An overview of the Brazilian offshore wind scenario
(+ R,D&I groups and topics)

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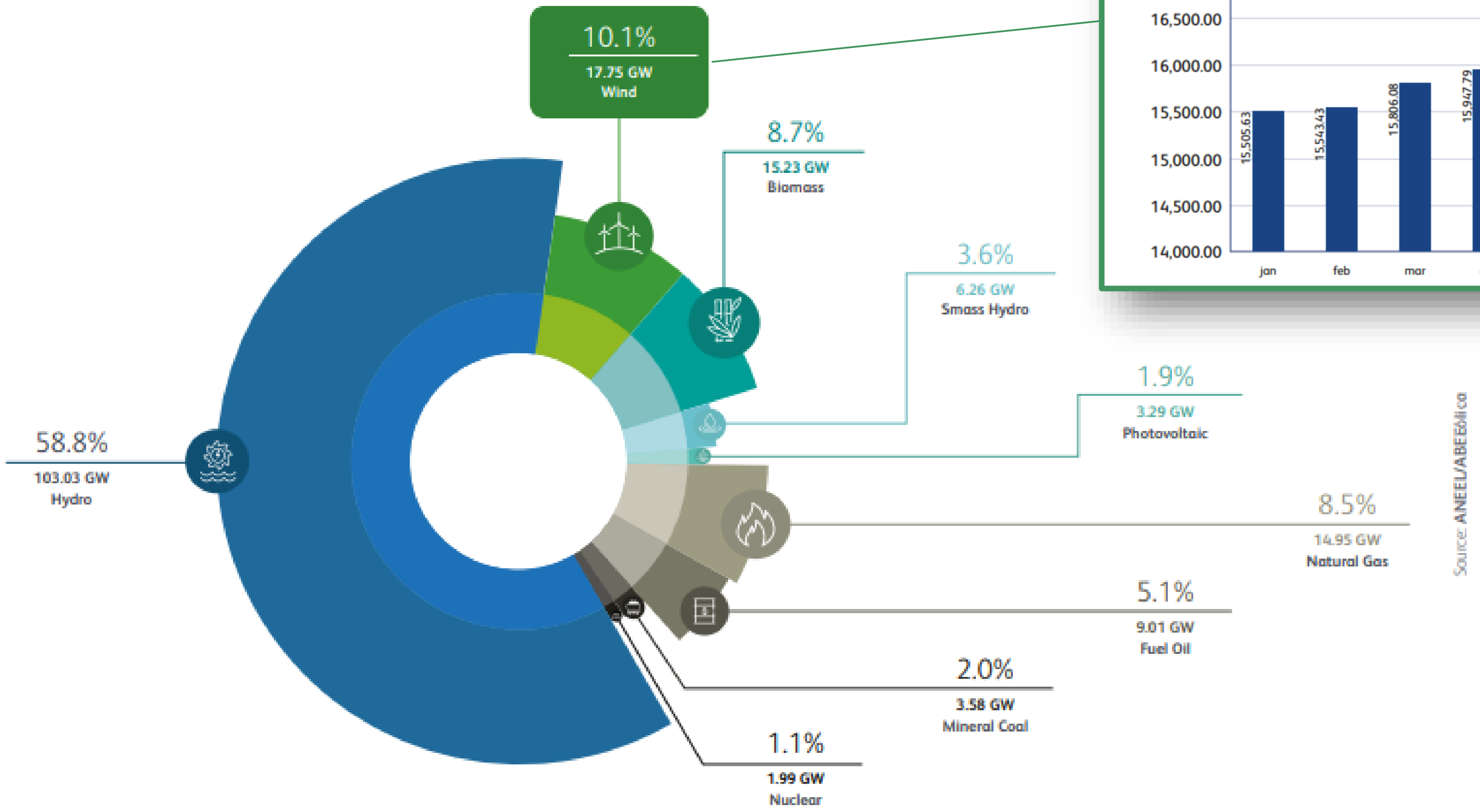
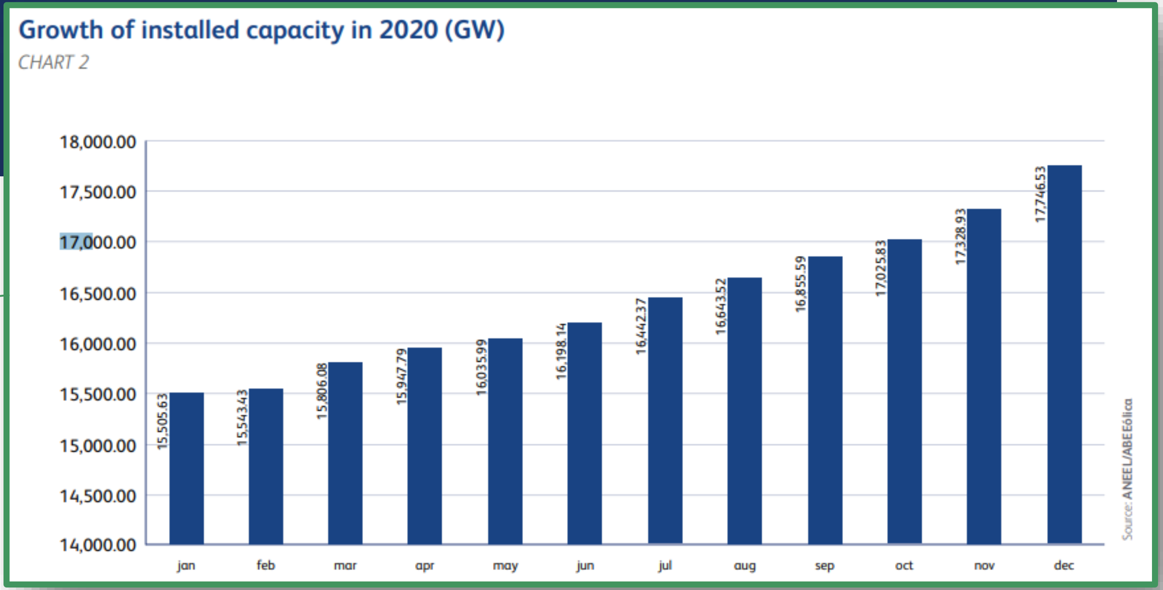
École Centrale de Nantes
Oct/2022

Onshore wind energy in Brazil





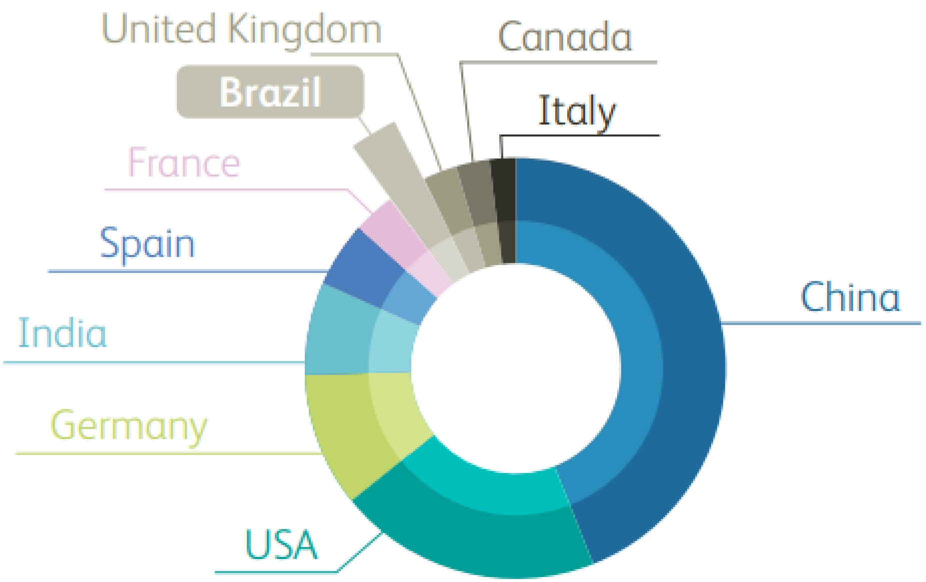
Source: Boletim Anual 2021, ABEEOLICA

Onshore wind energy in Brazil

TOP 10 cumulative capacity 2020

CHART 11

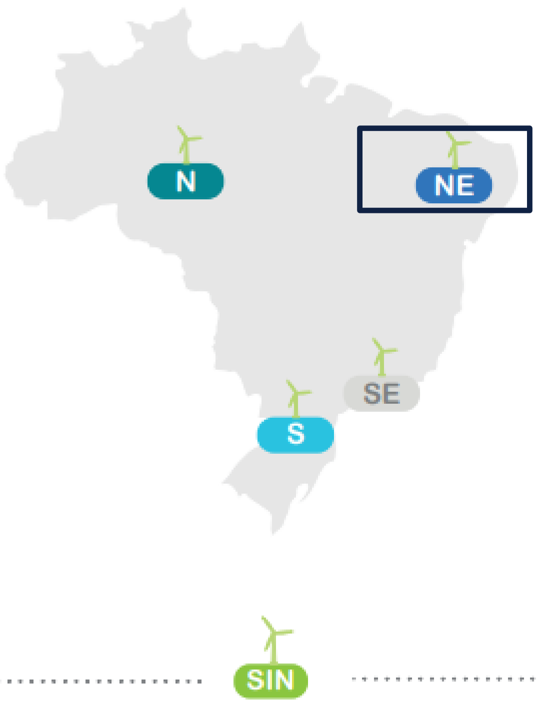
COUNTRY	Power (MW)
China	278,324 MW
USA	122,275 MW
Germany	55,122 MW
India	38,625 MW
Spain	27,238 MW
France	17,946 MW
Brazil	17,750 MW
United Kingdom	13,731 MW
Canada	13,578 MW
Italy	10,543 MW



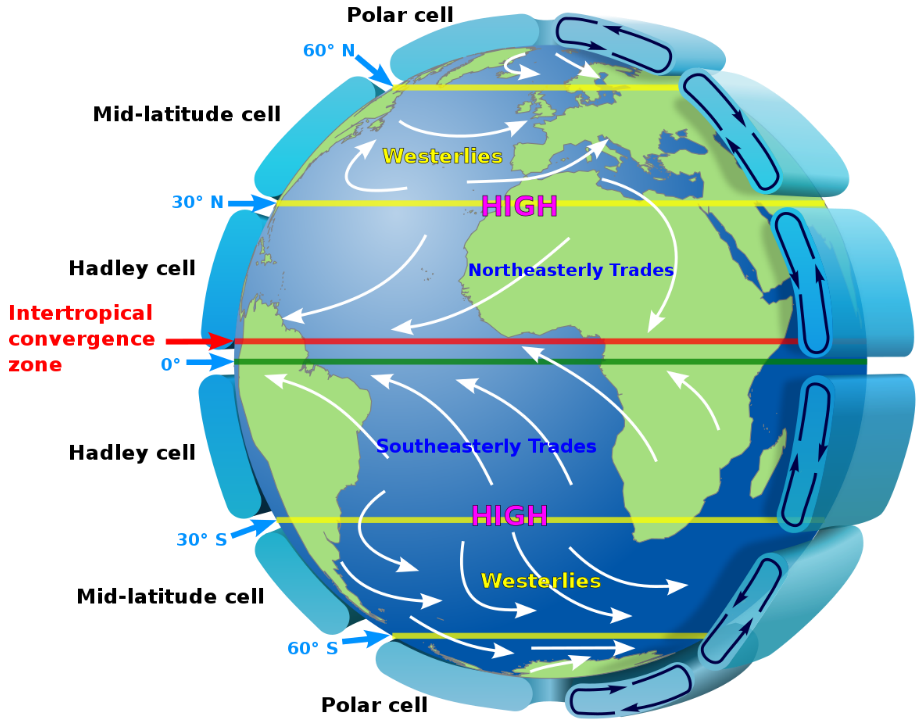
Source: Boletim Anual 2021, ABEEOLICA

Onshore wind energy in Brazil

Capacity installed and number of wind farms by state



State	Installed Capacity (MW)	Wind farms	Wind turbines
RN	6,764.94	221	2,735
BA	6,259.48	237	2,521
PI	2,788.05	91	1,095
CE	2,496.94	97	1,121
RS	1,835.89	80	830
PE	989.77	38	456
PB	628.44	30	257
MA	426.00	15	172
SC	242.70	15	174
SE	34.50	1	23
RJ	28.05	1	17
PR	2.50	1	5
TT	22,497.25	827	9,406



Source: ABEEOLICA, InfoWind #27, Sept2022

Onshore wind energy in Brazil

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Imagem: ABEEólica/Divulgação

Source: ABEEOLICA, InfoWind #27, Sept2022

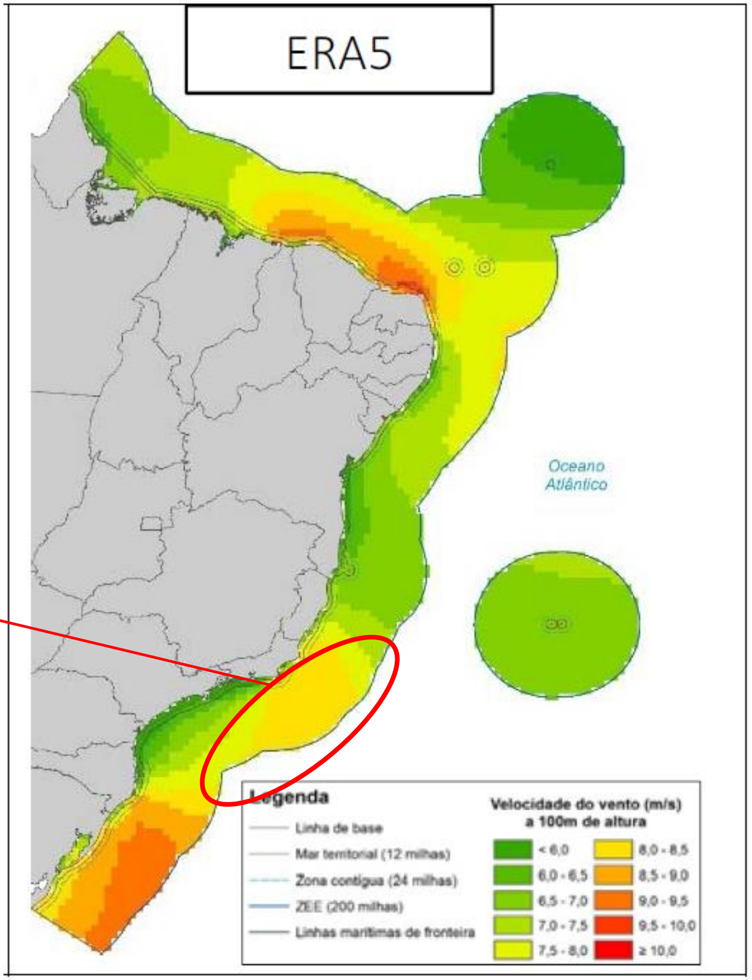
Offshore Wind: Status

Brazil has large potential for offshore wind generation

Federal Government recently established regulations for exploration of offshore energy areas

Possible contribution to decarbonization of O&G fields (deep waters)

Campos and Santos basins



Source: EPE, Roadmap Eólica Offshore 2020

DIÁRIO OFICIAL DA UNIÃO

Publicado em: 25/01/2022 | Edição: 17-B | Seção: 1 - Extra B | Página 1

Órgão: Atos do Poder Executivo

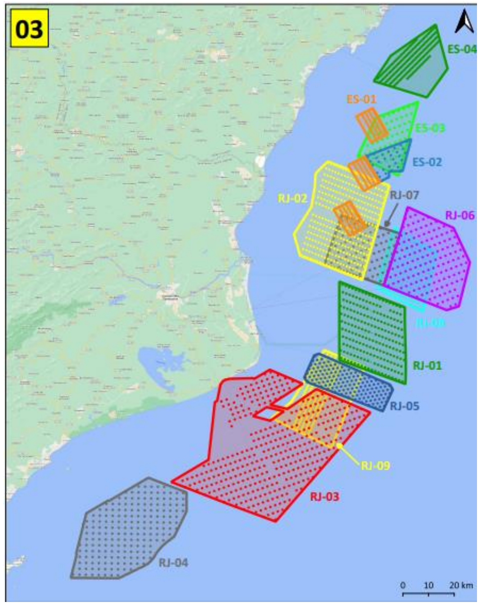
DECRETO Nº 10.946, DE 25 DE JANEIRO DE 2022

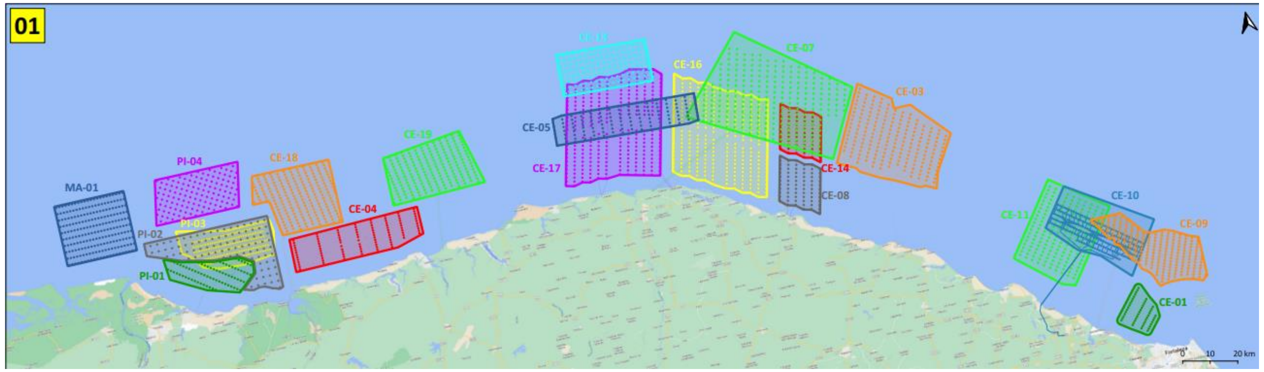
Dispõe sobre a cessão de uso de espaços físicos e o aproveitamento dos recursos naturais em águas interiores de domínio da União, no mar territorial, na zona econômica exclusiva e na plataforma continental para a geração de energia elétrica a partir de empreendimento **offshore**.

Offshore Wind: Status

60+ projects requested environmental licensing

http://www.ibama.gov.br/laf/consultas/mapas-de-projetos-em-licenciamento-complexos-eolicos-offshore

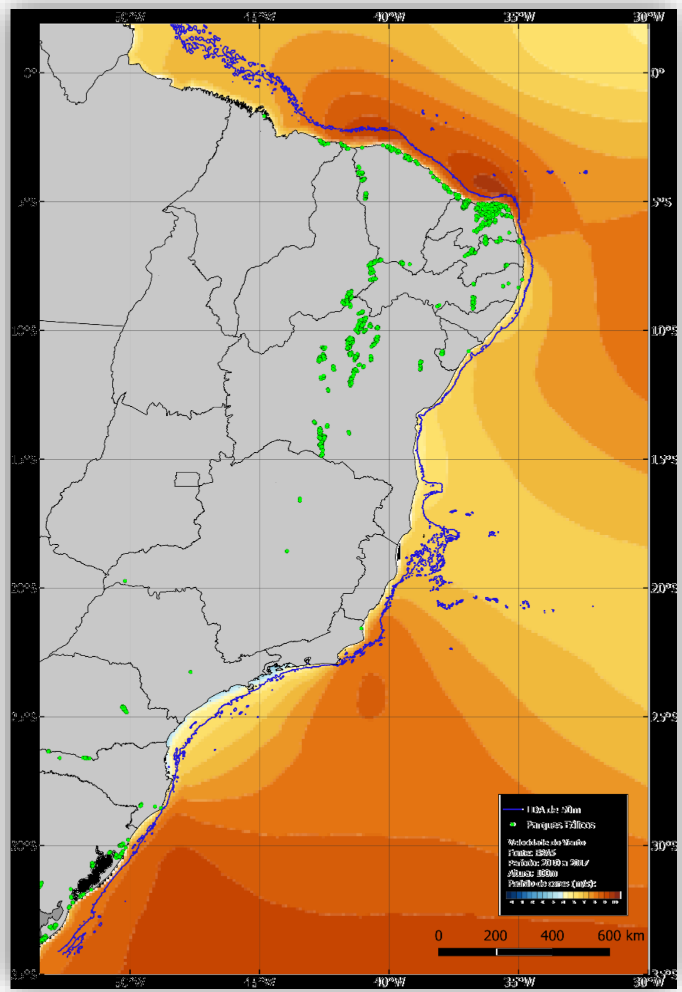


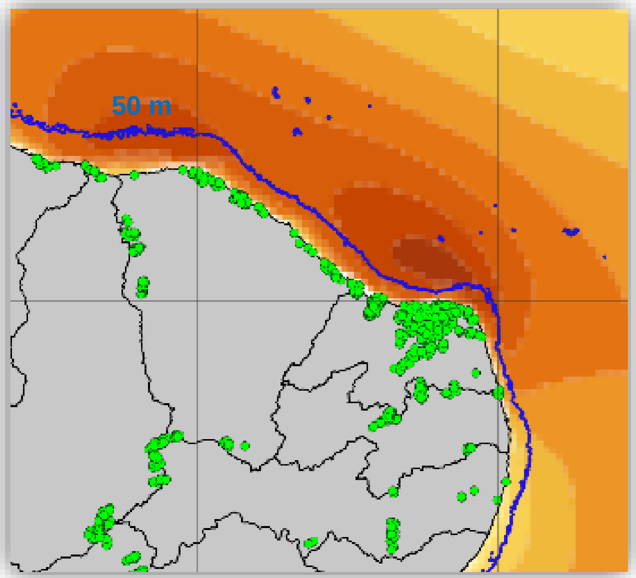


Offshore Wind: Status

#	Código	Empreendimento	Empreendedor	Processo	Sobreposição	Data FCA	Aerogerador	Pot. unitária (MW)	Quantidade	Pot. total (MW)
01	CE-01	Caucaia - Bi Energia	Bi Energia Ltda	02001.003915/2016-68		10/08/2016	Haliade-X	12	48	576
02	CE-03	Jangada	Neoenergia Renováveis	02001.035371/2019-46		27/01/2020	WTG-15.0-246	15	200	3.000
03	CE-04	Camocim	Camocim Eirelli	02001.015445/2020-61		06/07/2020	Haliade-X	12	100	1.200
04	CE-05	Dragão do Mar	Qair Marine Brasil	02001.015184/2021-61		22/07/2021	MHI Vestas 174	9,5	128	1.216
05	CE-06	Alpha	Alpha Wind Morro Branco Projeto	02001.018580/2021-40		01/09/2021	V236-15.0 MW	15	400	6.000
06	CE-07	Costa Nordeste Offshore	Geradora Eólica Brigadeiro I	02001.001545/2022-72	*	21/01/2022	V236-15.0 MW	15	256	3.840
07	CE-08	Asa Branca I	Eólica Brasil	02001.001606/2022-00		23/01/2022	VESTAS V236	15	72	1.080
08	CE-09	Sopros do Ceará	Totalenergies Petroleo & Gas Brasil	02001.004068/2022-05		17/02/2022	V236-15.0 MW	15	200	3.000
09	CE-10	Projeto Pecém	Shell Brasil Petróleo	02001.006219/2022-51	*	16/03/2022	SG-14-222-DI			
10	CE-11	H2GPCEA	H2 Green Power Ltda	02001.007283/2022-50	*	28/03/2022	SG-14-236-DI			
11	CE-12	Projeto Colibri	Equinor Brasil Energia	02001.008207/2022-61		05/04/2022	Turbog.15 MV			
12	CE-13	Projeto Ibitucatu	Equinor Brasil Energia	02001.008209/2022-51		05/04/2022	Turbog.15 MV			
13	CE-14	Asa Branca II	Eólica Brasil	02001.009548/2022-54	*	21/04/2022	VESTAS V236			
14	CE-15	Ventos dos Bandeirantes	Kaanda R. M. Cunha	02001.009558/2022-90		22/04/2022	Haliade-X			
15	CE-16	Asa Branca III	Eólica Brasil	02001.009562/2022-58	*	22/04/2022	VESTAS V236			
16	CE-17	Asa Branca IV	Eólica Brasil	02001.009563/2022-01	*	23/04/2022	VESTAS V236			
17	CE-18	Araras Geração Eólica Offshore	Shizen Energia do Brasil	02001.020087/2022-71		29/07/2022	V236-15.0 MV			
18	CE-19	Tatajuba Geração Eólica Offshore	Shizen Energia do Brasil	02001.020093/2022-28		29/07/2022	V236-15.0 MV			

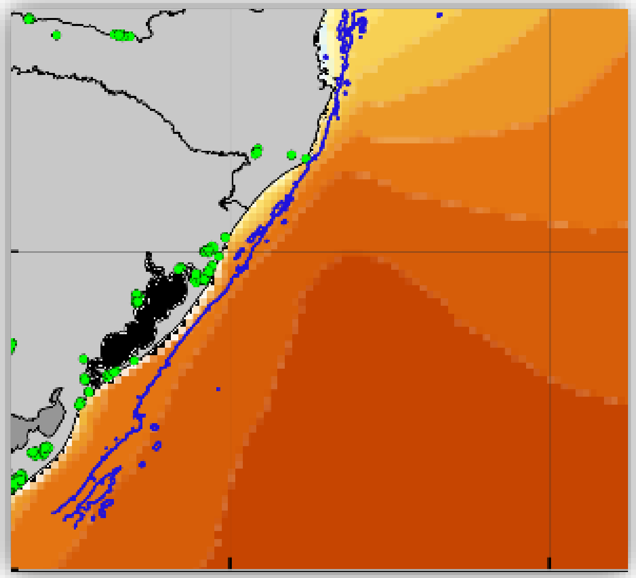
Depth: the 50m line





N/NE area
Largest wind potential
Mainly fixed turbines

South area
Good wind potential
Opportunities for FOWTs



Research groups and main topics

Brief overview of the research in OW in USP

Offshore Wind

RESEARCH GROUP ON FLOATING OFFSHORE WIND TURBINES (FOWT)

POLI USP

PNV USP Departamento de Engenharia Naval e Oceânica	**Alexandre Nicolaos Simos** alesimos@usp.br	FOWT design, Hydrodynamics
	Hélio Mitio Morishita hmmorish@usp.br	Control systems
	Jordi Mas-Soler jordi.msoler@usp.br	FOWT design, Optimization
	Marcelo Ramos Martins mrmartin@usp.br	Reliability and Risk Analysis
PEFUSP Departamento de Engenharia de Estruturas e Geotécnica	**Alfredo Gay Neto** alfredo.gay@usp.br	Aeroelasticity, Moorings
	Guilherme Rosa Franzini gfranzini@usp.br	Aeroelasticity, Moorings
PME Departamento de Engenharia Mecânica	**Bruno Souza Carmo** bruno.carmo@usp.br	CFD (rotor and hull)
	Celso Pupo Pesce ceppesce@usp.br	Dynamics, Cables
Departamento de Engenharia de Energia e Automação Elétricas	**Maurício B. C. Salles** mausalles@usp.br	Electrical systems
	Renato Machado Monaro monaro@usp.br	Electrical systems

Partners and Sponsors

POLITÉCNICA
"Ingeniamos el futuro"

UNICAMP

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THE UNIVERSITY OF TOKYO

YNU
YOKOHAMA National University

UNIVERSIDADE DE SÃO PAULO
IO
Instituto Oceanográfico

UFSC

UNIVERSITY OF OXFORD

epcc

KTH
VETENSKAP OCH KONST

UNIVERSITY OF TWENTE.

Imperial College London

DNV

DTU

HLRS
High-Performance Computing Center | Stuttgart

Office of Naval Research GLOBAL Science & Technology

VORTEX

JAPAN SOCIETY FOR THE PROMOTION OF SCIENCE · FOUNDED 1932 ·

CAPES

CPFL ENERGIA

FAPESP

Laboratório Nacional de Computação Científica
UNIDADE DE PESQUISA DO MCTI

BR
PETROBRAS

anp
Agência Nacional do Petróleo

European Commission

FLOATING WIND: PREVIOUS RESEARCH

2012-13

Investigation on the wave drift forces on a FOWT floater and applications to mooring system design

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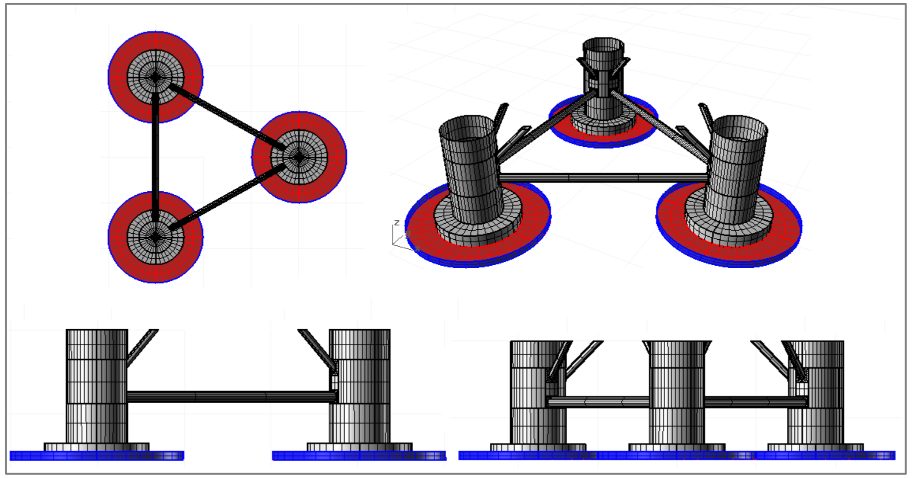
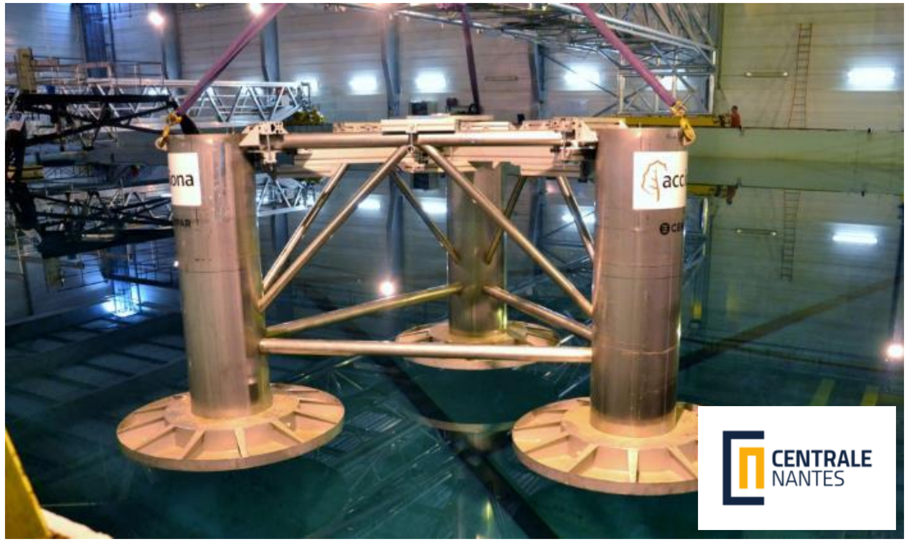
SCIENTIA VINCES





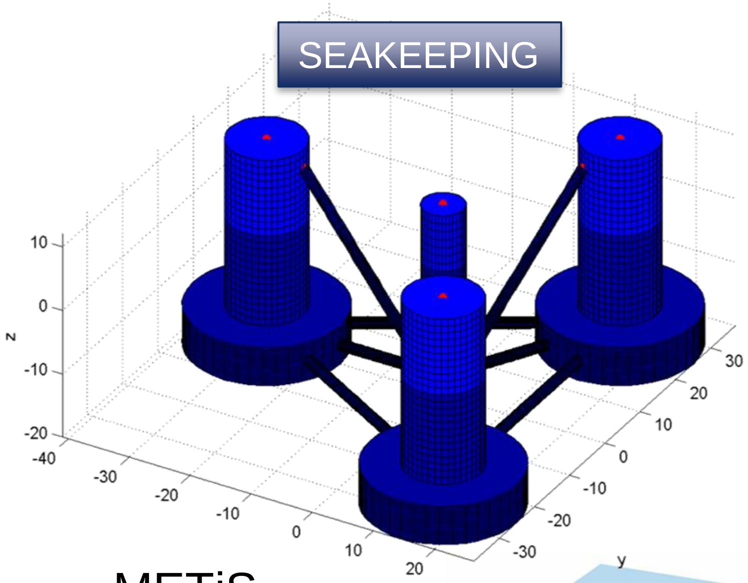
FLOATING WIND: PREVIOUS RESEARCH

2016-19

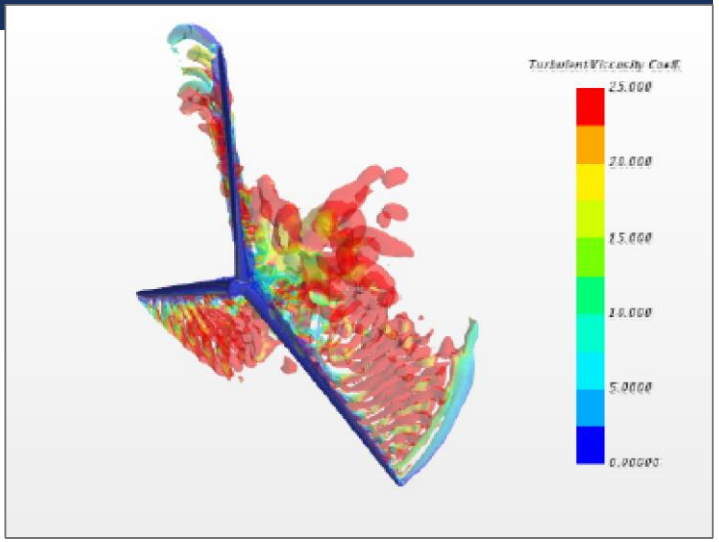
Computational Tools for Research on FOWT

Financed by:

SEAKEEPING

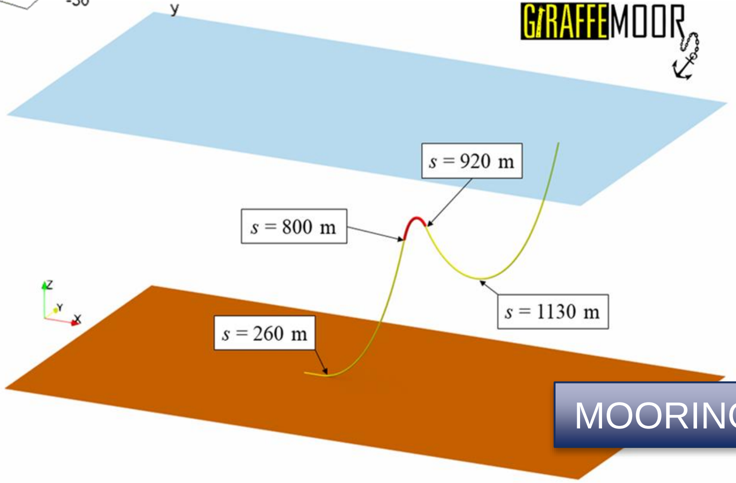


METiS-USP



AERODYNAMICS

GIRAFFEMOOR



MOORINGS, CABLES

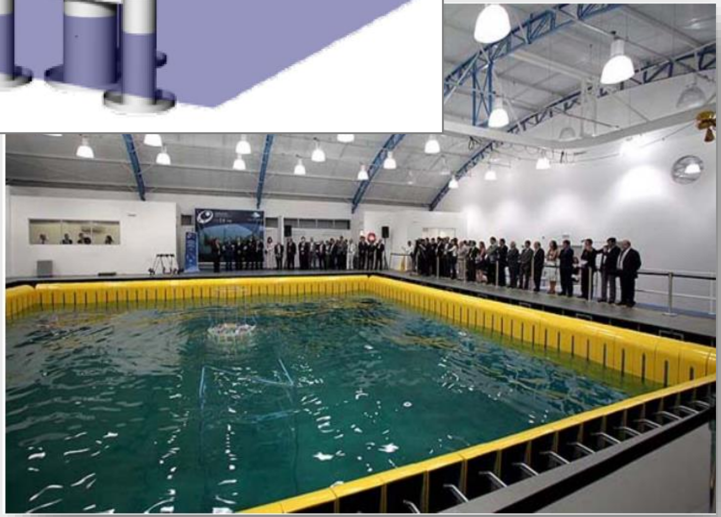
FLOATING WIND: PREVIOUS RESEARCH

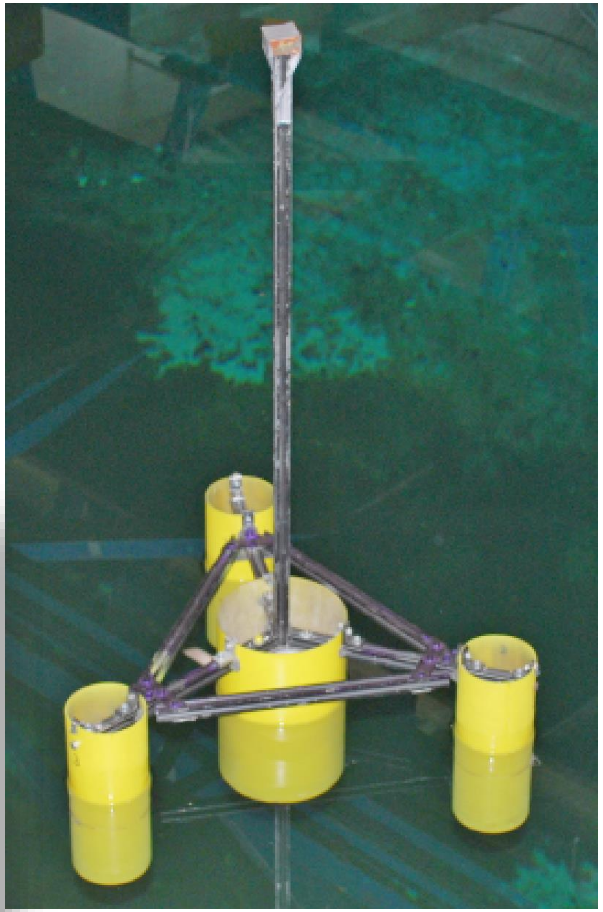
2018-20

FOWT for Brazilian Waters

THE UNIVERSITY OF TOKYO

Financed by:





CH-TPN/USP

FLOATING WIND: ON-GOING RESEARCH

2020-23

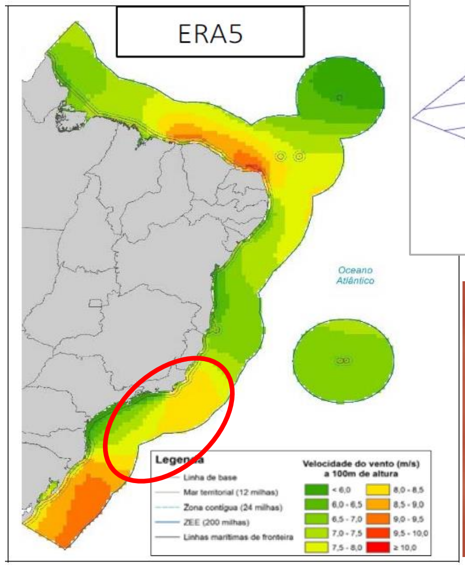
Investigating technical and economic feasibility of deep-water FOWT in Brazilian Oil&Gas fields

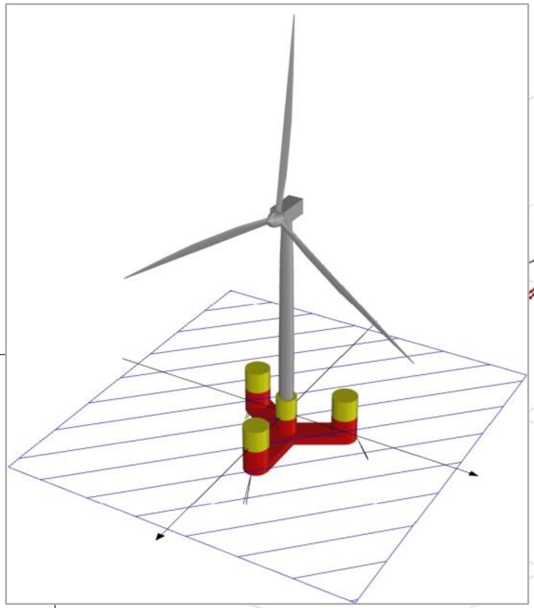
Supported by:

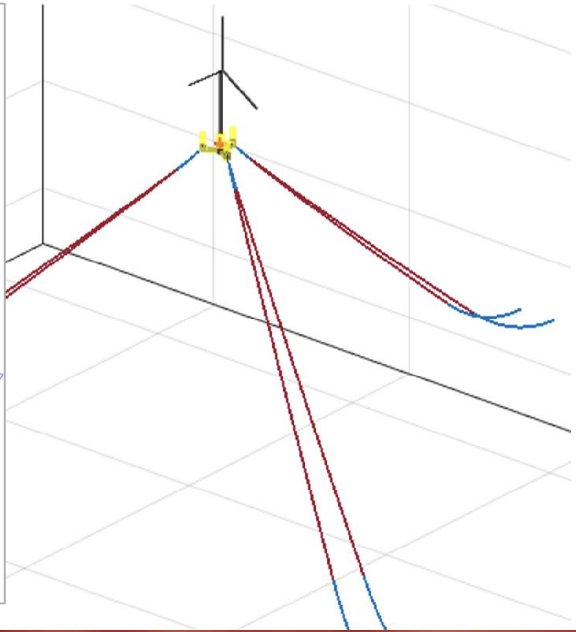
PETROBRAS

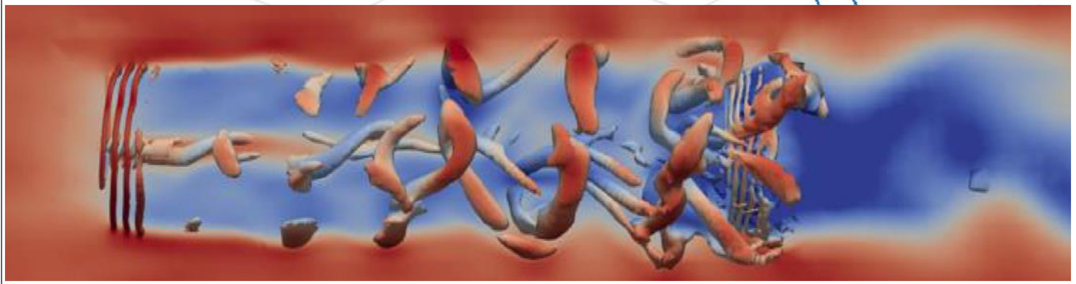
anp Agência Nacional do Petróleo

Technical collaboration:







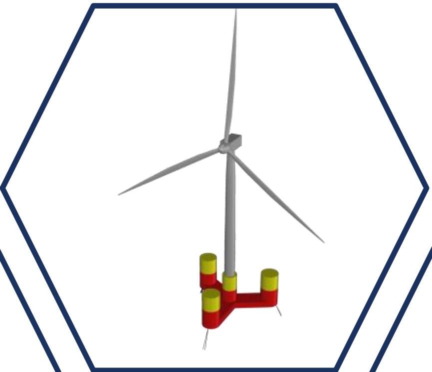


DESIGN AND SIMULATION OF OFFSHORE SYSTEMS

Numerical Offshore Tank (TPN) - http://tpn.usp.br/

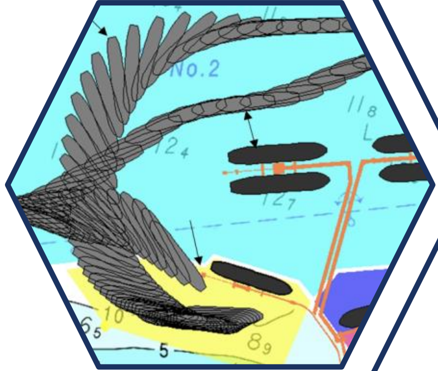
Investigators:
Alexandre Simos (Naval Arch & Ocean Eng Dept)
Chen Yang Yee (Civil Eng Dept)
Eduardo Tannuri (Mechatronics Eng Dept)
Jordi Mas-Soler (Naval Arch & Ocean Eng Dept)
Kazuo Nishimoto (Naval Arch & Ocean Eng Dept)

Main Research Lines



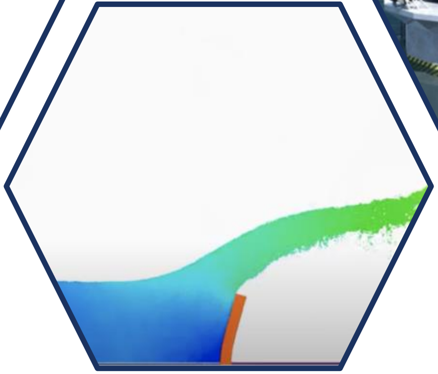
Offshore Wind

Seakeeping



Particle Methods

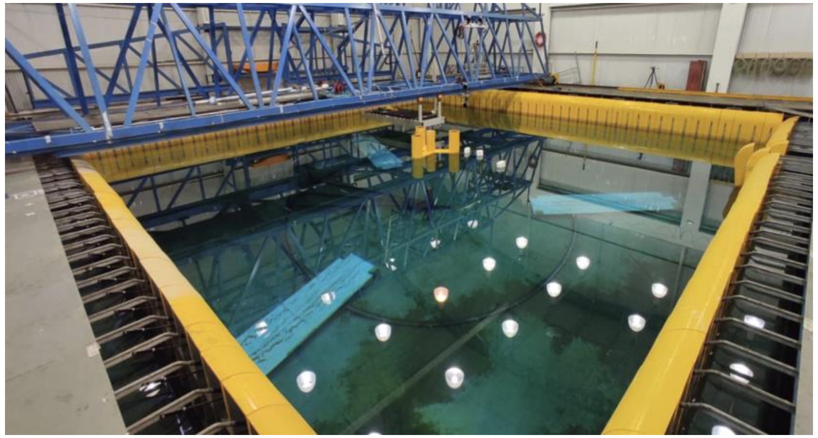
Maneuvering Simulations



Facilities

Wave Basin

Tank dimensions:14m x 14m x 4.1m; Generates and absorbs waves from 0.5Hz to 2.0Hz using a set of 148 flap-type wavemakers.



High-performance Computing Clusters

Cluster 1: 960 processors @ 2.80GHz · 28.4 Tflops · 148 TB

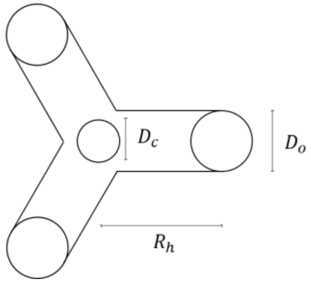
Cluster 2: SUN - 192 blades X6175 · @ 2.8GHz · 15 TFlops · 4.5 TB RAM

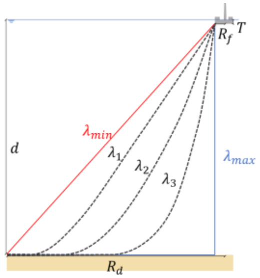
Maneuvering Simulation Center

3 Full mission simulators

3 Tug stations and crane simulators

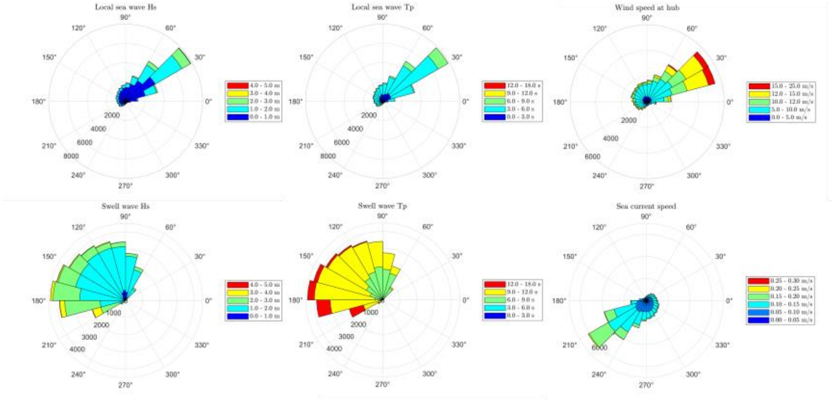
FOWT Optimization Framework (TPN-USP)





Hull-Mooring
Parametrization

Long-term Environmental Series
N>32000

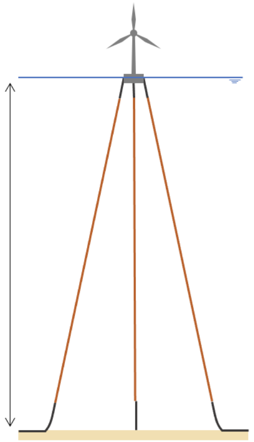


Genetic Algorithm

$min\{Cost_{hull}, Cost_{moor}, acc.\}$

Subjected to: stability, structural and mooring design criteria

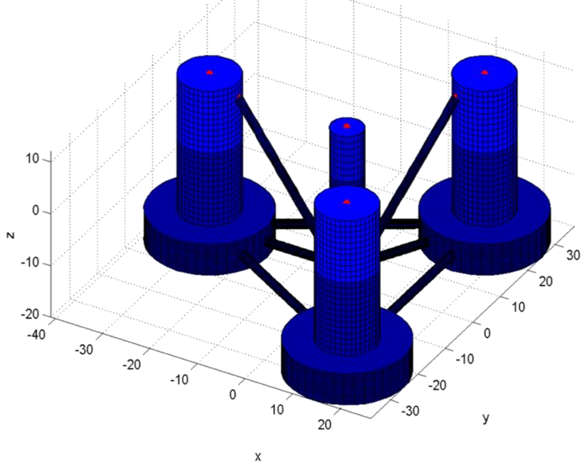
Preliminary Design



FOWT Computational Tools (TPN-USP)

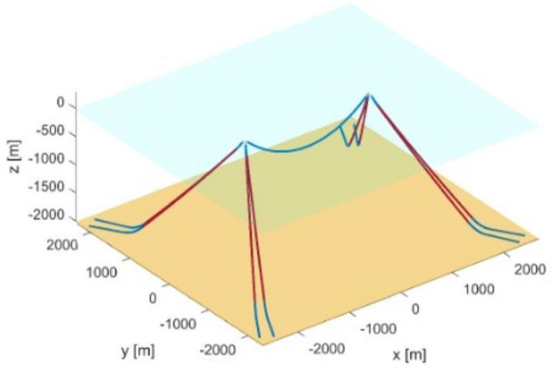
METiS-USP
(developed in-house)
Morison **E**quation **Ti**me Domain **S**imulation

Dynamic coupled analysis including hydrodynamic and aerodynamic loads.



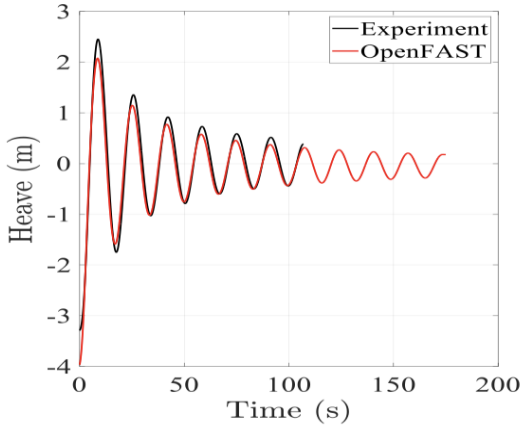
SuSSA
(developed in-house)
Subsea **S**ystem **A**nalysis

Analytical assessment for solving slender subsea structures, such as mooring lines and power cables.



OpenFAST

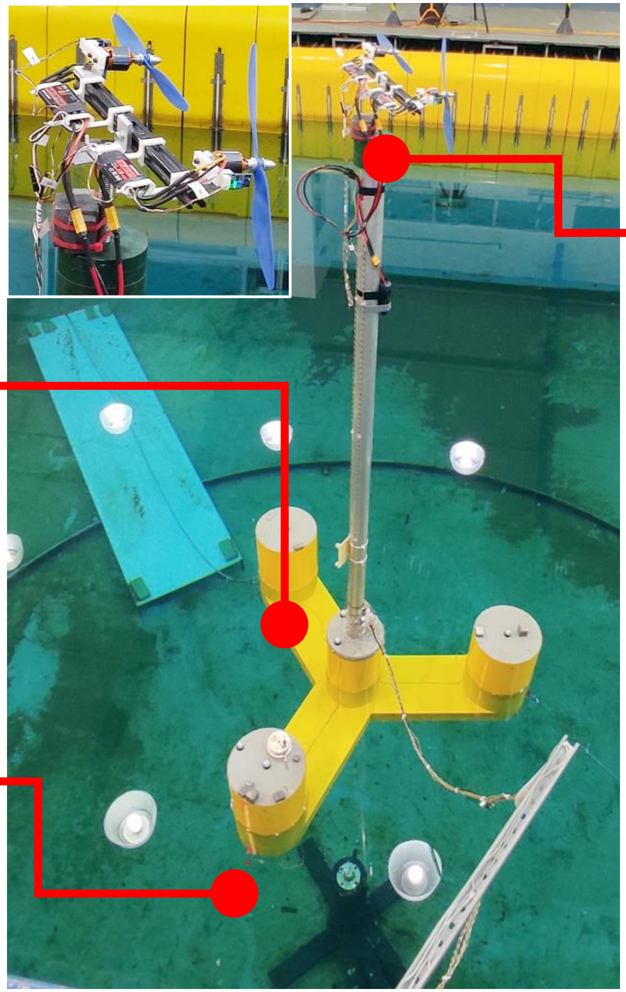
Coupled dynamic response of wind turbine



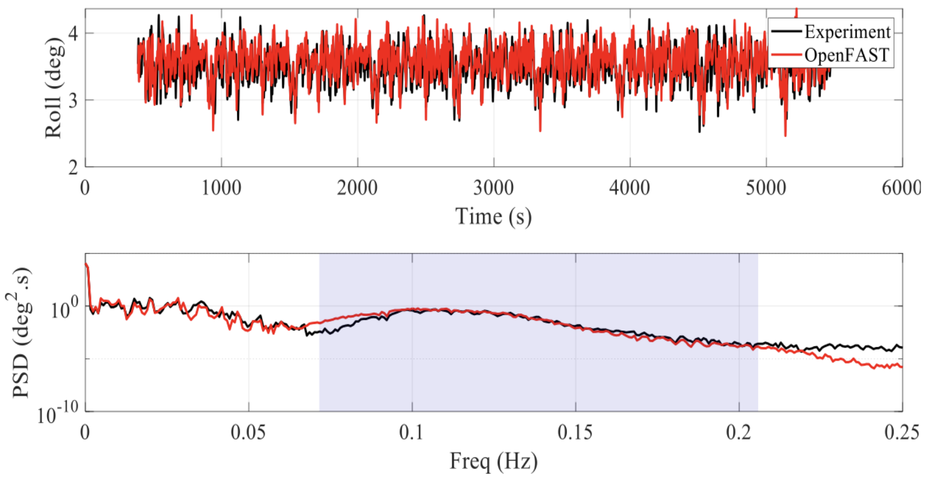
FOWT Model Scale Tests (TPN-USP)

Floater
- Scaled geometry
- Ballast optimal distribution

Mooring
- Moored FOWT
- Line dynamics (load cells)



Hybrid Testing (fans)
- SIL developed *in-house*
- BEMT algorithm
- Blade pitch controller
- Optical tracking system



Other Research Topics

- Wave estimation using onboard motion measurements
- Digital twin of maneuvering vessel
- Cooperative DP vessels
- Ship Interactions with bottom, margin and other ships
- Assessment of STS operations
- CFD computations of hydrodynamic maneuvering coefficients

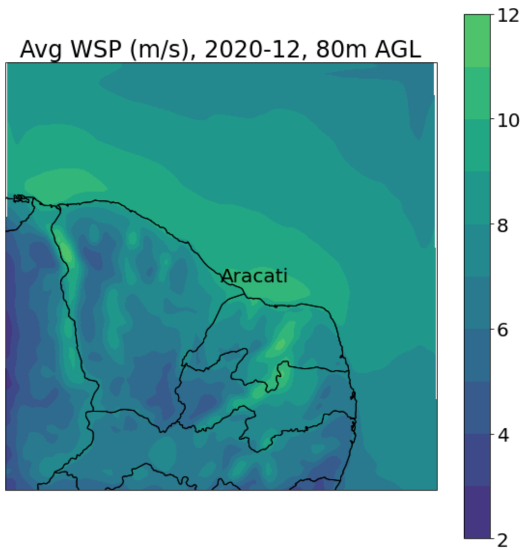
HIGH FIDELITY MODELLING AND EXPERIMENTS APPLIED TO WIND AND TIDAL ENERGY

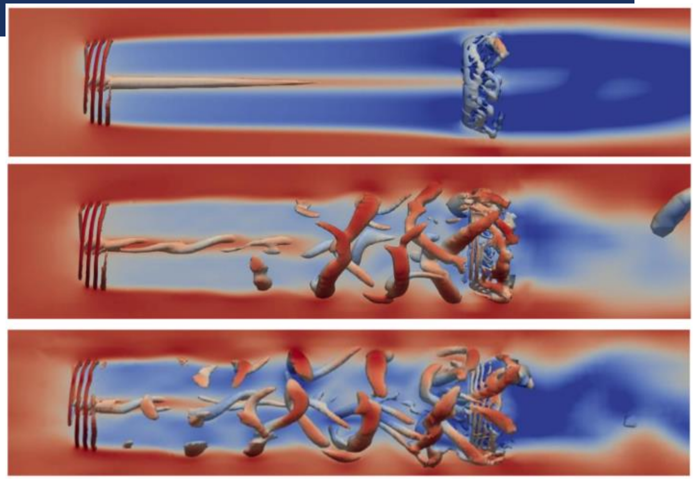
Centre of Dynamics and Fluids (NDF) - http://ndf.poli.usp.br/

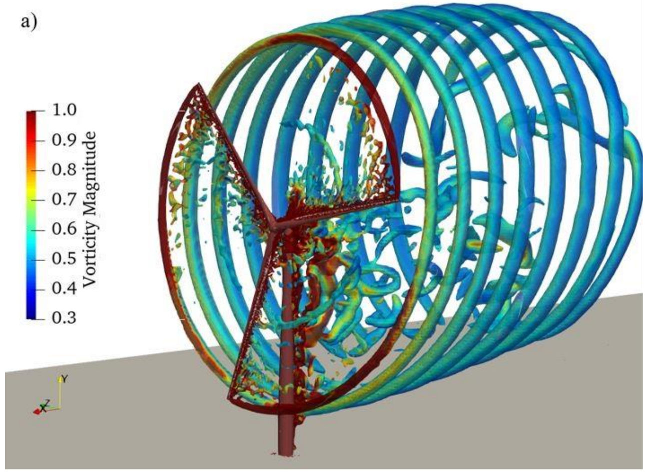
Coordinator: Dr Bruno Carmo (Department of Mechanical Engineering)

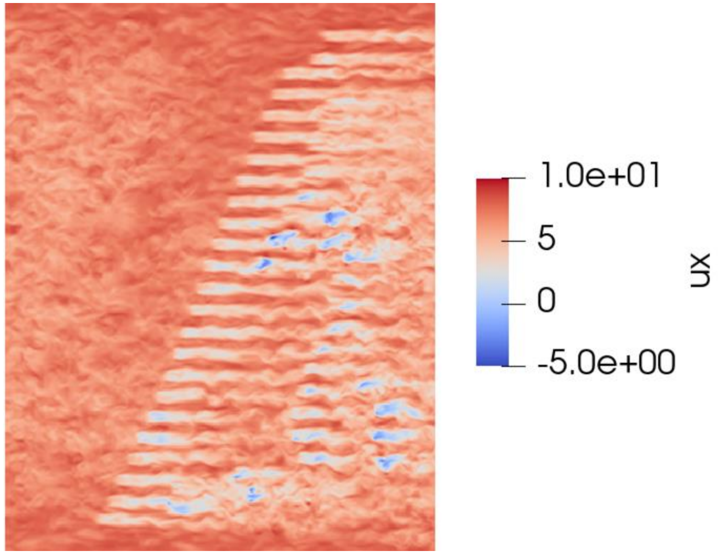
MODELLING CAPABILITIES

- Mesoscale simulations
- Coupling of meso and microscale models
- Wind farm simulations (actuator disks and lines)
- Blade-resolved simulations
- Fluid-structure interaction



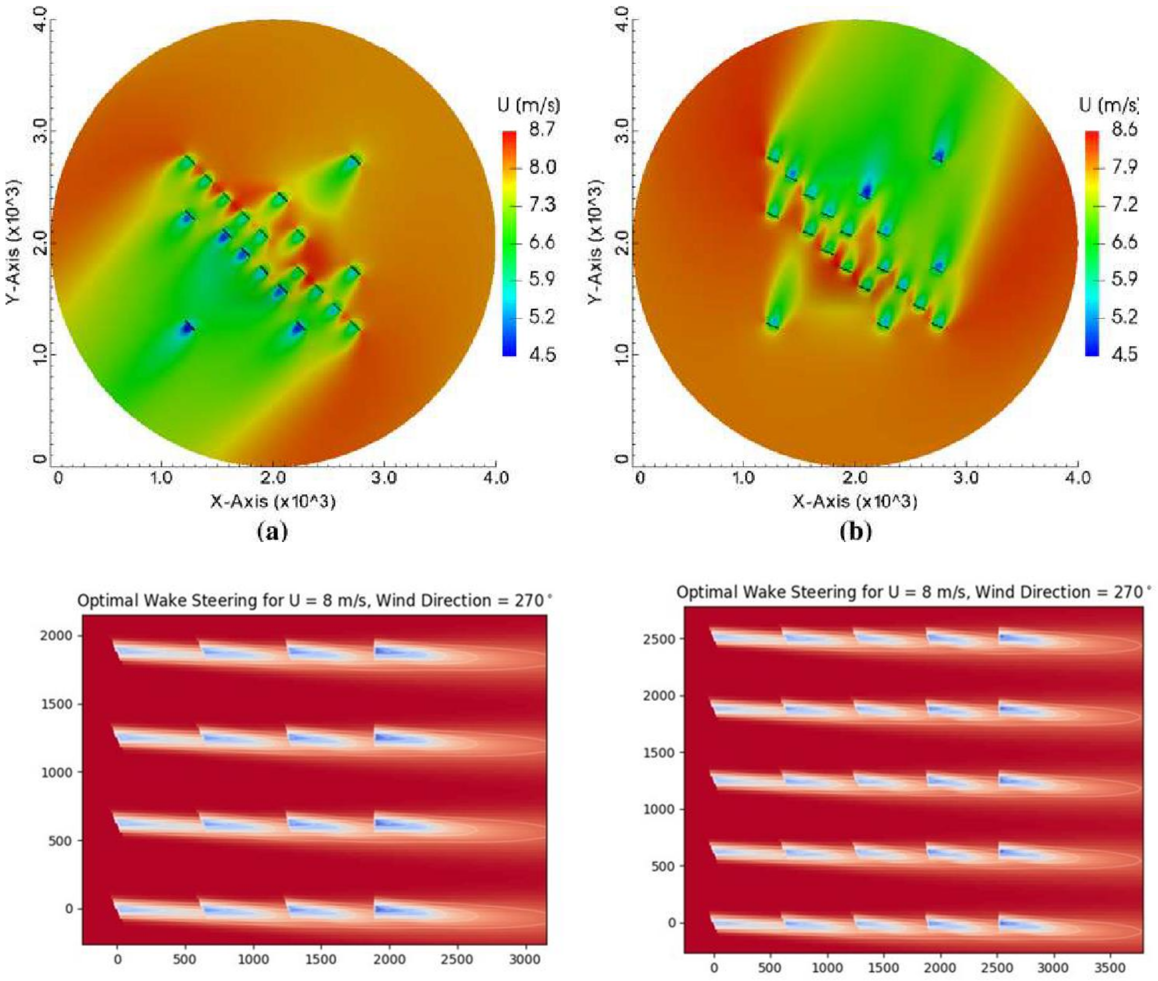






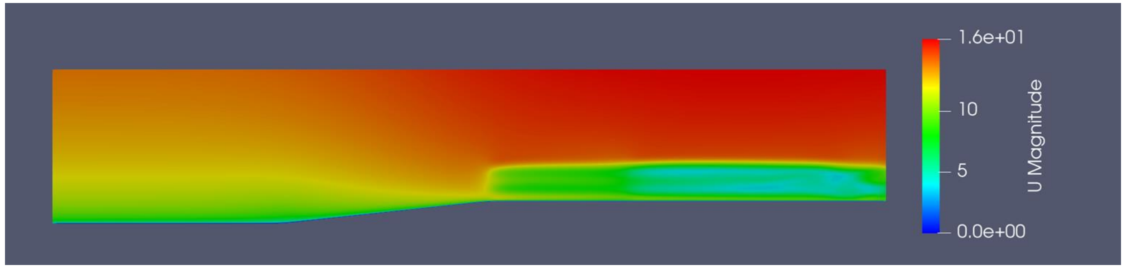
APPLICATIONS

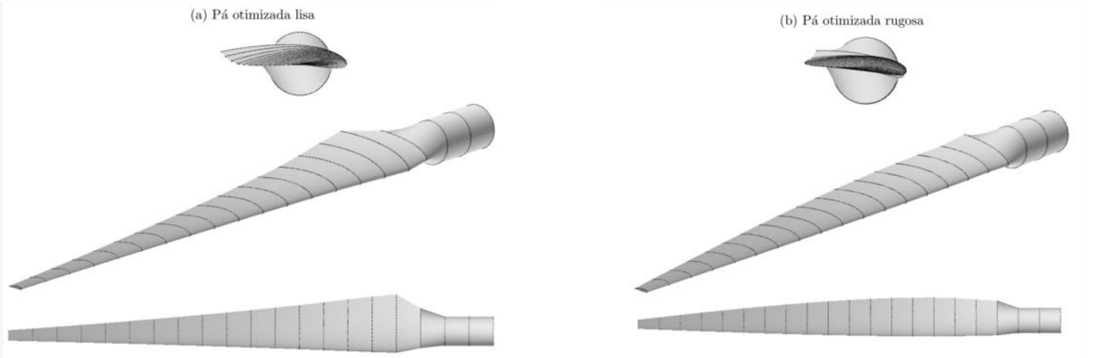
- Wind resource assessment
- Prediction of power production and mechanical loads
- Wind farm layout optimization
- Integrated control of wind farms
- Investigation of the influence of atmospheric conditions – stability and other phenomena (e.g. low level jets)



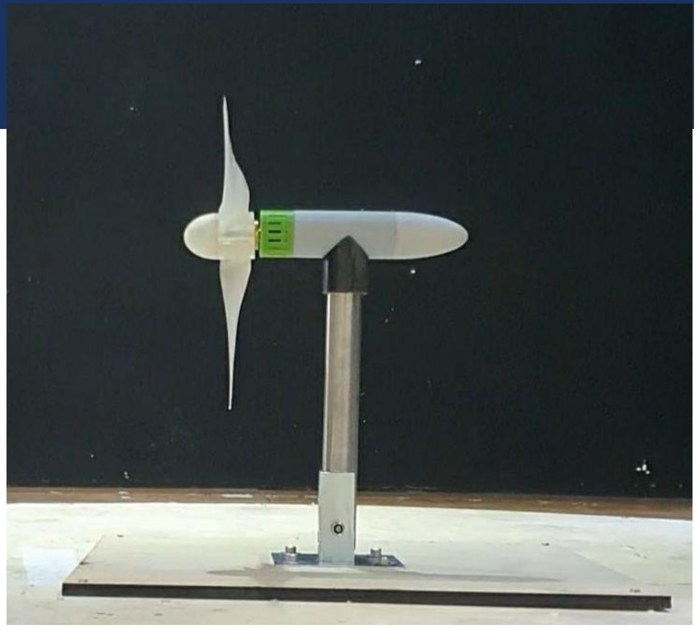
APPLICATIONS

- Investigation of the influence of complex terrain
- Interaction between atmosphere and ocean (mechanical and thermal)
- Operation of floating offshore wind turbines (FOWTs)
- Integration with lower fidelity models
- Blade optimization

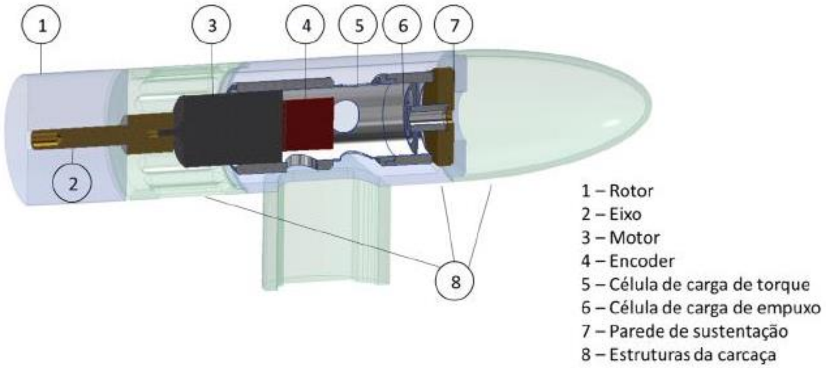




WIND TUNNEL EXPERIMENTS

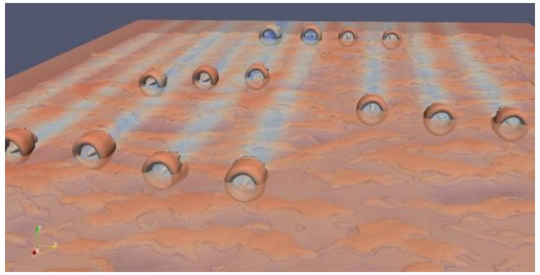


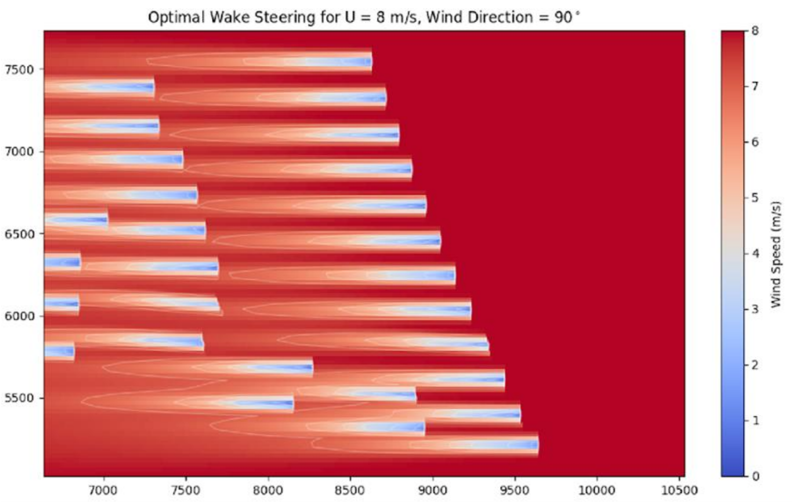
- Collaboration with IPT (Atmospheric Boundary Layer Wind Tunnel)
- Validation of numerical models
- Studies about interference, turbulence, terrain, rugosity etc.

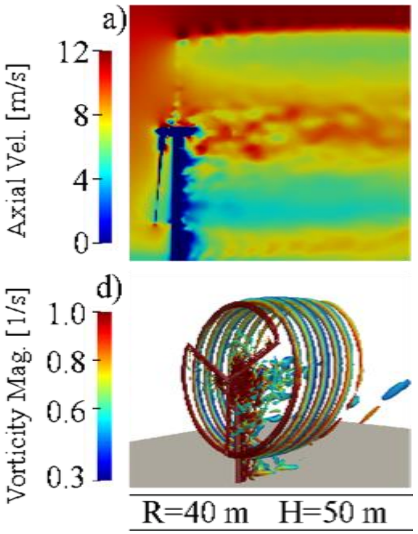


RESEARCH PROJECT EXAMPLE

High-Peformance Computing for Wind Energy (HPCWE)







UNIVERSIDADE DE SÃO PAULO

KTH VETENSKAP OCH KONST

UNIVERSITY OF TWENTE.

UNIVERSITY OF OXFORD

epcc

HLRS High-Performance Computing Center | Stuttgart

Imperial College London

DTU

VORTEX

UFSC

UNICAMP

CPFL ENERGIA

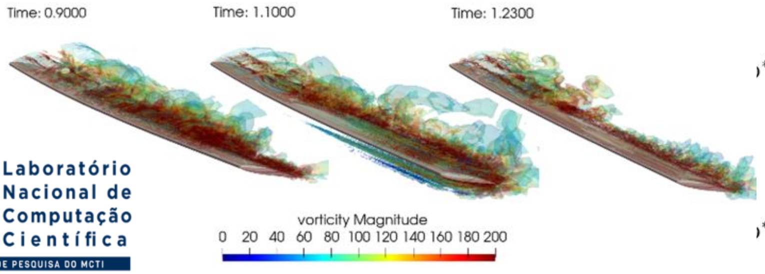
Financed by:

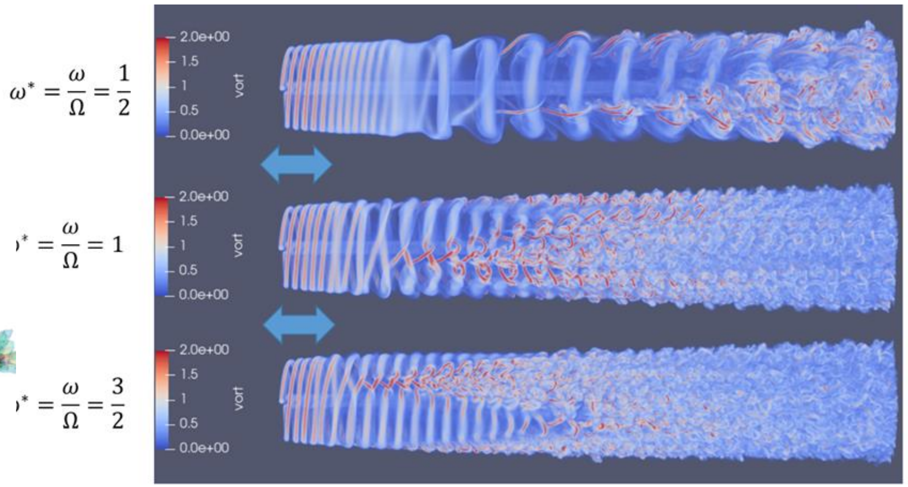
European Commission

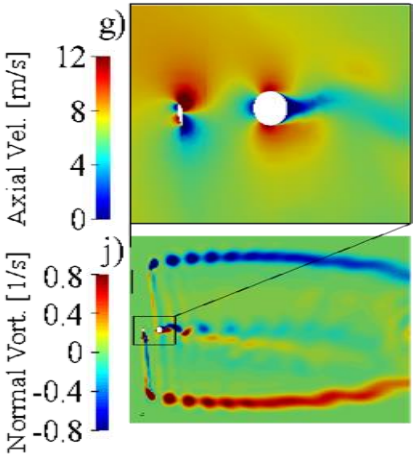
Laboratório Nacional de Computação Científica

UNIDADE DE PESQUISA DO MCTI

FAPESP





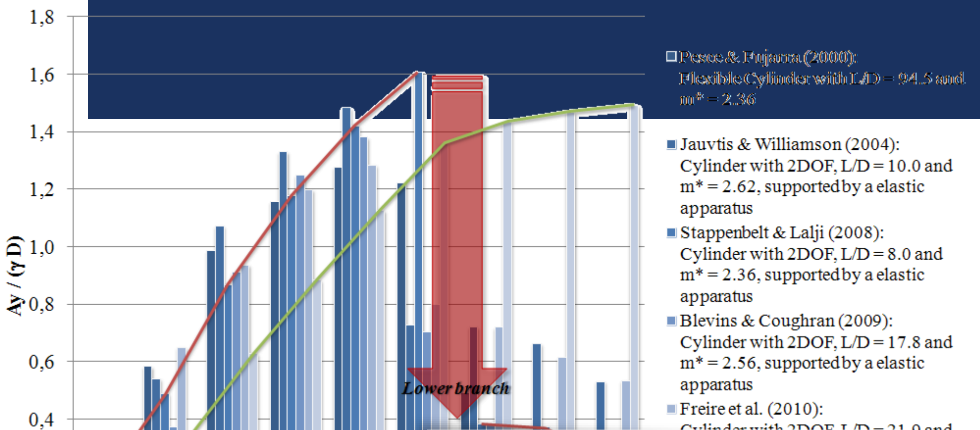


FLUID-STRUCTURE INTERACTIONS

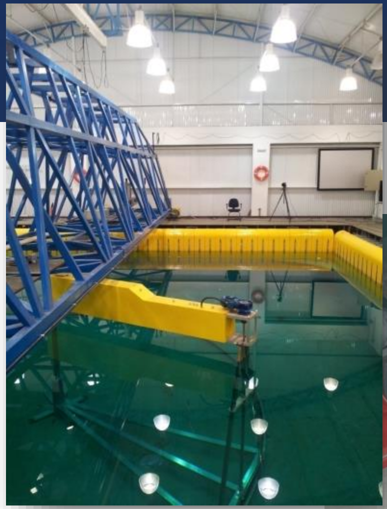
Offshore Mechanics Laboratory (LMO) - http://lmo.poli.usp.br

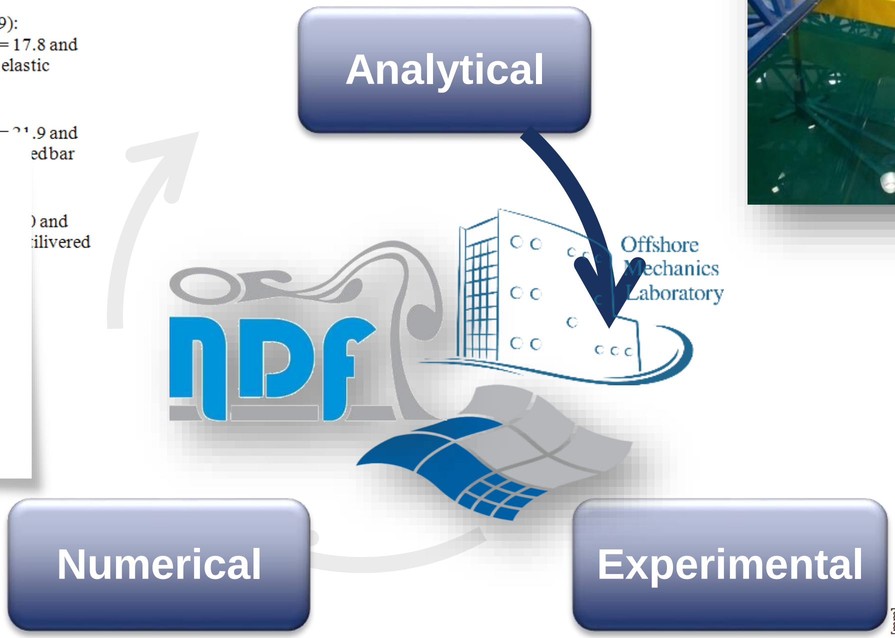
Coordinator: Dr Celso Pesce (Department of Mechanical Engineering)

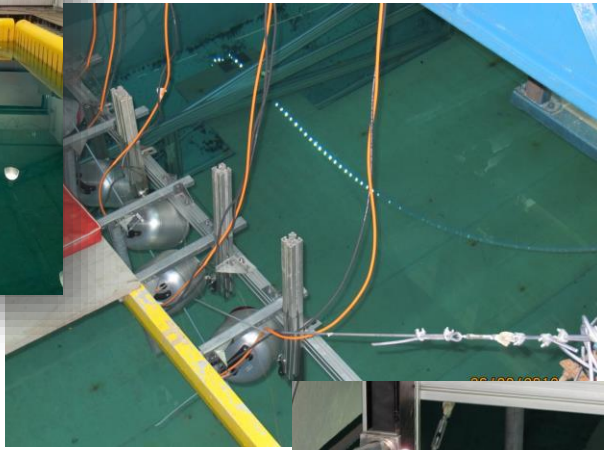
Nonlinear riser dynamics and VIV

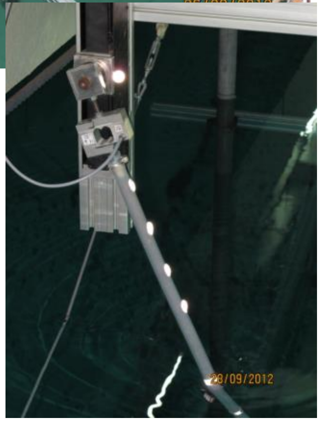


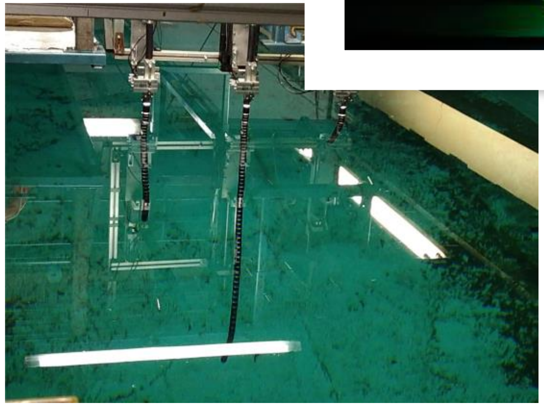
Numerical Models:
Calibration through Fundamental Experiments

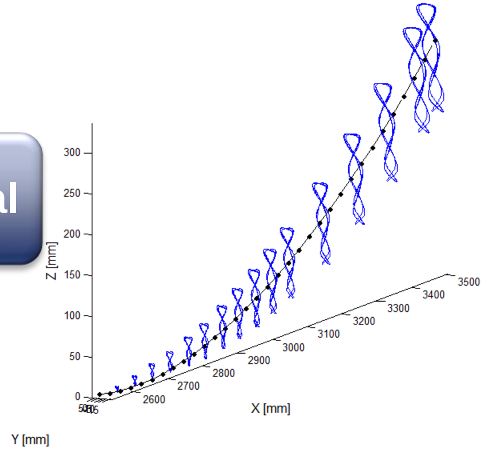




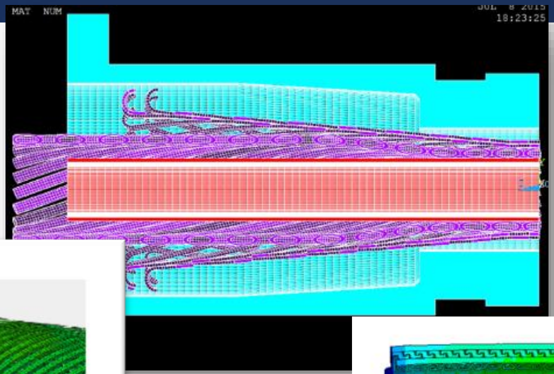


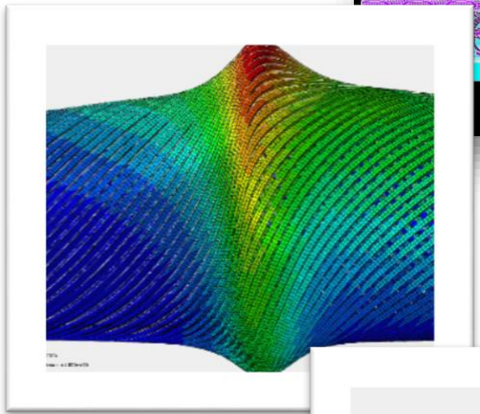


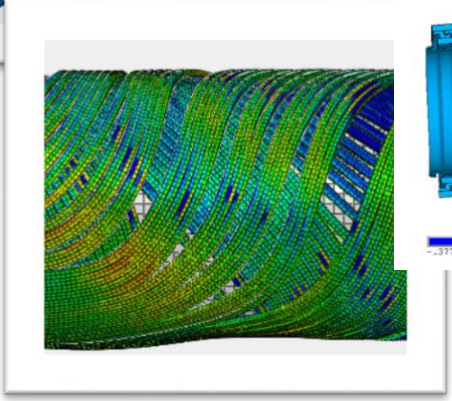


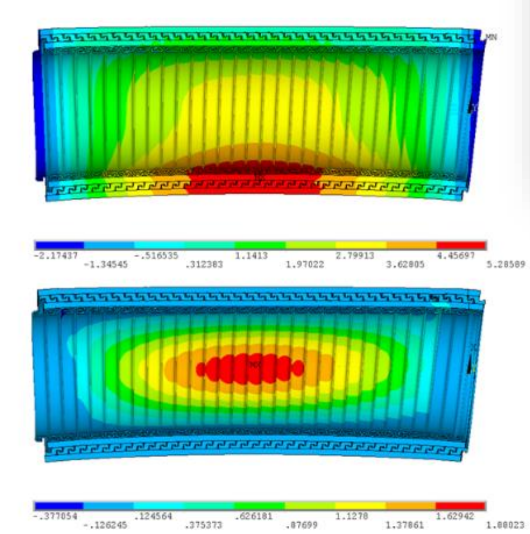


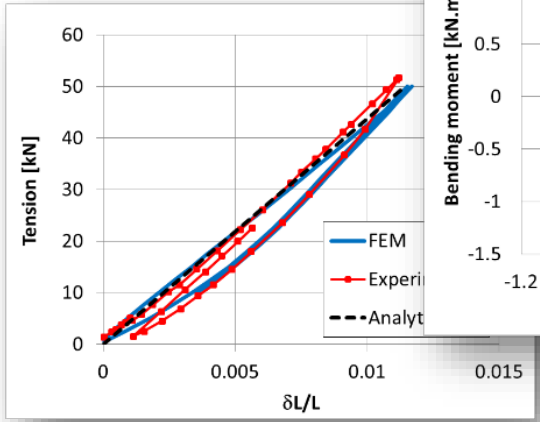
Riser and Cables Modeling, Analysis, Computational Tools

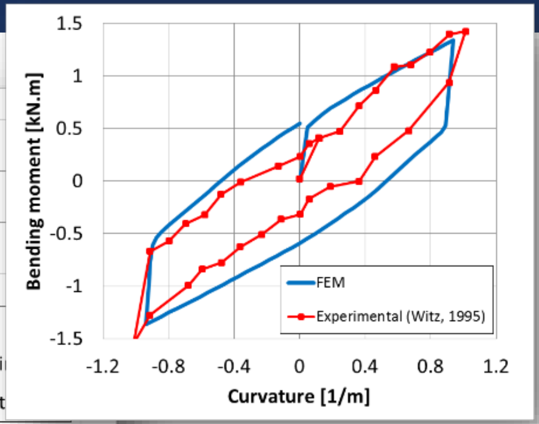


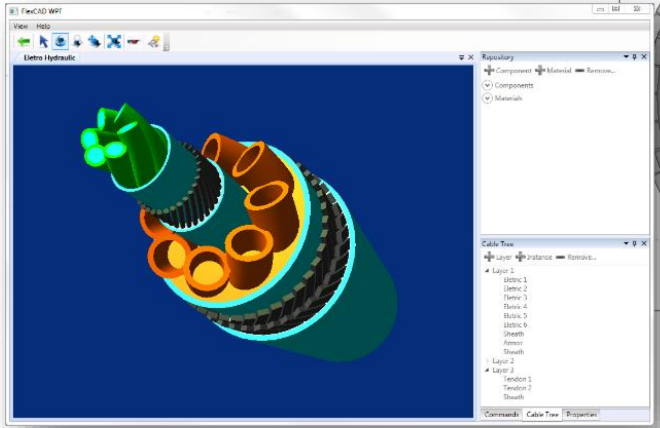


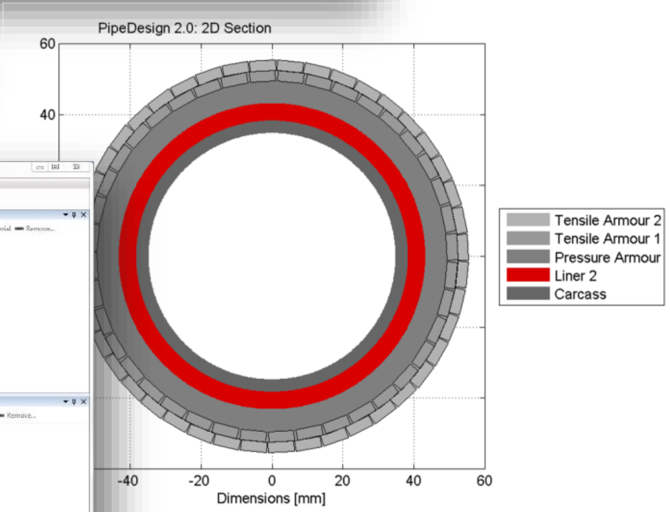












New trends: HVAC/DC – Dynamic Power Cables

HVDC/AC dynamic power cables below and above 66kV

Dynamic behavior

New shielding materials fatigue

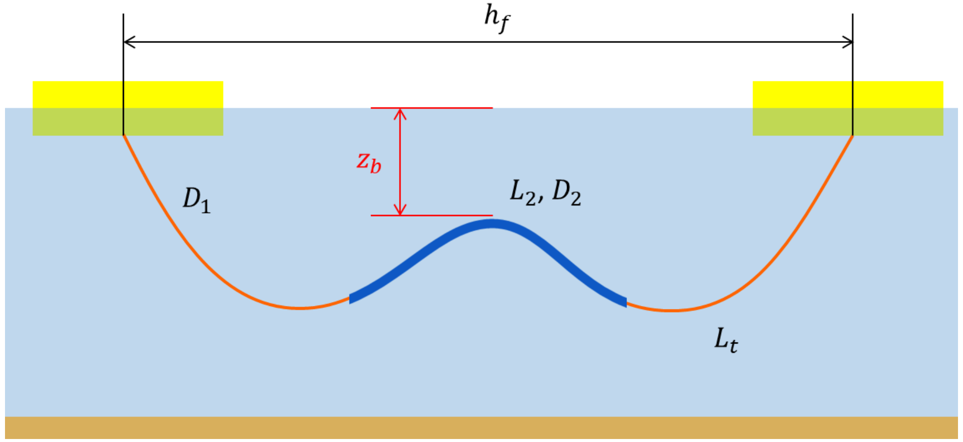
Structural monitoring

Digital Twins (DT)

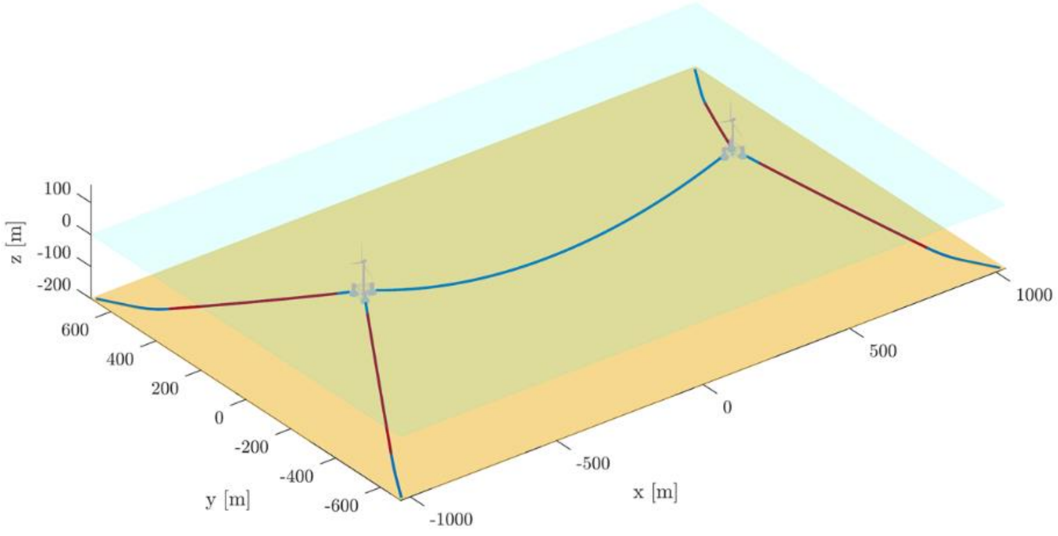
….

46 kV dynamic cable

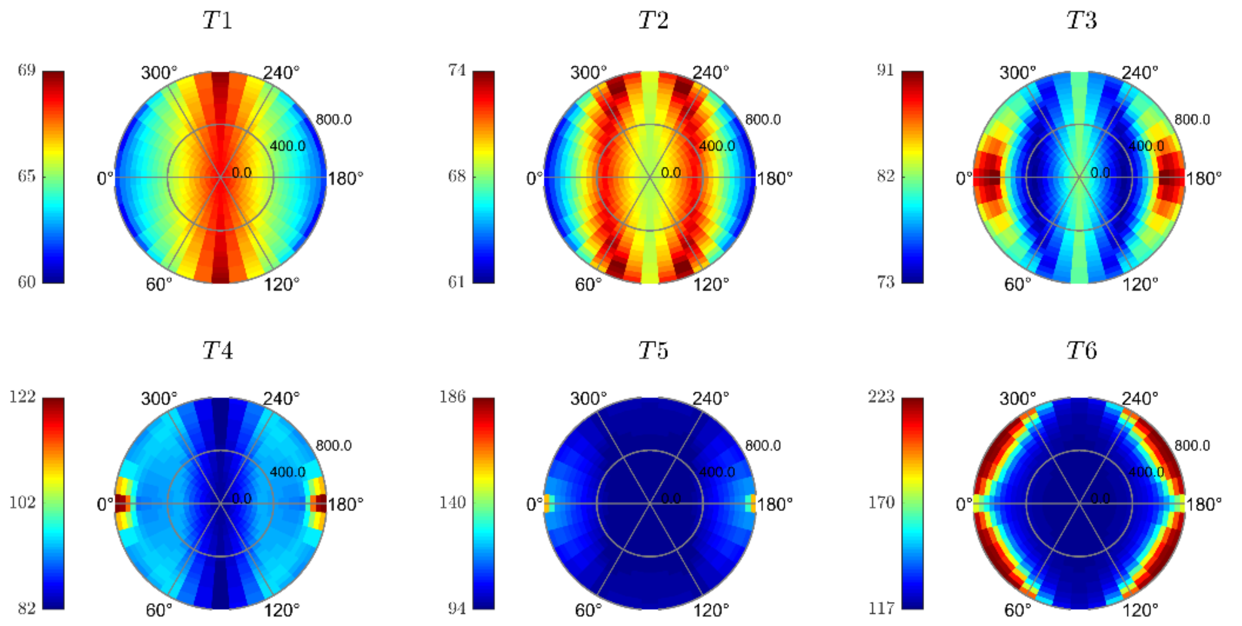
66 kV cable



New trends: deep water FOWT mooring



FOWT farm
shared mooring



Natural periods of oscillation in the horizontal plane as function of current forces and heading

INTEGRATION OF HYBRID ENERGY SYSTEMS

Laboratory of Advance Electric Grid (LGRID)

Maurício Salles (Dep of Electrical Engineering)
Renato Monaro (Dep of Electrical Engineering)

Floating Power Hub (2018-21, Petrobras)

Technical-Economic Analysis (HVAC and HVDC)
Steady State and Transient Analyses (HVAC and HVDC)

Outcomes

- Economic analysis of each configuration;
- Steady state tool for dimensioning the system;
- Dynamic Modelling of the AC and DC transmission system;
- Motor starting analysis;
- Loss of generation analysis;
- Critical clearance time for protection schemes (AC and DC transmission);
- Carbon capture for power hubs;
- Two paper in preparation stage

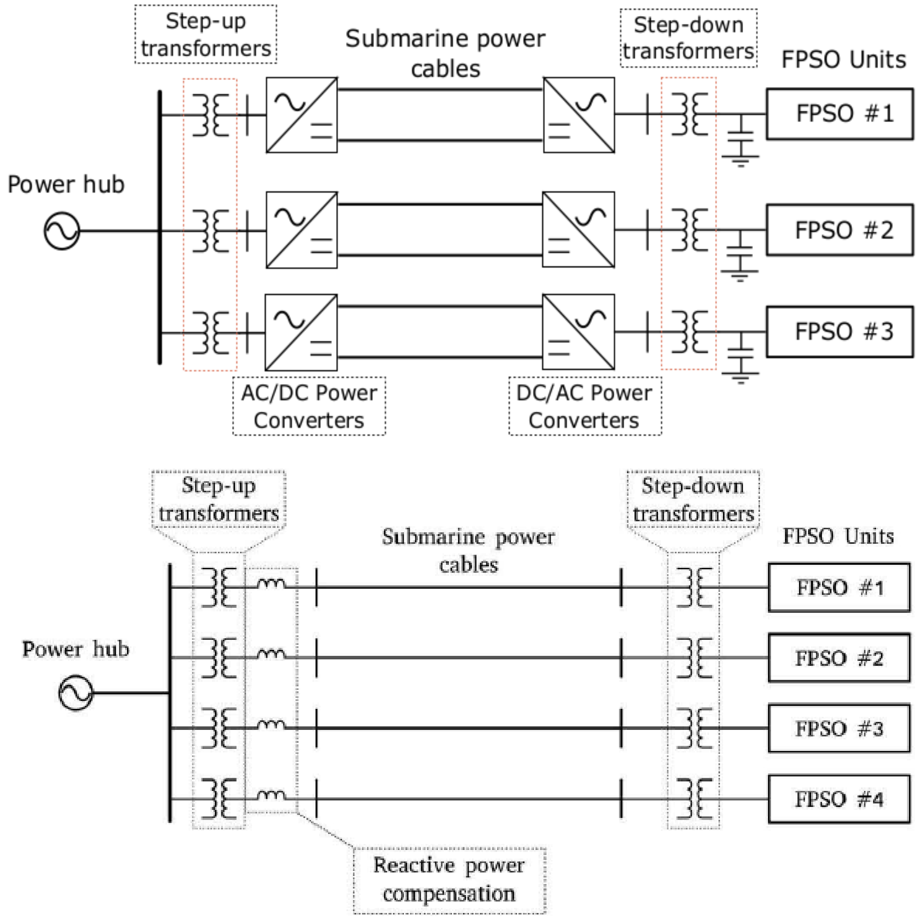


Fig. 1. Topology of the offshore isolated electric grid in the pre-salt region.

FWT for subsea equipment (2020-23, Petrobras)

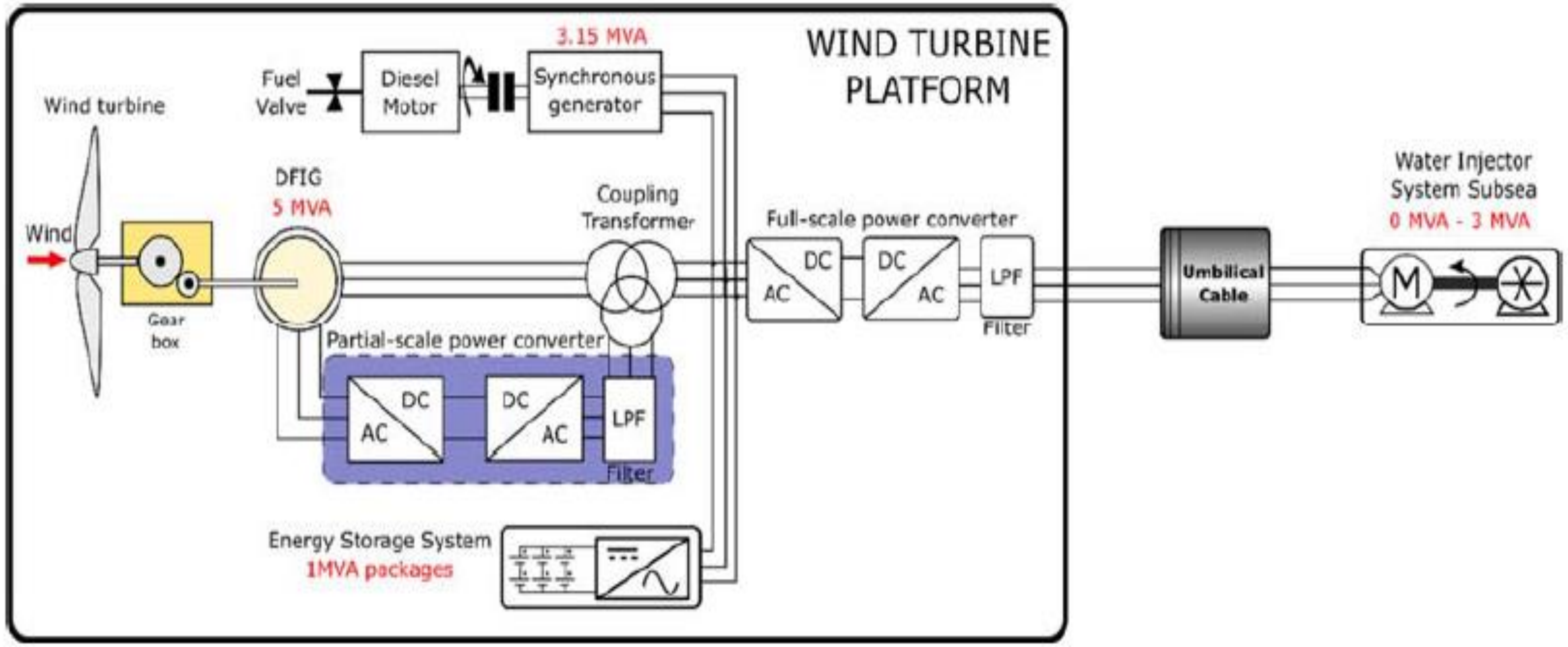
Technical-Economic Analysis

Steady State Analysis

Transient Analysis

BESS

Water Injection System topologies for Isolated operation



Thank You

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