the FWT



LOPEZ-PAVON, C.; WATAI, R.A.; RUGGERI, F.; SIMOS, A.N.; SOUTO-IGLESIAS, A., **Influence of wave induces second-order forces in semi-submersible FOWT mooring design**. J. Offshore Mechanics and Arctic Engineering 137 (3) 031602, 2015

SIMOS, A.N.; RUGGERI, F.; WATAI, R.A.; SOUTO-IGLESIAS, A.; LOPEZ-PAVON, C., **Slow-drift of a floating wind turbine: An assessment of frequency-domain methods based on model tests**, Renewable Energy 116, pp.133-154, 2018

(1) Hydrodynamics

A thorough analysis of the performance of available approximations for computing the nonlinear force QTFs was made, with the help of extensive model tests