DTU

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Self-Alignment on Single Point Moored downwind Floater – The PivotBuoy® Concept

By Albert M. Urbán, Laura Voltà, Rocío Torres and W. H. Lio

Agenda

- **Floating Wind Turbines – Market Perspectives**
- PivotBuoy® Concept
- PivotBuoy Project
- Dynamics Single Point Moored Platforms
- Future Work
- Conclusions

Floating Wind Turbines – Market perspectives

- Operating, under (Pre)-construction and awarded floating wind projects

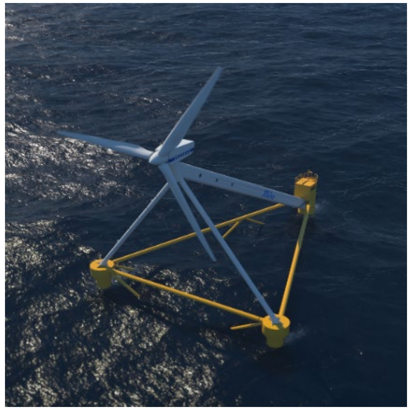
  Windfloat demonstrator (2MW)
  Hywind Scottland (30MW)
  Maine Aqua Ventus I (12MW)
  Nedo demonstrator (4.4 and 3MW)
  Kincardine (50MW)
  Leucate (24MW)

https://www.equinor.com/en/what-we-do/floating-wind/hywind-scotland.html

https://www.principlepowerinc.com/en/windfloat

- Innovation in Floating Wind Turbines
  - Ability to harness energy at deep water depths
  - Cost efficient solutions

- Among different solutions: Single Point Moored Platforms (SPM)



http://www.x1wind.com

https://saitec-offshore.com/projects/

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PivotBuoy® Concept

- PivotBuoy Platform developed by X1Wind brings to the table:
  - Single Point Moored connection integrating anchoring, mooring and electrical in a unique point
  - Wind self-orienting system
  - Easy manufacturing, towing and platform installation
  - Downwind concept, which allows increase of blade flexibility and bending

- Brief introduction: images are worth more than words…

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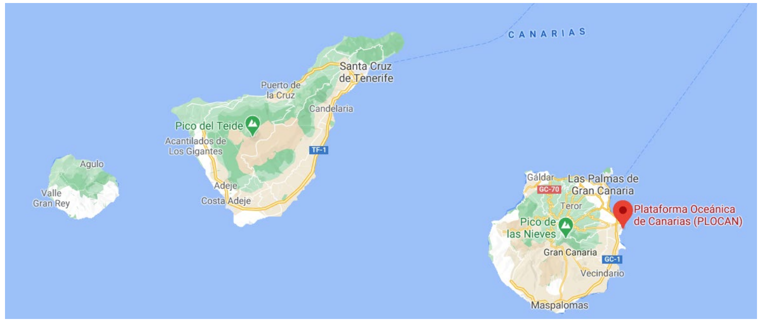
PivotBuoy Project

- H2020 funded project to validate the PivotBuoy® system
- Prototype to be tested at PLOCAN **in a real environment**
- System **under construction,** installation in coming months
- **Consortium:** 9 industrial + R&D partners



- PLOCAN test site (Spain)
- X30 platform (1:3 scale)
- 50m water depth
- 3 tensioned moorings + GBS
- Vestas V29 + ABB converter
- 20kV cable connection

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement Nº815159

https://pivotbuoy.eu/

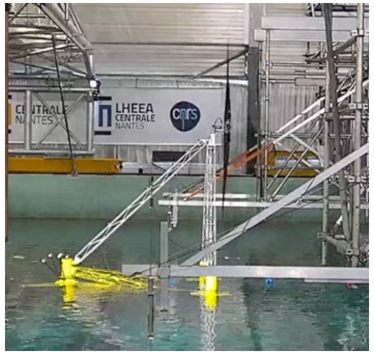
PivotBuoy Project

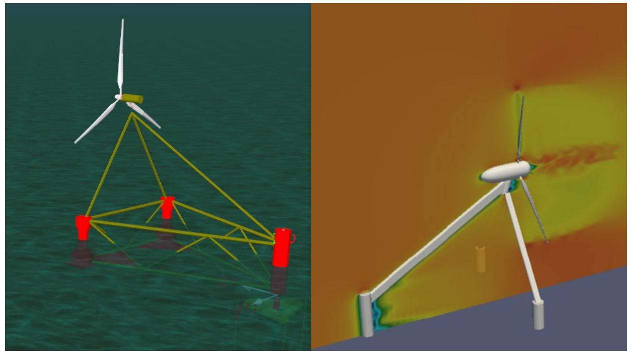
Lab validation
- 1:64 & 1:50 scale tests
- Stability
- Survivability
- Wind alignment

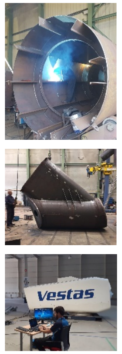
Design optimization
- Coupled analysis
- Structural optimization
- CFD modeling
- Fabrication & O&M aspects

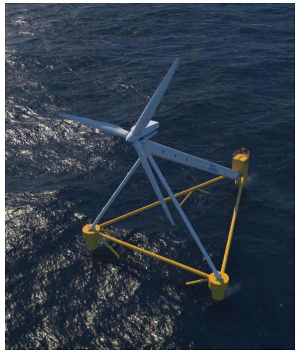
Part-scale demo
- 1:3 scale floater
- Vestas V29
- Validation of all subsystems
- Real conditions

Scaling-up
- Scale up design
- Learning transfer
- Certification
- Industrialization
- Cost reduction









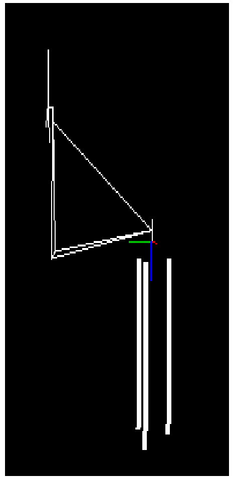
PivotBuoy Project

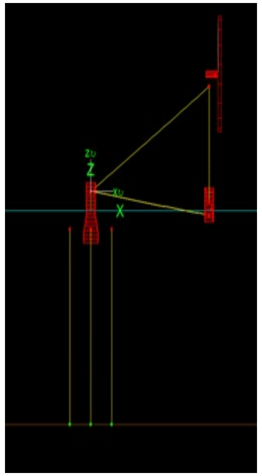
- Manufacturing at DEGIMA facilities has finished
- Assembly on-going, ready to be deployed in the next months

PivotBuoy Project

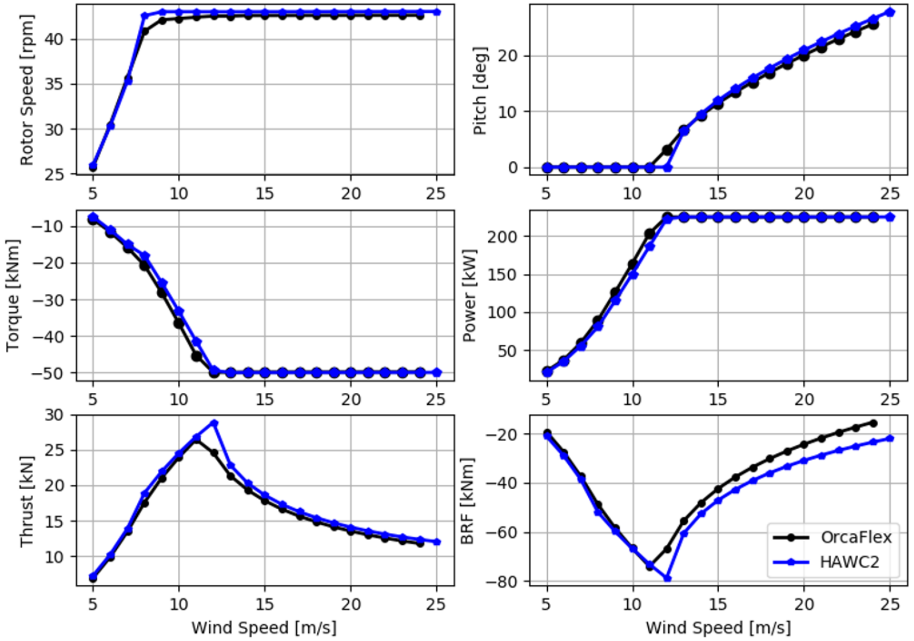
- DTU's role in the project:

HAWC(Stab)2 - A state-of-the-art framework for multi-physics/fidelity frequency and time domain analysis





- Set-up and calibration of different numerical models
- Simulation results for PLOCAN 1:3 part-scale prototype
- Full-scale PivotBuoy System Simulation
- Calibration of the numerical models with experimental data
- Comparison between numerical and experimental data



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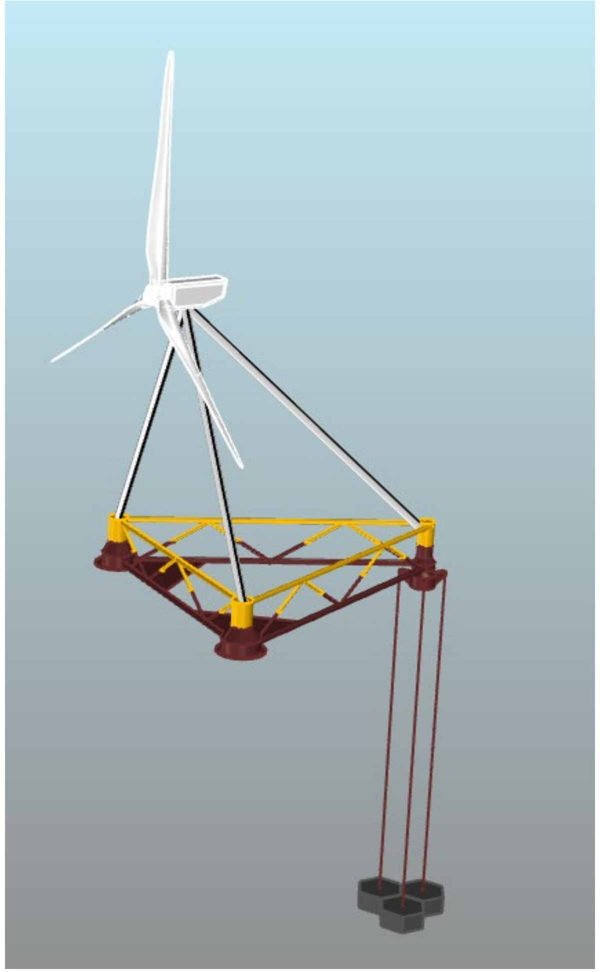
Dynamics Single Point Moored Platforms

- Platform Modelling
  - Preliminary Full Scale design
    - *Hub Height 140m*
  - 15MW Reference Wind Turbine
    - *Downwind adaptation & No tilt - 240m Rotor*
  - Frictionless Spherical Bearing
    - *Free Rotation TLP – Floater 3DOF*
  - Aerodynamic Drag Included for all elements
    - *Improves Self-alignment platform*

- Software: **HAWC2** & Hydrodynamics based on Morison's approach

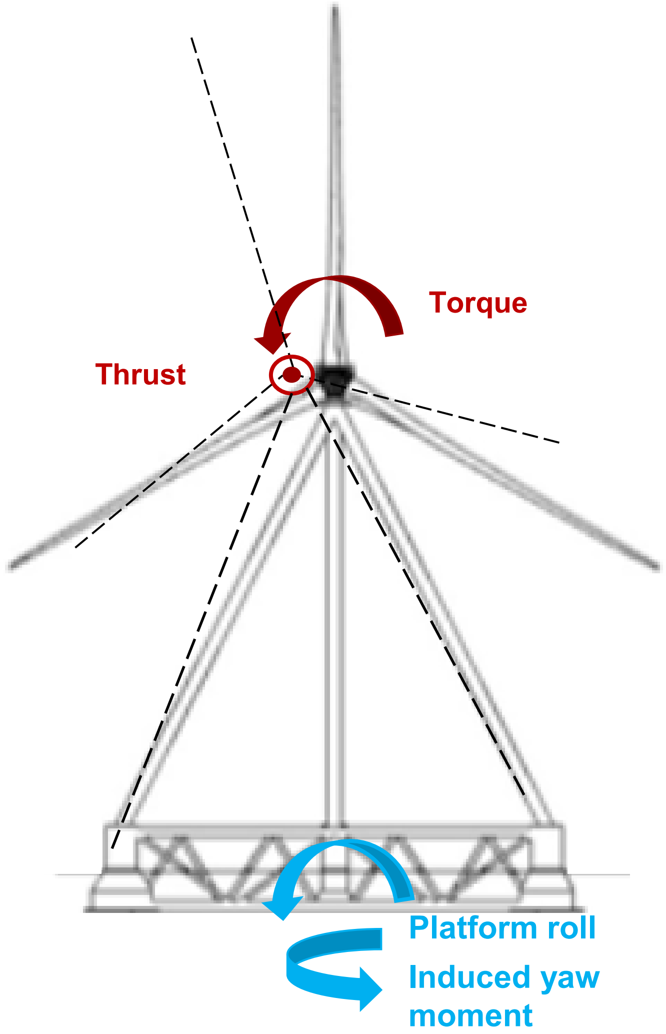


Dynamics Single Point Moored Platforms

- Free yawing platform

- Generator torque causes a platform roll motion
- Thrust force is no longer aligned with the pivoting point
- Yaw moment induced by the platform roll angle and the thrust force

- Considerations
  – In HAWC2, bearing is frictionless
  – Roll and pitch motion depend on platform stiffness



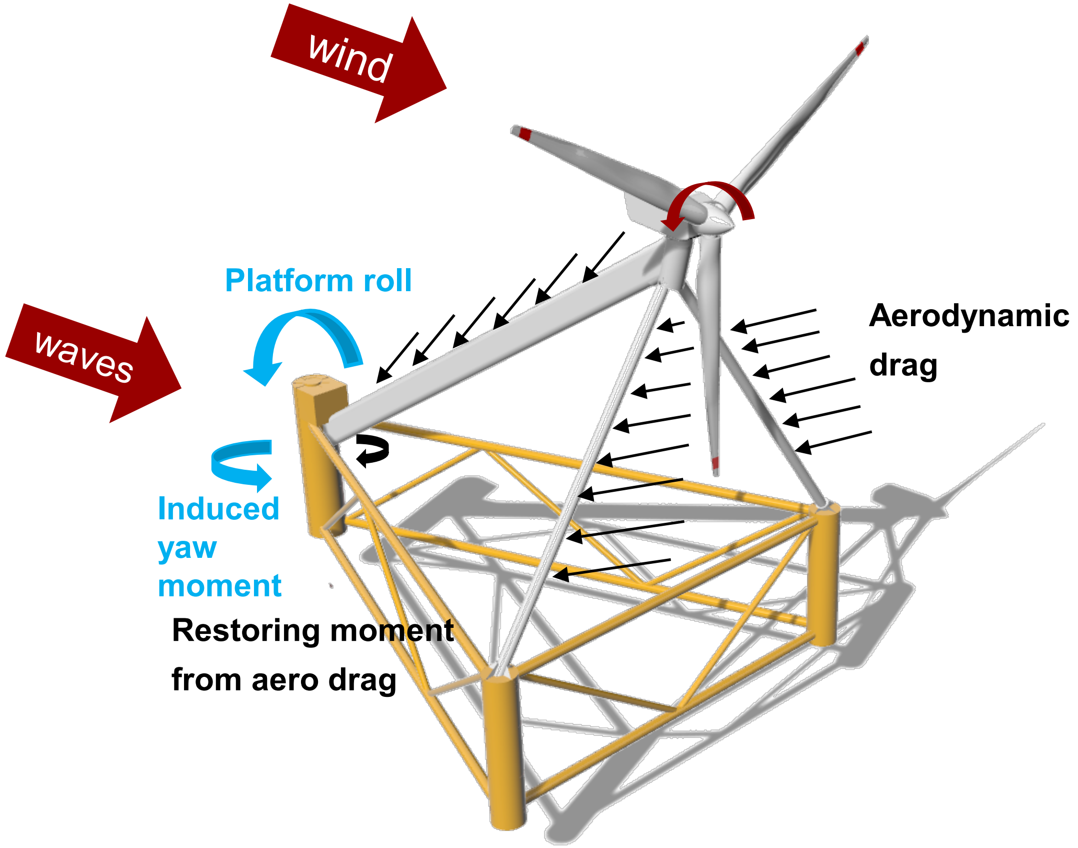
Dynamics Single Point Moored Platforms

- Under wind and waves aligned:
  - Aerodynamic drag acting as a restoring force, balances the yaw moment induced by the platform roll

    Mz_{thrust} (roll, pitch, yaw) + $Mz_{\text{aero drag}}$ (yaw) + $Mz_{\text{downwind aero}}$ (yaw) = 0

    Platform-wind missalignment = yaw

  - Platform misalignments are very small



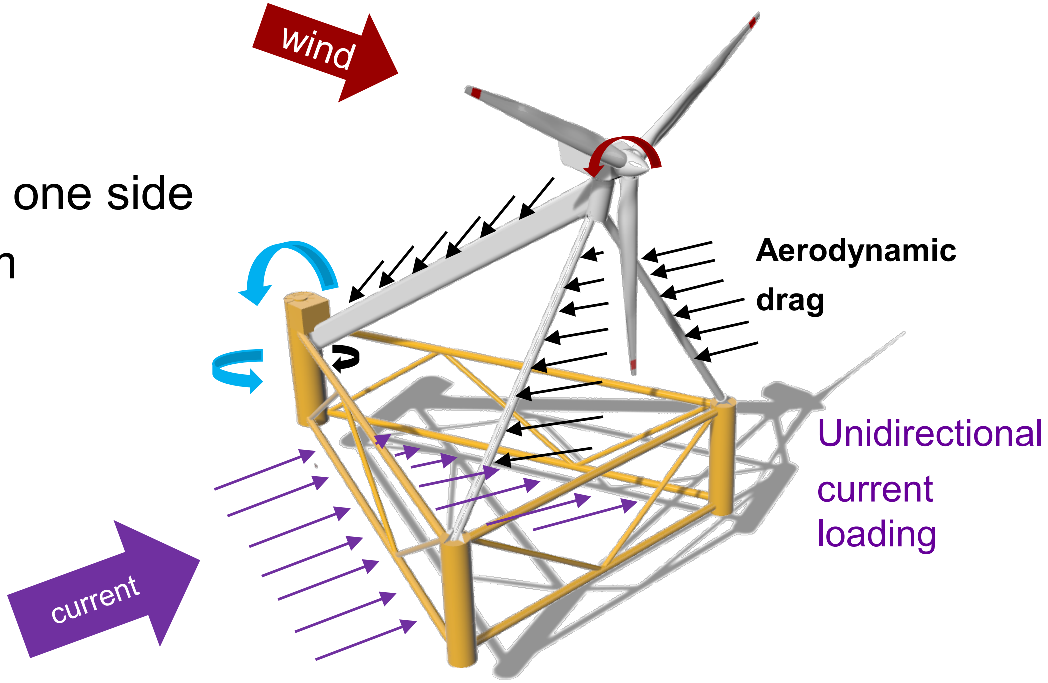
Dynamics Single Point Moored Platforms

- What happens if you have misaligned forces ?

  Example case study: wave current

  – New Force Diagram. Constant loading to one side
  – The turbine will find a different equilibrium

    - wind speed
    - wave condition
    - current velocity and profile
    - Current angle ß
    - roll-yaw platform stiffnes



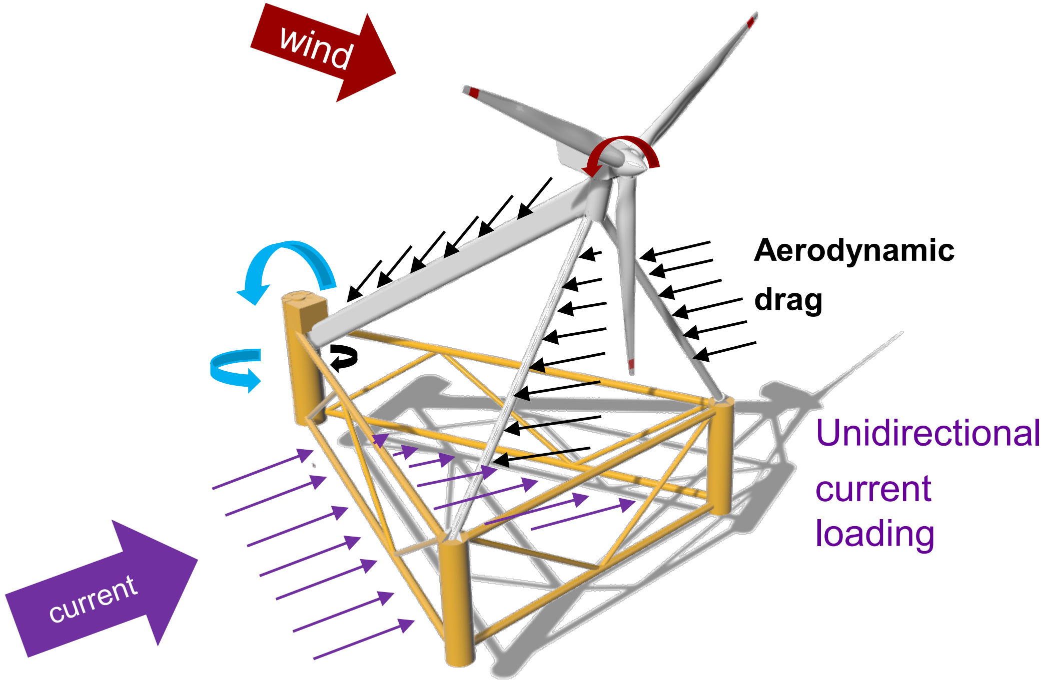
Dynamics Single Point Moored Platforms

<u>Example case study: wave current</u>

Mz_{thrust} (roll, pitch, yaw) + $Mz_{aero\ drag}$ (yaw) + $Mz_{current}$ (yaw-ß) + $Mz_{downwind\ aero}$ (yaw) = 0

ß: current angle, yaw- ß ≠ 0

Platform-wind Missalignment ≠0



Dynamics Single Point Moored Platforms

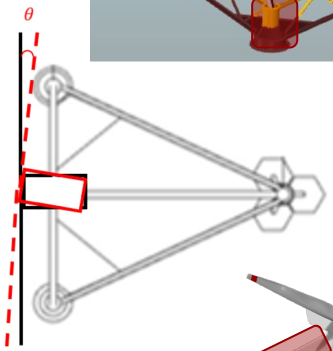
- What can be done to increase Power production ?

  – **Passive Solutions**

    - Design Asymmetry on Buoys based on nominal turbine torque

    - Constant yaw turbine Misalignment to compensate the yaw-roll induced moment around the vertical axis

    - Increase passive drag elements - inclusion of sails or another type of structure where huge area can be used at the expense of mass



Dynamics Single Point Moored Platforms

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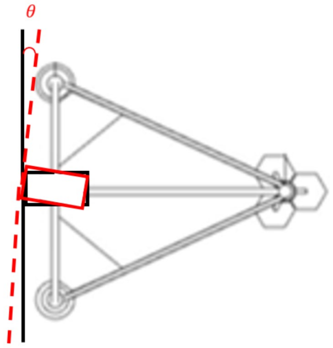


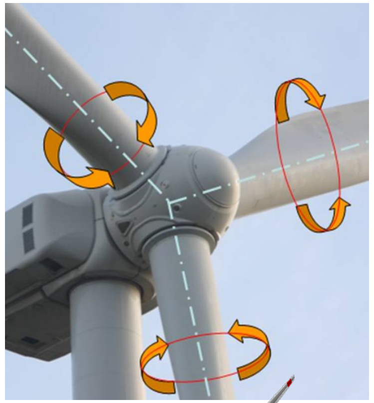
Dynamics Single Point Moored Platforms

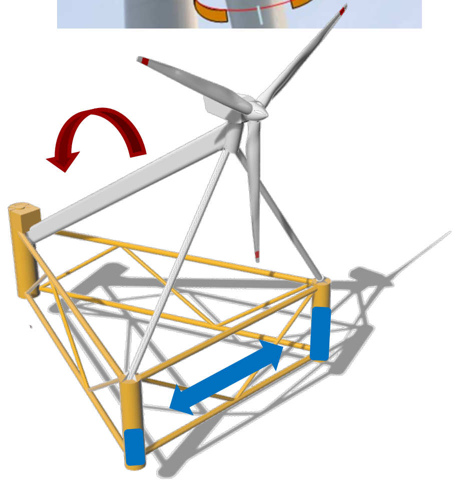
- What can be done to increase Power production ?

  – **Active Solutions**

    - Individual Pitch Control – to generate an aerodynamic yaw moment to actively compensate the roll-yaw platform moment.

    - Ballast Control – to actively eliminate the platform roll





Dynamics Single Point Moored Platforms

- What can be done to increase Power production ?
  - **Active Solutions**
    - Individual Pitch Control – to generate an aerodynamic yaw moment to actively compensate the roll-yaw platform moment.
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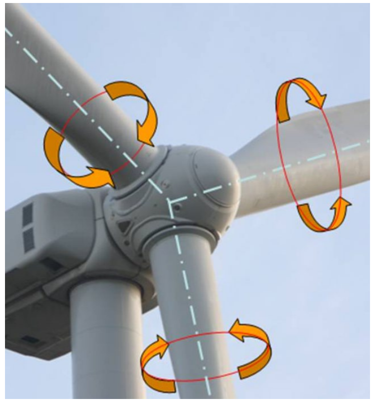
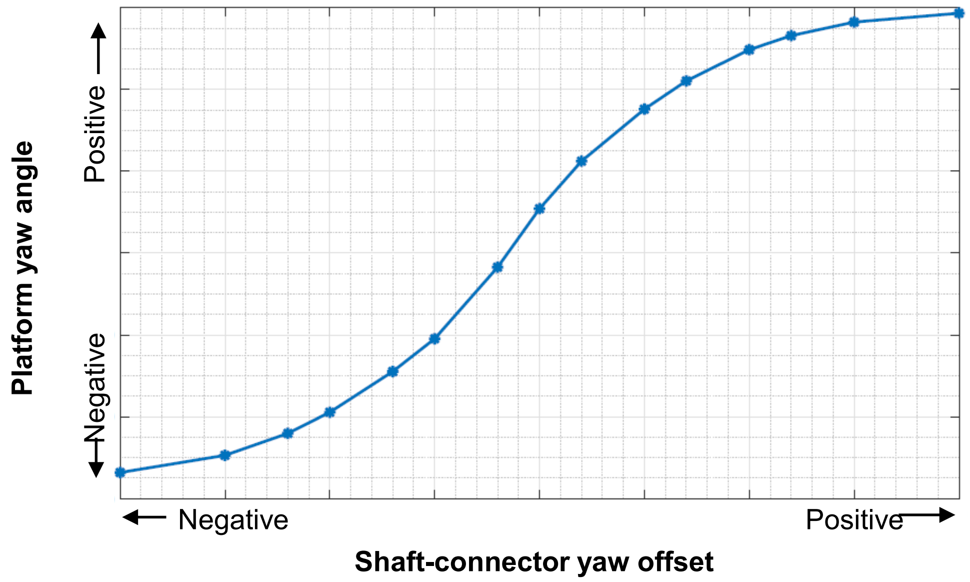
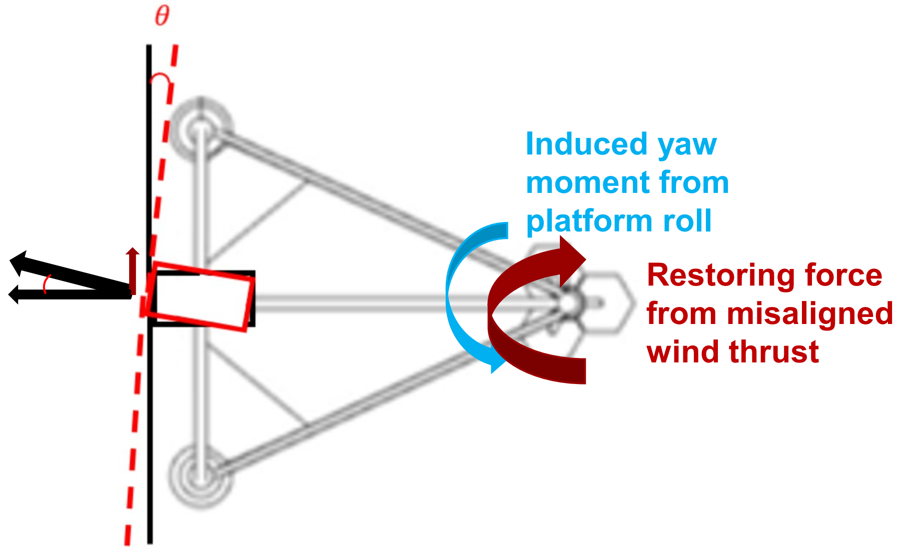


Dynamics Single Point Moored Platforms

- Passive Strategy: Constant design nacelle yaw offset

By misaligning the nacelle with respect to the pivoting point, the downwind turbine will generate an aerodynamic restoring moment



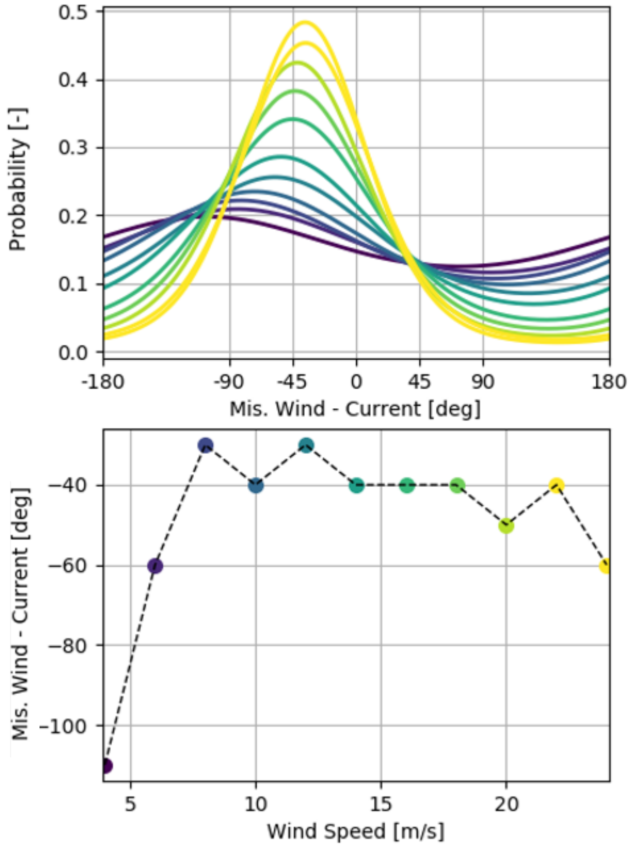


Dynamics Single Point Moored Platforms

- Passive Strategy: Constant design nacelle yaw offset
  - But, can we optimize for all the cross aligned cases?
    - Multi-dimension problem
    - AEP needs to be optimized for a given site. Find the yaw offset that optimizes power

Advantages: passive strategy which does not require actuator, no increased blade-pitch activity

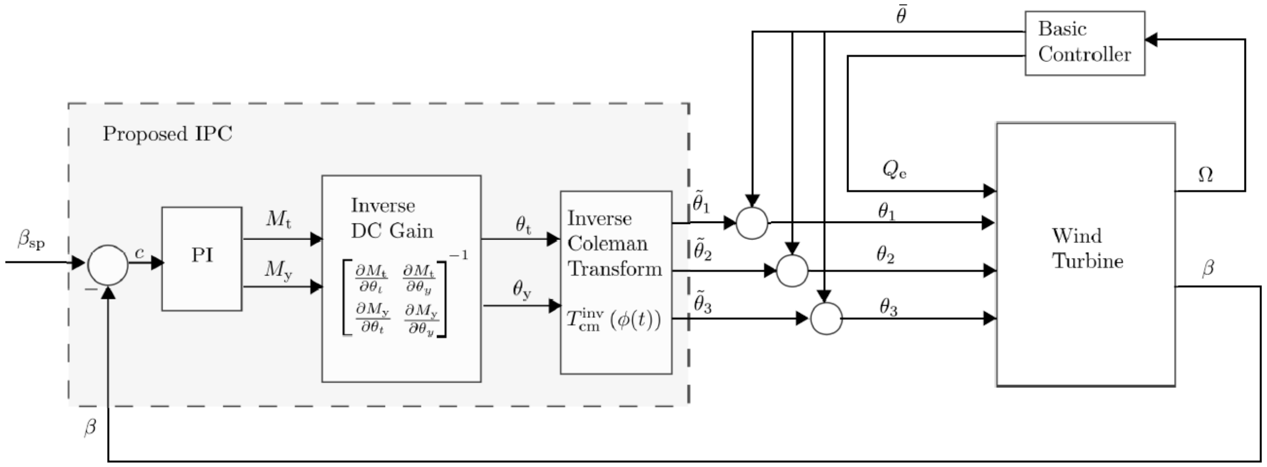
Disadvantages: Site-specific dependent, uneven weight loading, additional axial loading on the connector, fatigue increase on axial elements



Example of site-specific wind-wave misalignment analysis

Dynamics Single Point Moored Platforms

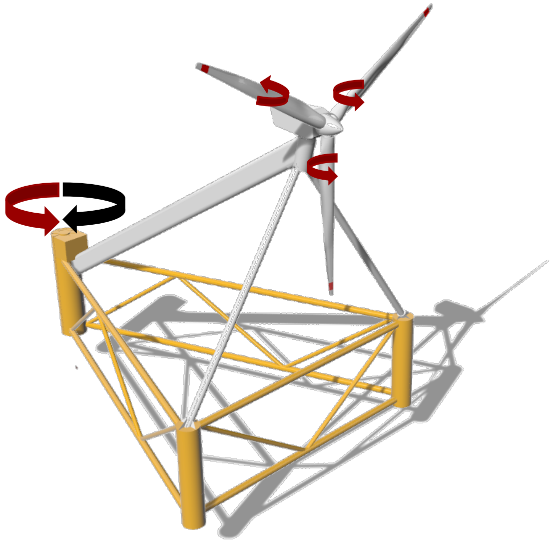
- Active strategy: Individual Pitch Control
  - Traditional IPC is designed to alleviate (among others) shear contribution on the turbine
    - In this study, the IPC is changed to create a restoring moment around vertical axis
      - Open source DTU WEC is used
      - Yaw error becomes the driver of the IPC signal

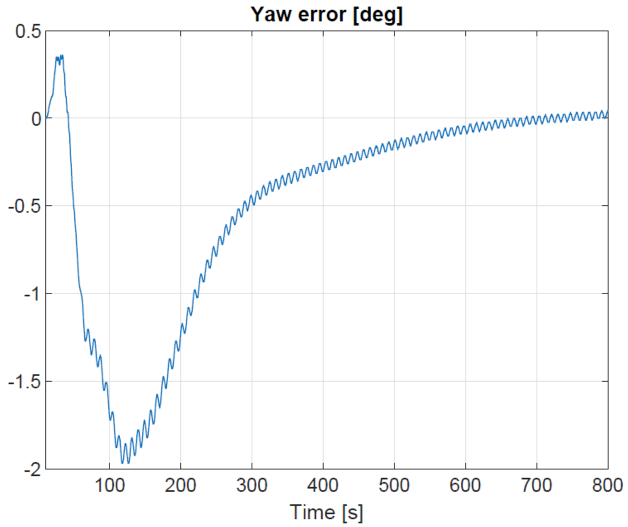


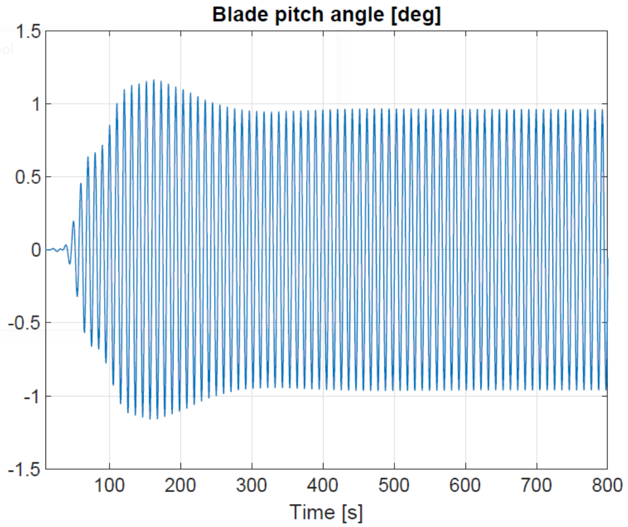
1. Input signal: yaw error
2. Low pass filter and notch filter
3. PID controller
4. Apply coupling (inverse Jacobian) matrix
5. Transform pitch amplitude in MBC to pitch action in rotating blade coordinates
6. IPC action is added on top of the collective pitch set-point of the DTU WEC

Dynamics Single Point Moored Platforms

- Active strategy: Individual Pitch Control







Platform yaw and blade pitch activity with the IPC control strategy, under a cross-aligned current

<u>Advantages</u>: can be used and is valid for all the sites – principle holds

<u>Disadvantages</u>: increased loading (specially fatigue) on blades, increased pitch activity

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Future work

- Detailed explanation of concepts presented here. Numerical results of specific first test cases
- Expand the analysis and modelling. Evaluate more realistic cases
- Explore together with the consortium different approaches for enhanced alignment
- Test side PLOCAN – analyze measured results to verify our assumptions

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Conclusions

- X1 platform is platform concept which holds a downwind turbine and presents an innovative Single Point Moored connection

- SPM platforms are interesting concepts and challenging to model

  – Alignment under misaligned loading can be improved in passive and active ways
    - Static yaw offset and Individual pitch control strategies are studied
    - Between 1 and 2 % increase in power under aligned 8 m/s steady wind, regular waves, and 0.4 m/s 30 deg current missalignement

- Floating is the future and is here! Future work will be carried out to expand the current study

Thank you!

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