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Controller influence on the fatigue of a floating wind turbine and load case impact assessment

DeepWind 2024, Trondheim

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Overview

NAUTILUS JOURNEY

- Who are we?
- Design concept
- Wind Turbine Controller development
    - Recent achievements

WIDER CHALLENGES FOR WIND TURBINE CONTROLLERS

- Complexity of FOWT dynamics
- Control strategies
- Control Co-Design (CCD)
- Measured Data

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ESTABLISHED:

2013, Bilbao
(Basque Country)

SHAREHOLDERS:

subsea 7

tecnalia
MEMBER OF BASQUE RESEARCH
& TECHNOLOGY ALLIANCE

VICINAY marine innovación

Who are we?

VISION:

To be a global player in the Floating Offshore Wind market

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Nautilus Design

Semi-submersible four columns steel design

Central Wind Turbine Generator (WTG)

- Better stability during integration operations
- More balanced dynamic behaviour in operation

Main Deck above the splash zone, with **clearance above the highest expected wave crest**

Transition Piece embedded into the Main Deck central position

Ring Pontoon filled with **sea water,** lowering the centre of gravity, improving stability

Pontoon divided into several **Passive Ballast Tanks**

Fairlead in the **submerged part:**

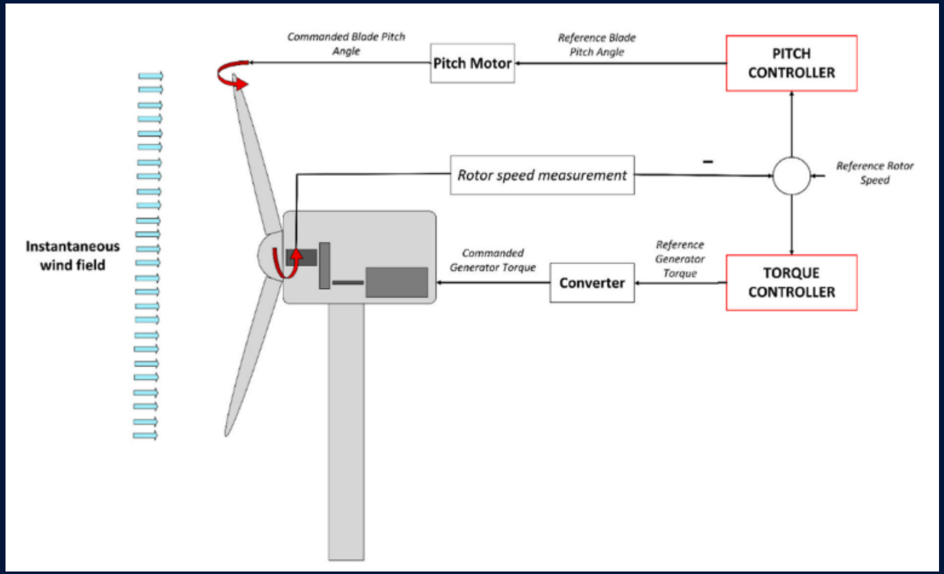
- Avoiding splash zone, reducing corrosion & fatigue
- Improved accessibility

Inter Array Cable (IAC) routed to the **inner part of the pontoon through an I-tube**.

Hang off system installed inside main deck

Wind Turbine Controller development

- **Initially, only constant Thrust was considered as an approximation**
  - Fine for generic early designs, but clearly not enough for detailed, more refined computations
- **Nautilus has collaborated with TECNALIA to make the most out of its capabilities and expertise to study and develop Wind Turbine Controllers**



Wind Turbine Controller development. Recent achievements

- A PhD thesis dedicated to the subject
- Several papers published
- Sensitivity analyses performed using different designs
- Partnership with Tecnalia in Control Co-Design (CCD)

ELSEVIER
Renewable and Sustainable Energy Reviews
Volume 167, October 2022, 112787

Review of control technologies for floating offshore wind turbines

Javier López-Queija [a b], Eider Robles [a c], Josu Jugo [d], Santiago Alonso-Quesada [d]

ELSEVIER
Renewable Energy
Available online 9 January 2024, 119973
In Press, Journal Pre-proof What's this?

A novel python-based floating offshore wind turbine simulation framework

Javier López-Queija [a b], Eneko Sotomayor [c], Josu Jugo [c], Ander Aristondo [a], Eider Robles [a d]

energies
MDPI

Article

A Simplified Modeling Approach of Floating Offshore Wind Turbines for Dynamic Simulations

Javier López-Queija [1,2,*], Eider Robles [1,3], Jose Ignacio Llorente [2], Imanol Touzon [1] and Joseba López-Mendia [1]

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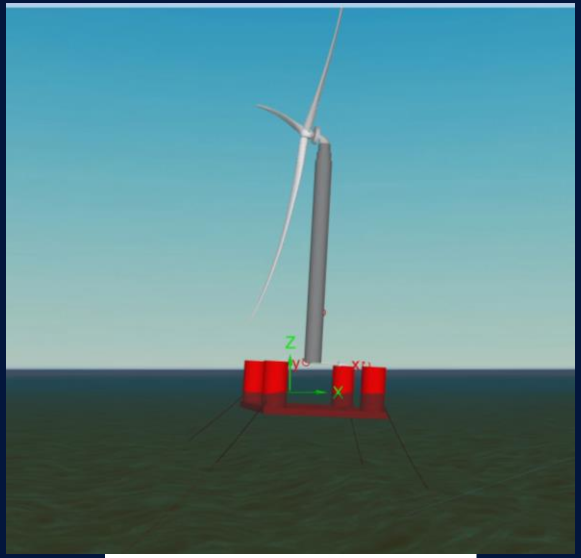
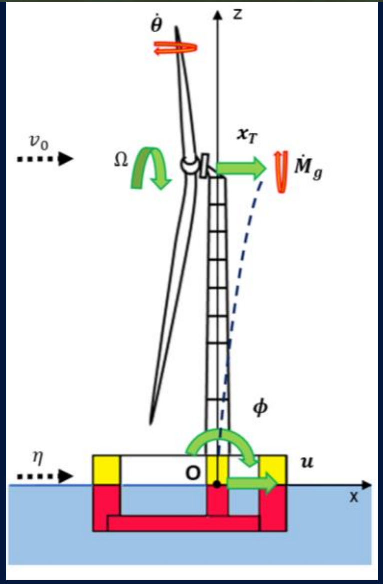
Complexity of FOWT dynamics



- **Extremely complex and coupled dynamics with different sources of excitation**
  - Sea: Wave, currents
  - Wind: Speed, direction, gusts, turbulence, shear
  - Wind Turbine in operation:
    - Blade dynamics
    - Controller
    - Structure hydrodynamics
- **Fine modelling of all physical phenomena involved becomes non-affordable computationally**
  - Reduced and simplified models must be used



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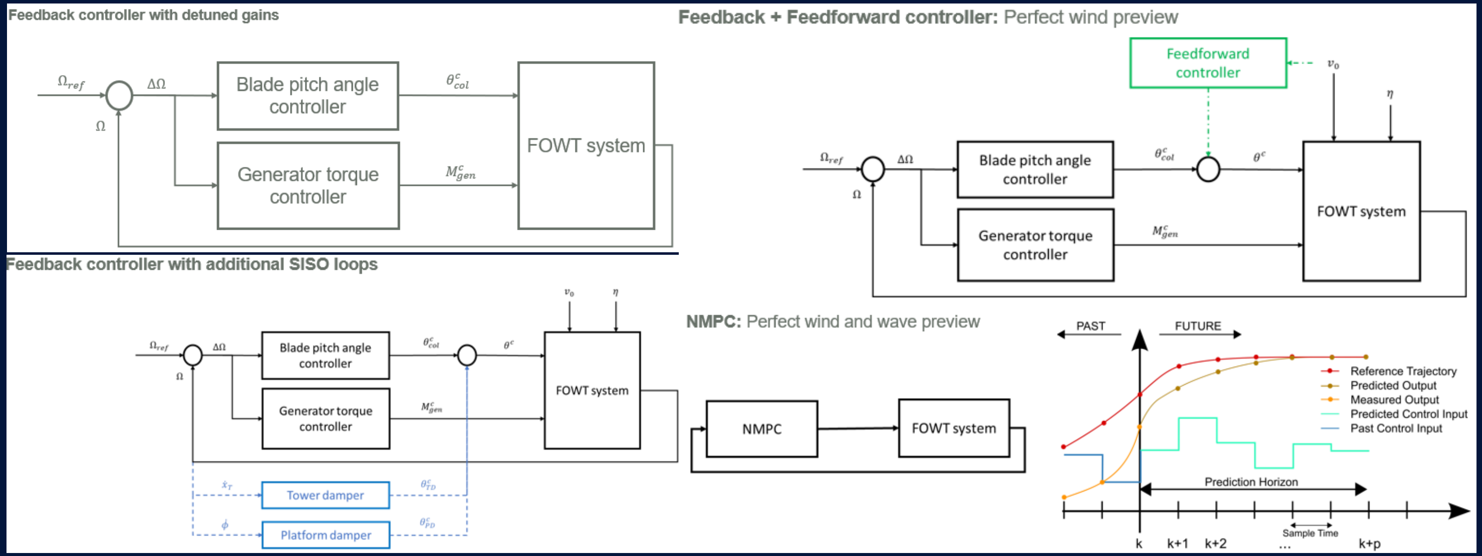
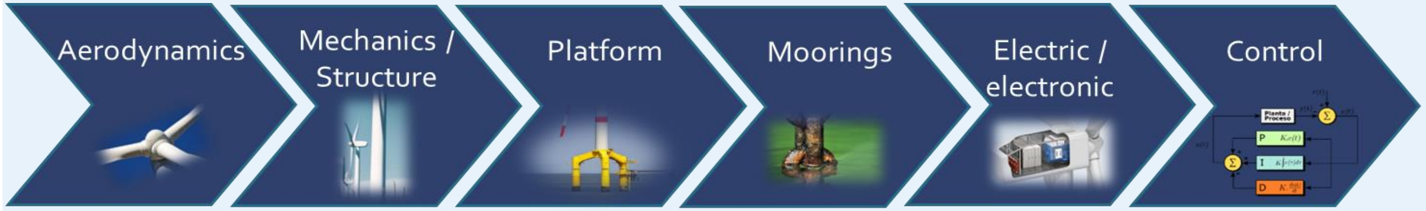
Control strategies

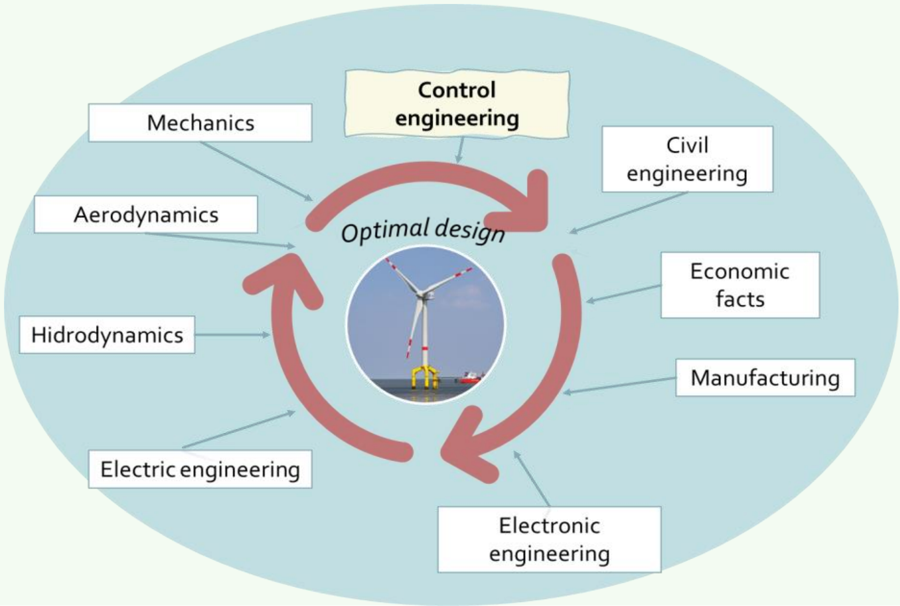
- **Different control strategies available in literature**
  - Not all of them have been used for commercial FOWT
- **It takes a lot of resources and time to**
  - Evaluate and study all control strategies applicable to FOWT
  - Implement control in our model
  - Simulate
  - Assess pros and cons



Control Co-Design (CCD)



- Sequential and independent design
- Each step limits the possibilities of the next
- Control takes part in the end, once the design is finished: no influence on design



~~Sequential~~ — Different disciplines work concurrently from the start

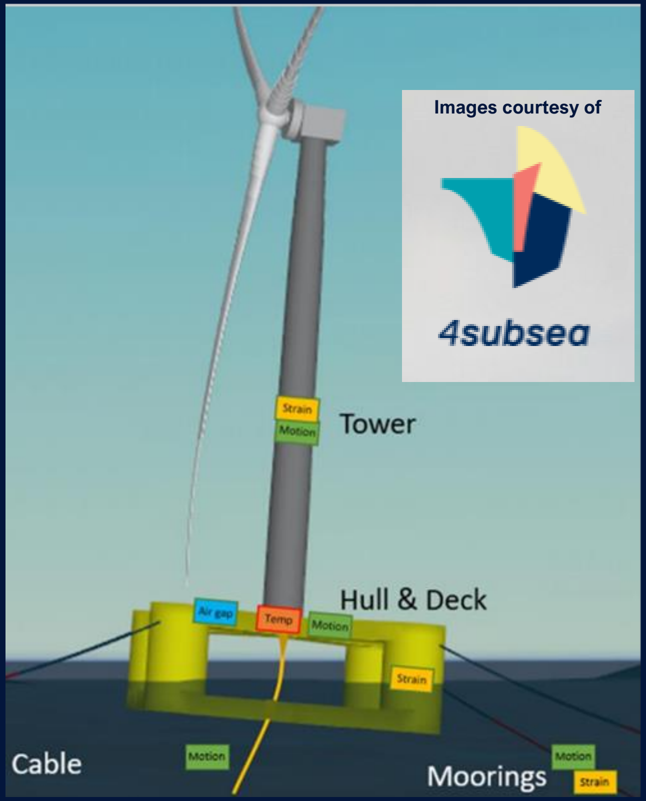
~~Independent~~ — Emphasis on interactions between subsystems and control paradigms

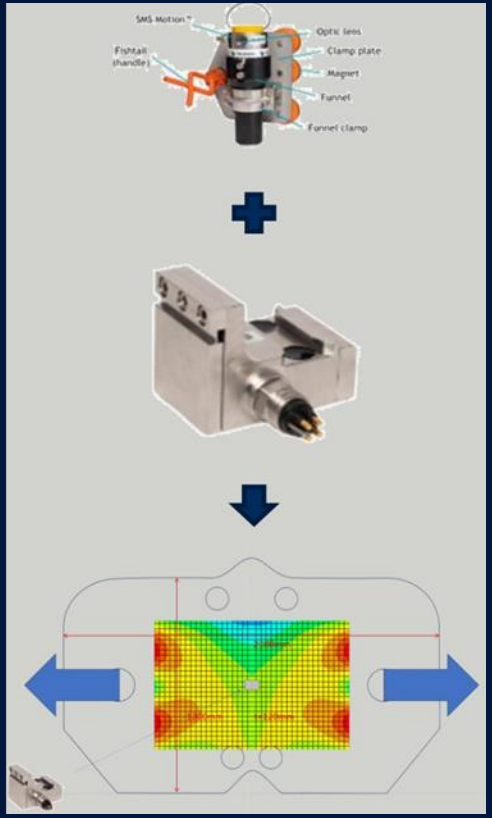
KONFLOT Control co-design for floating renewable energy

NAUTILUS is member of the Advisory Committee of KONFLOT project

Measured data

- **Real data is essential and very hard to get given the current Technology Readiness Level**
  - None FOWT operating, fully instrumented and happy to share data with others
- **Key in many aspects that involves control**
  - Validation of models and digital twins
  - Read live data in order to improve control



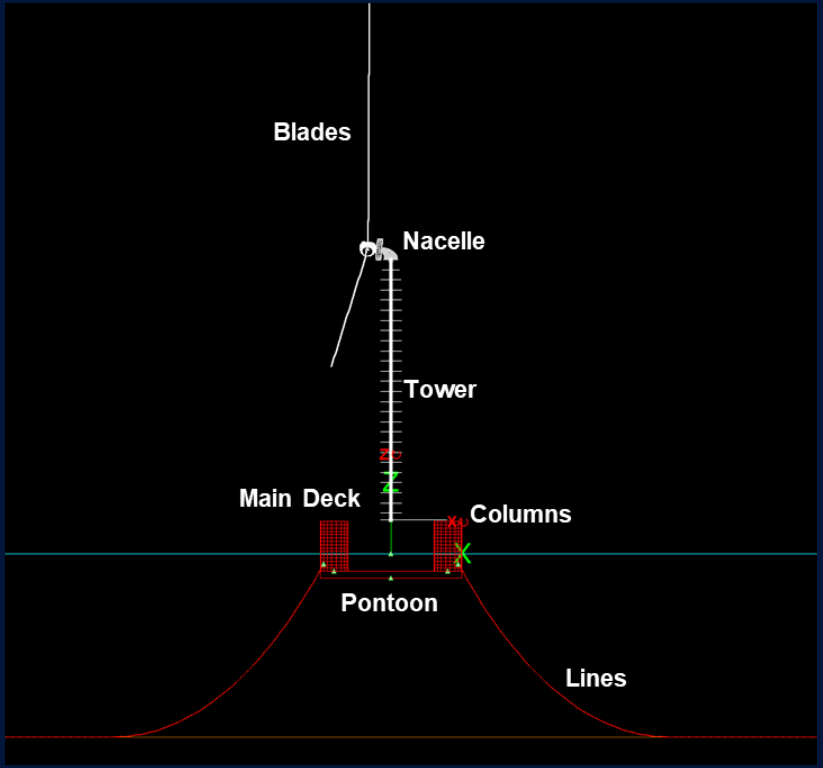


Content overview

- **Reduced order coupled model and controller**
- **Fatigue calculation**
  - DEL
  - Advantages of normalised DEL
- **Analyses performed**
- **Results**
  - Turbine performance
  - Fatigue
  - Discussion
- **Conclusions**

Reduced Order Coupled Model and Controller

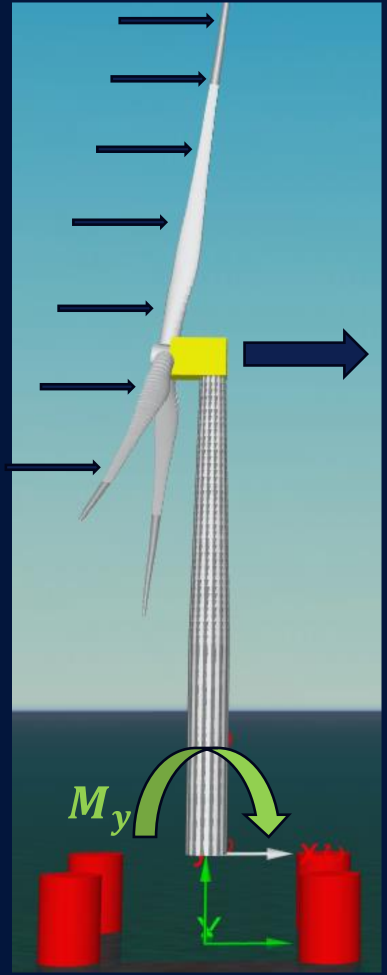
- **5 different models in OrcaFlex**
- **Controller: Proportional Integral (ROSCO)**
  - Tunned differently: Controller1, Controller2



Model	Blade Formulation	Controller
Control 1 flex	Flexible blades	Controller 1
Control 2 flex	Flexible blades	Controller 2
Control 1 rigid	Rigid blades	Controller 1
Control 2 rigid	Rigid blades	Controller 2
Constant Thrust	Buoy	No

Lines	**Line** type object from Orcaflex
Pontoon	**Lumped type buoy** object from Orcaflex with a constant equivalent volume
Columns	**Spar type buoy** object with the specific geometry
Main deck	**Constraint** type object with specific structural flexibility extracted from static unit load analysis
Tower	**Line type** object to represent the flexible tower considering the different sections with specific dimensional properties
Nacelle	**Lumped type buoy** object with specific mass properties

Fatigue Calculation. DEL



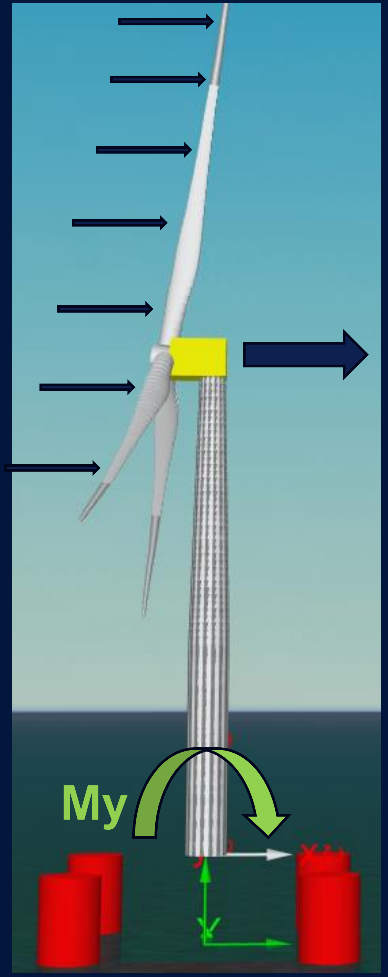
- M_y Fatigue at tower bottom is generally the most limiting in a FOWT
- Different methodologies available in literature to successfully predict life and fatigue of FOWT
- Damage Equivalent Loads (DEL) is perhaps the most widely used in FOWT

$$DEL = \left(\sum_k \frac{L_i^{\,m} n_i}{N_{ref}} \right)^{1/m}$$

$$DEL_{GENERAL} = \left(\sum_{i=1}^{n} (DEL_i^{\,m} * PO_i) \right)^{\frac{1}{m}}$$

- Drawback: DELs obtained from individual load cases cannot be compared with each other

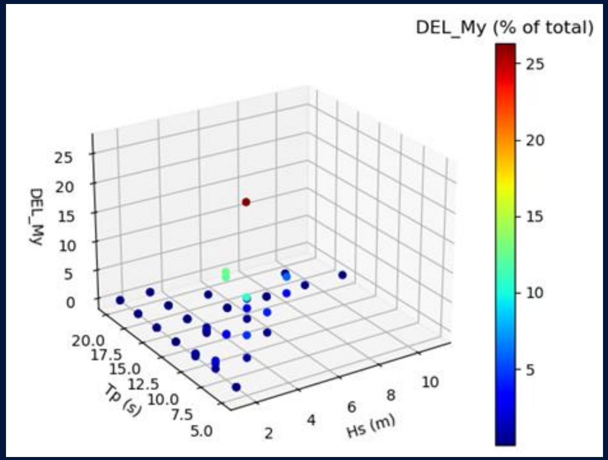
Fatigue Calculation. Advantages of normalised DEL



- A modification in the formulation can be introduced in order to normalise individual DELs with probability

$$DEL_{norm}(\%) = 100\,\frac{{DEL_i}^{m} * PO_i}{\sum_{i=1}^{n}({DEL_i}^{m} * PO_i)}$$

- It allows the direct comparison of load cases, identifying the most critical to the structure

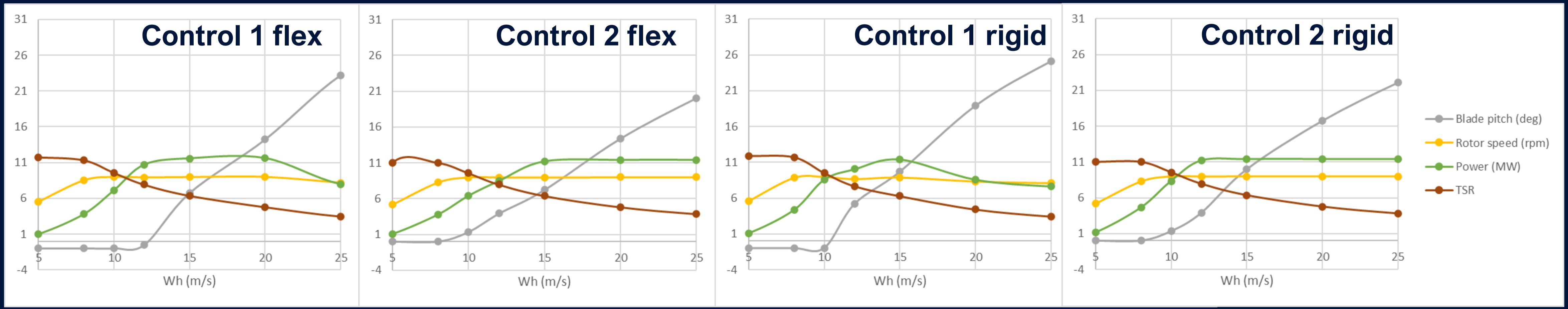


Analyses performed

- 9 points of operation along the Wind Turbine power curve
- Wave H_s and T_p: statistical average was chosen for all W_h bins considered based on existing metocean database
- Seeds: seed variability was studied, resulting in a low figure of 2%.
- Irreg wave profile JONSWAP spectrum
- Unidirectional wind and wave directions for an initial approx.
- Constant wind with vertical profile as initial approx.

W_h Wind at hub (m/s)	H_s Wave Height (m)	T_p Wave period (s)
3	1	9
5	1	9
8	1.4	9
10	1.7	8.5
12	2	8.5
15	2.8	9
20	4.2	10
25	6	11
30	8	13

Results. Turbine performance



- **Control 1:**
  - Higher blade pitch at high W_h→ Rotor speed decreases → Power decreases
  - Blade pitch does not increase at lower W_h
- **Control 2:**
  - Lower blade pitch at high W_h maintains rotor speed constant → Power constant
  - However, does not reach Max Power at rated speed due to peak shaving filter
- **Blade formulation clearly impacts the turbine performance too**

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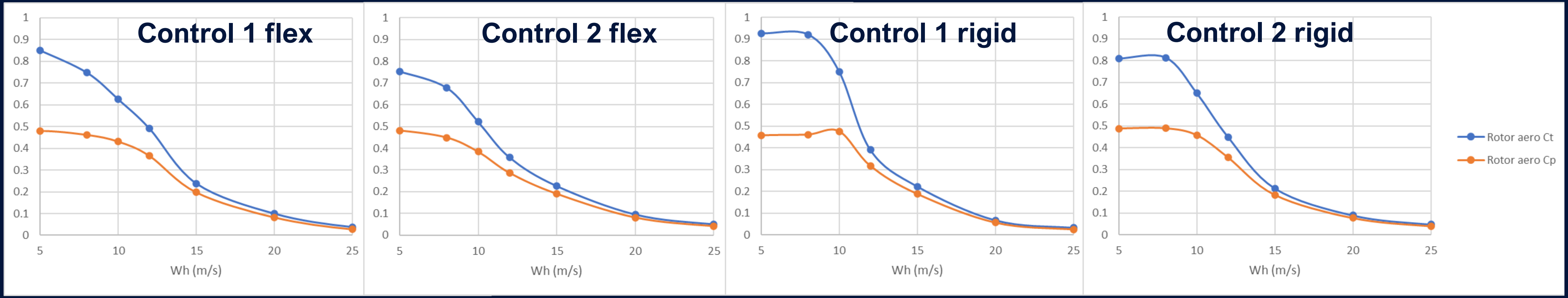
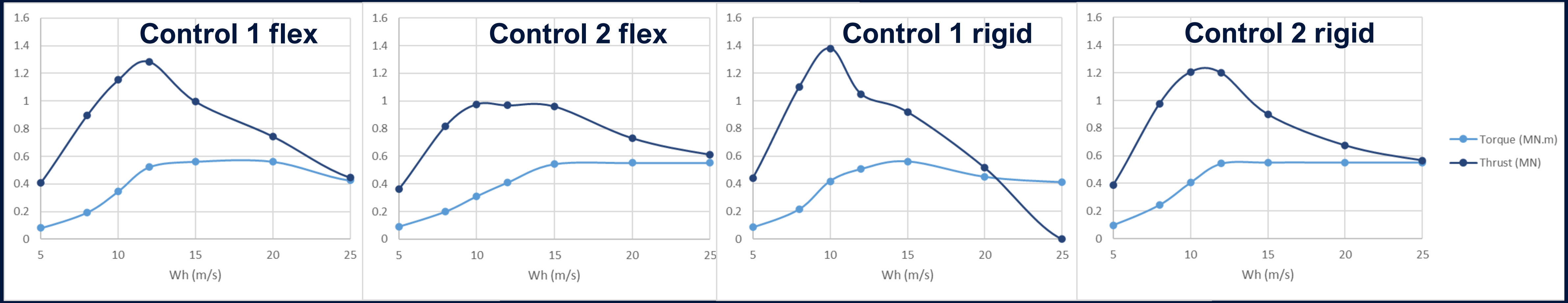
Results. Turbine performance II



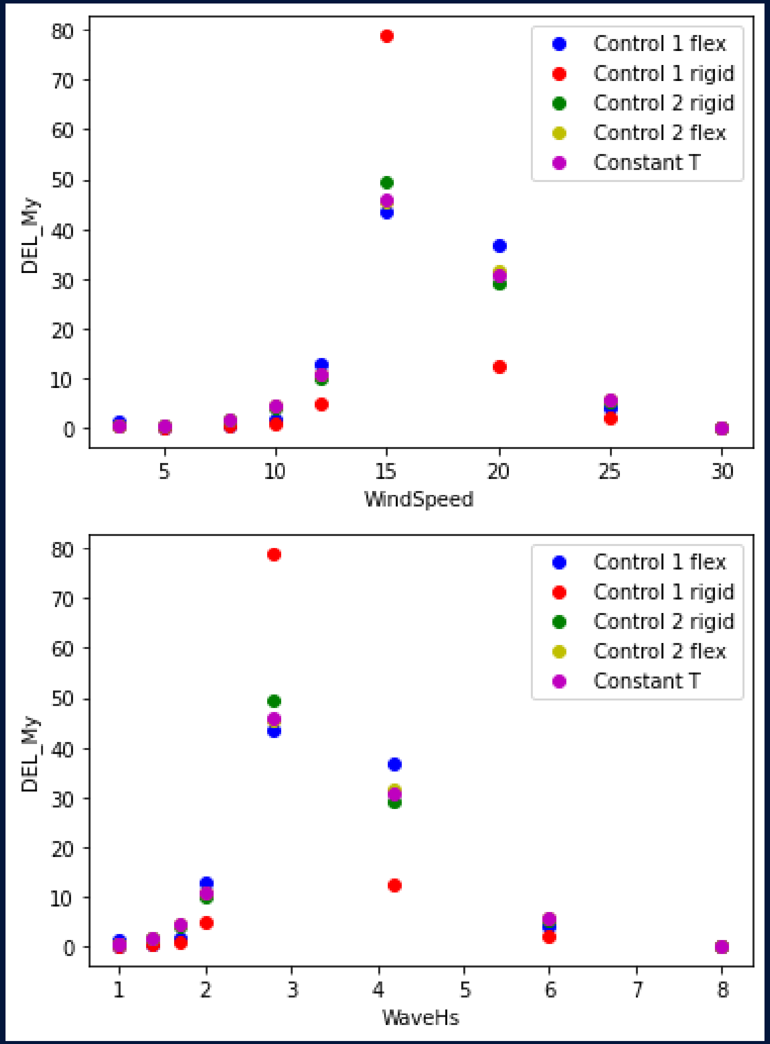
- Blade formulation greatly impacts C_t and C_p, more than controller used

Results. Turbine performance III



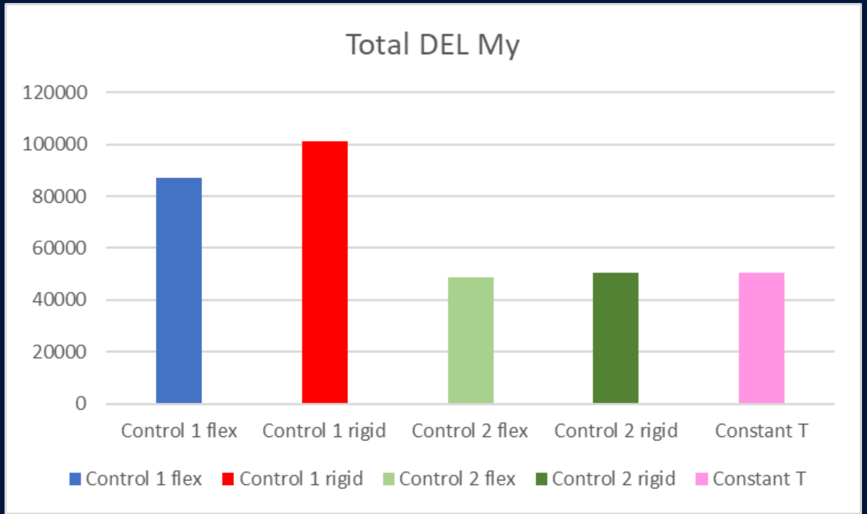
- **Thrust and Torque are heavily influenced by control tunning and blade formulation**
  - Trade off: Max power and Thrust at rated speed VS Constant power and Torque throughout power curve

Results. Fatigue



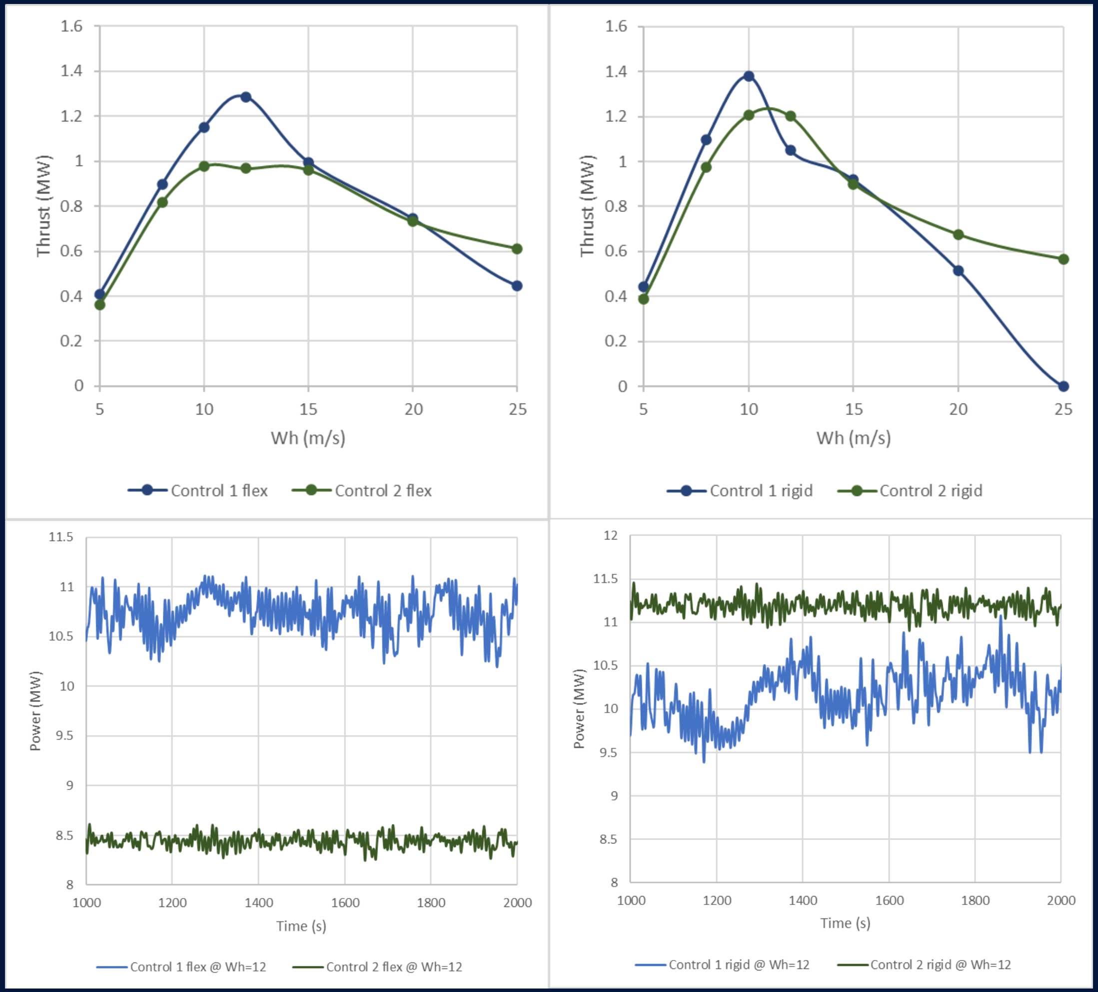
- **Normalised DEL measures the impact of each load case run on total DEL for a given controller and blade formulation (%)**
- **Most damaging cases:**
  - W_h between 12-20 m/s
  - H_s between 2-4 m
- **Blade formulation can notably modify the weight of each load case on the overall fatigue**

Results. Fatigue II



- **Controller adjustments and Blade formulation can massively impact fatigue in FOWT**
- **Control 1 tunning increases fatigue 2x compared to Control 2**
- **Blade formulation can also show a large influence**

Results. Discussion



- **Why these fatigue numbers?**
- **Rigid blade formulation reduces computational time significantly, but also impacts the estimation of:**
  - Thrust/Power curve
  - Fatigue life
- **Control tunning strategies come as a trade-off between power and fatigue life**

Parameters	Control 1	Control 2
Control tunning	-More reactive pitch control -Less peak shaving	-Less reactive pitch control -More peak shaving
Power/Thrust @ Vrated	-More power/thrust	-Less power/thrust
	-More variability -Higher fatigue	-Less variability -Lower fatigue
Power/Thrust along curve	-Larger drop at high wind speeds	-Slightly more constant

Conclusions

- **DEL normalisation allows the comparison of different load cases, quantifying their contribution to the total DEL**
  - Most damaging cases across all models studied:
    - W_h between 12-20 m/s
    - H_s between 2-4 m
- **Control tunning strategies have a large impact on fatigue and turbine performance**
  - Trade off: More power→ More variability → Worse fatigue life
- **Blade formulation also influences heavily turbine performance and fatigue**
  - Rigid formulation offers a clear computational advantage compared to flexible formulation
  - However, based on results obtained, blade dynamics differ noticeably, affecting both performance and fatigue computation, and therefore it is not recommended