Multi-Rotor Floating Wind Turbine Concepts: Control Co-Design to Ensure their Feasibility

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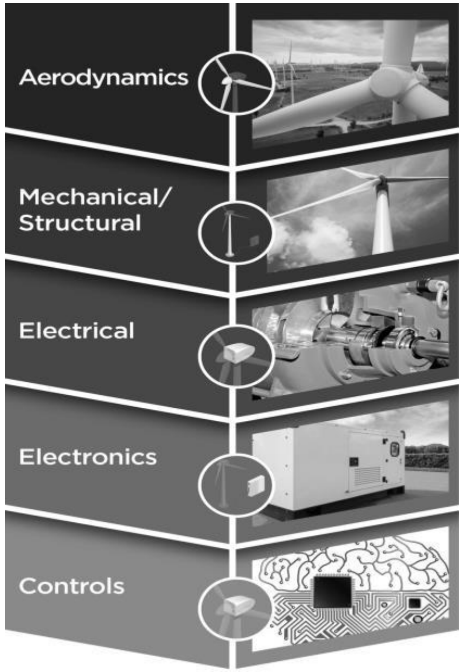
Introduction

“How should the physical aspects of an actively controlled system be designed such that passive and active properties interact synergistically for system-optimal performance?”

Control Co-Design (CCD) is a class of integrated engineering system design methods that considers the explicit relationship between physical and control system design decisions.

How **do** we design them?

- Classical sequential approach

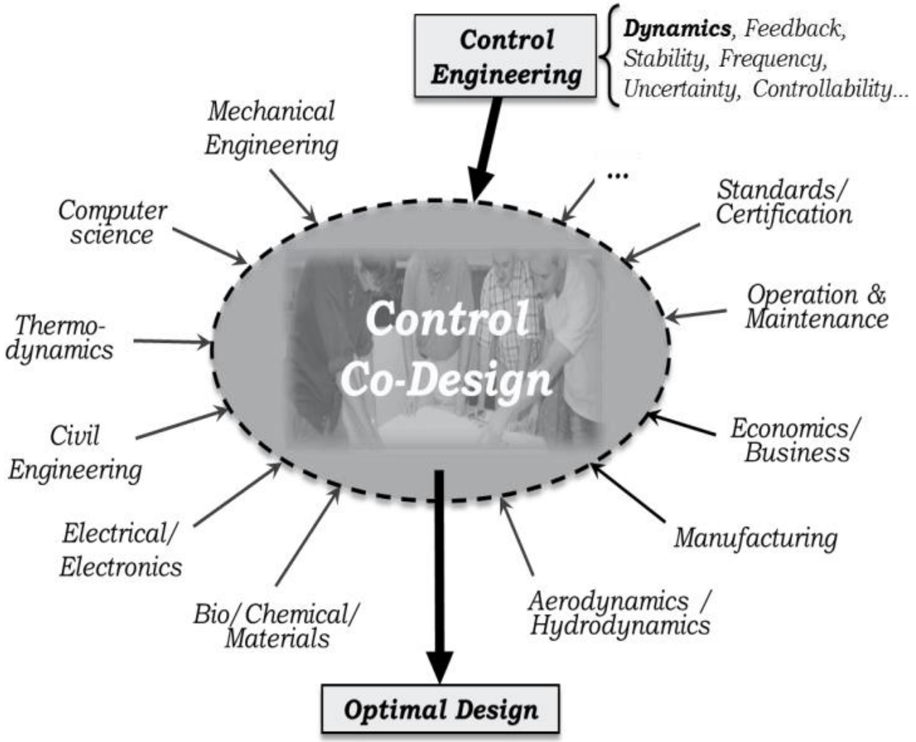


- Most common approach in wind energy industry nowadays
- Subsystems interactions not directly addressed
- Each step limits the following ones
- Control is usually developed in the final stage

How **should** we design them?

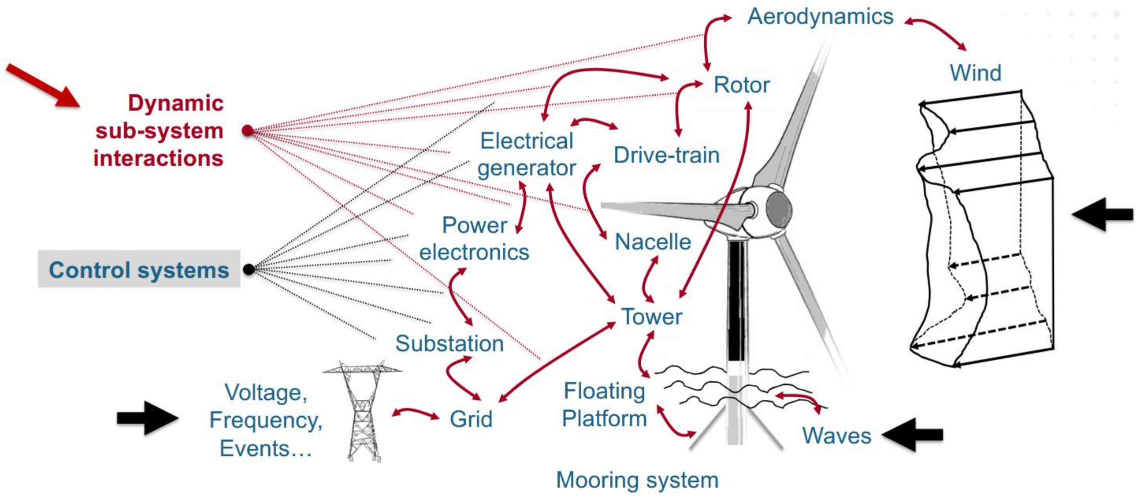
- All disciplines work concurrently from the start
- Subsystems interactions directly addressed
- More optimised design in comparison to the one obtained with sequential approach
- It has already been successfully applied to aircrafts, chemical reactors, underwater vehicles, power grids, …

- Control co-design (CCD) approach

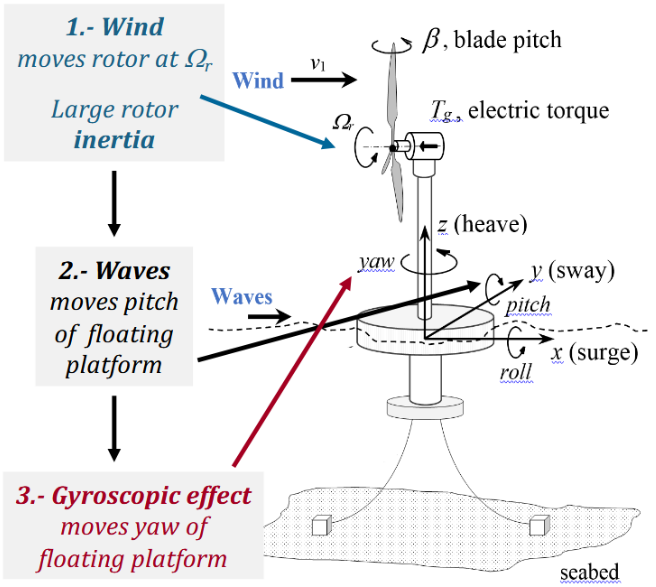


Wind turbines CCD

- CCD highly beneficial due to subsystems strong interaction (especially FOWTs, MRWTs…)
- Interactions emphasised due to external disturbances

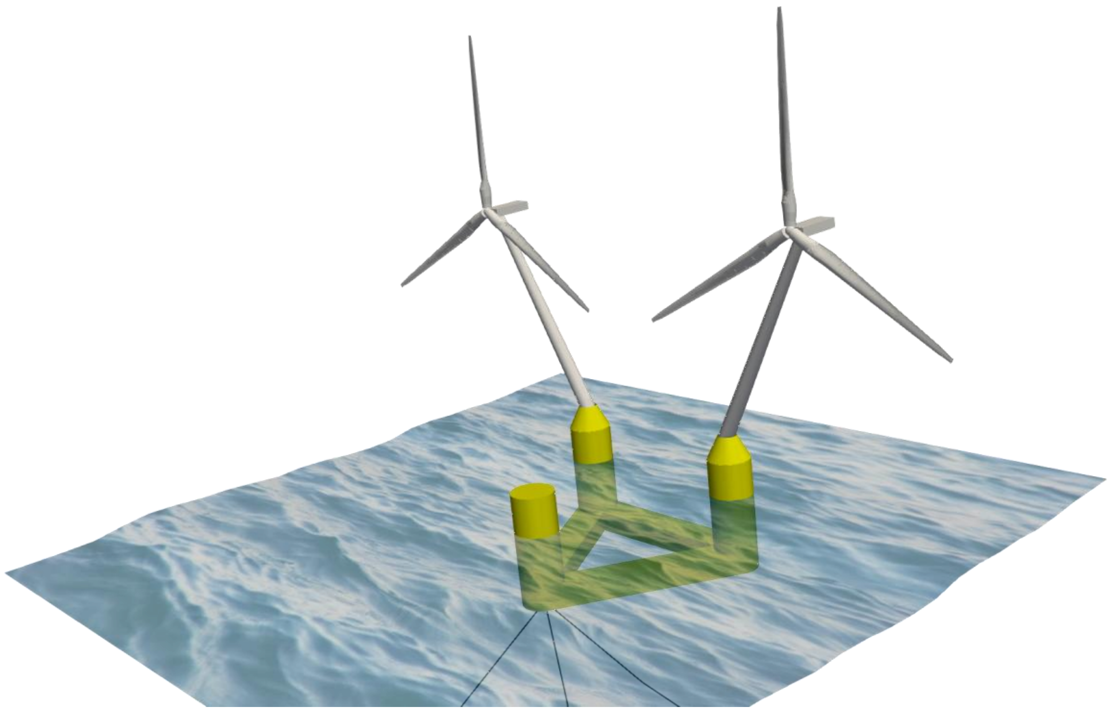


- Aerodynamics-hydrodynamics interaction → **Moment in Z direction** → Yaw drift (in SPMs)

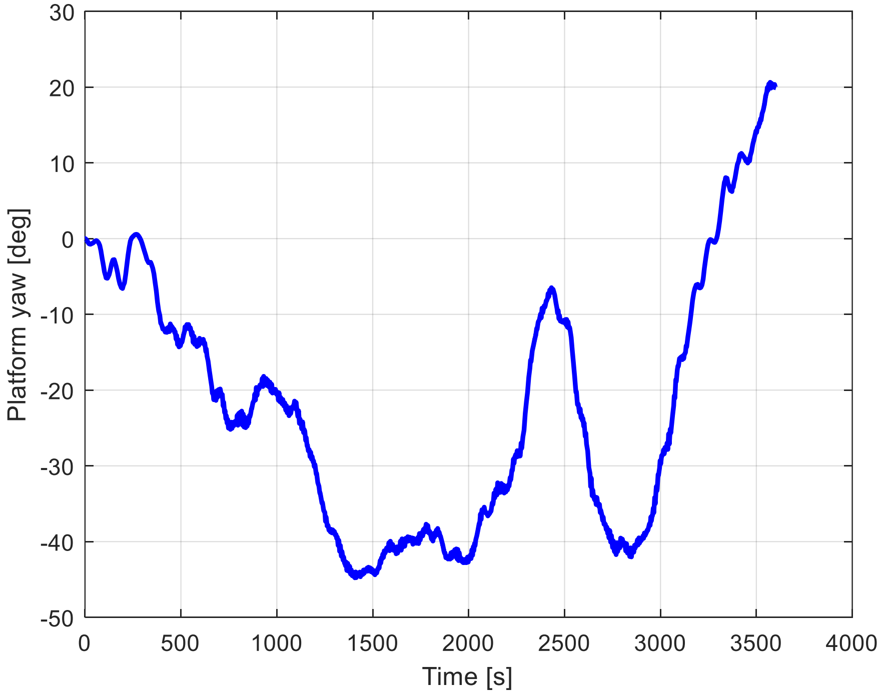


Multi wind turbines CCD

- CENER DeltaWind floating platform (modified) + 2 NREL 5MW wind turbines



- 8 m/s turbulent wind speed
- 6 m and 10 s irregular waves
- Aligned wind and waves



CCD motivation

Intrinsic limitation: yaw mechanism not advisable, due to high wake shadowing effect between turbines (power loss, …)

Advantage: FOWTs can make use of platform yaw DoF to keep the system aligned with wind

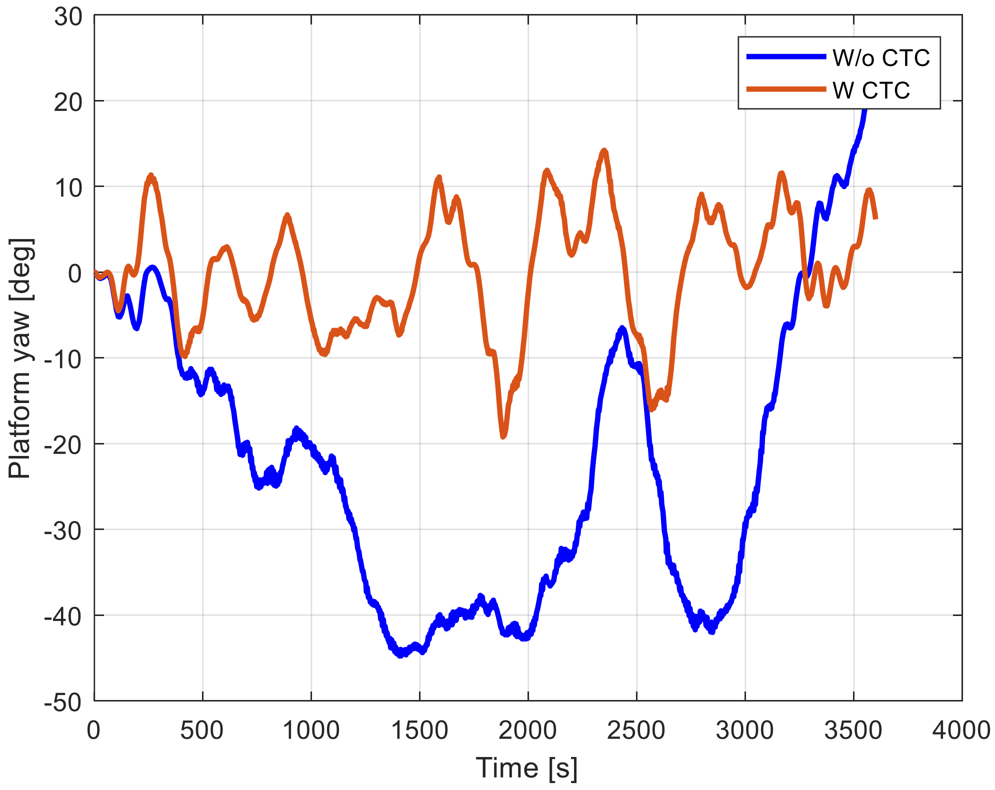
Challenge: this alignment is not straightforward

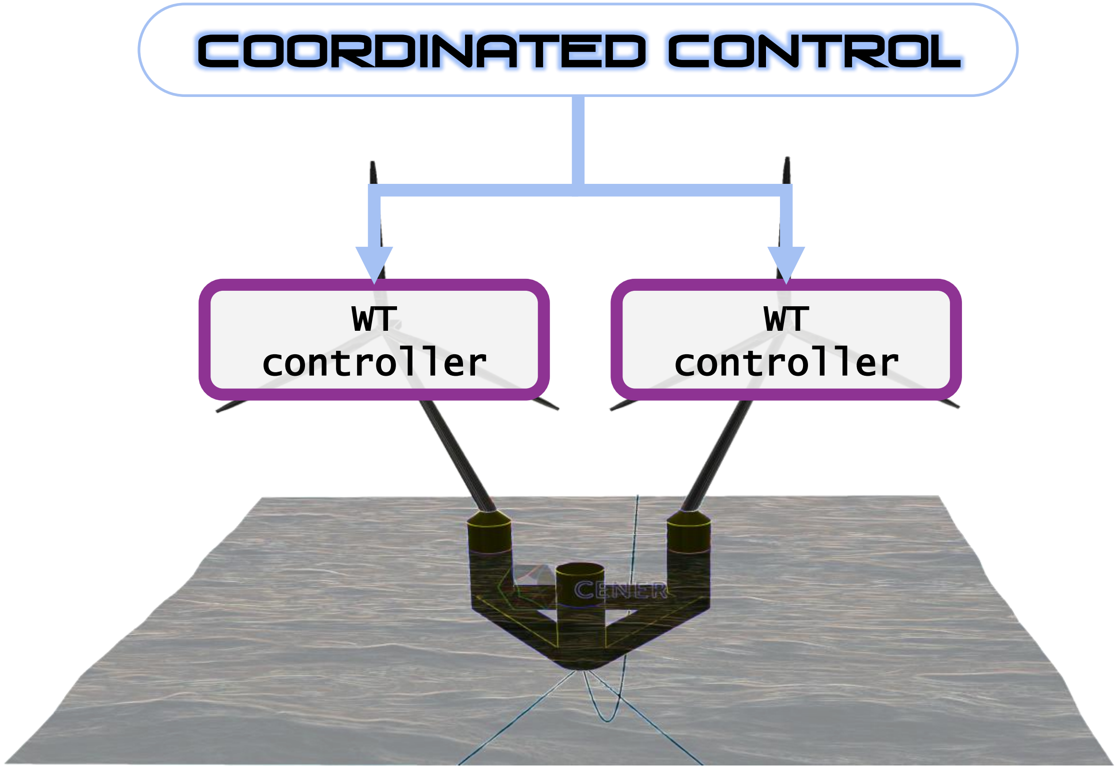
Control co-design!

Sequential approach

Coordinated control

- Coordinated thrust control (CTC)

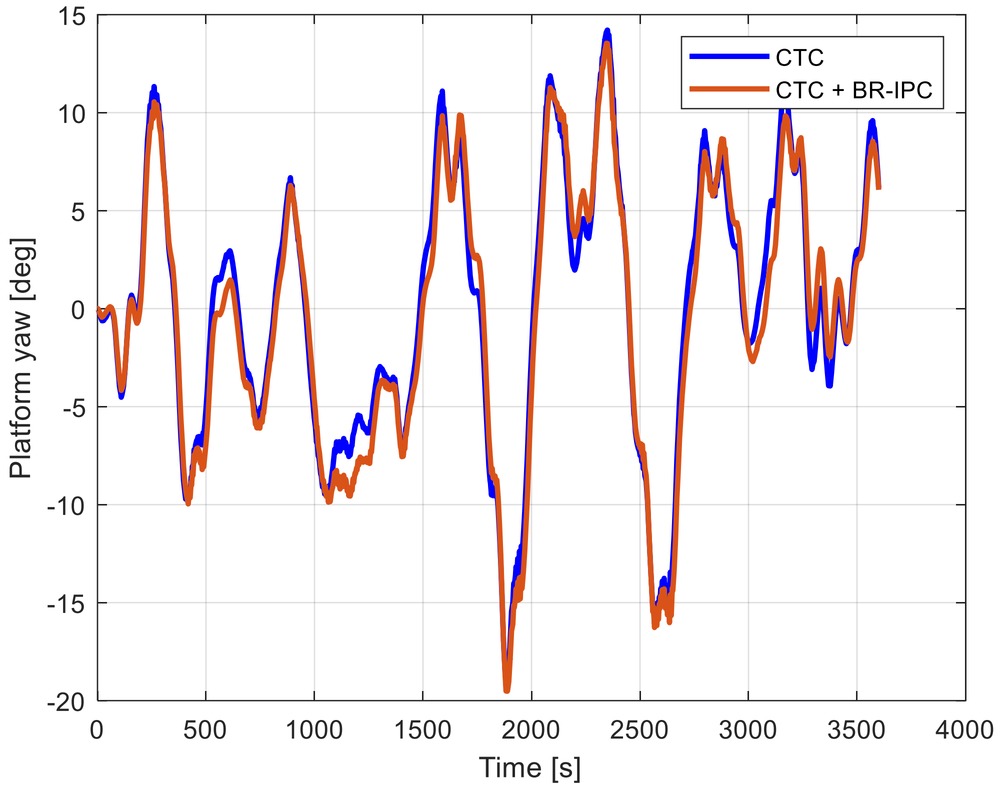




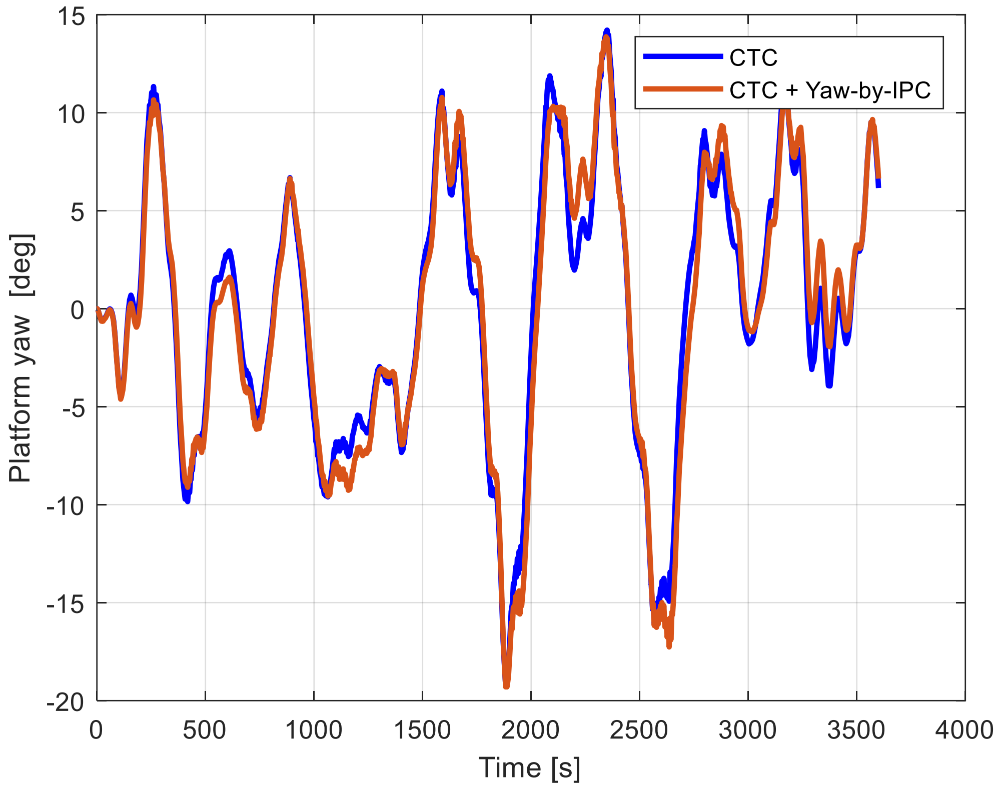
Sequential approach

Individual pitch control

- CTC + Blade root-based IPC



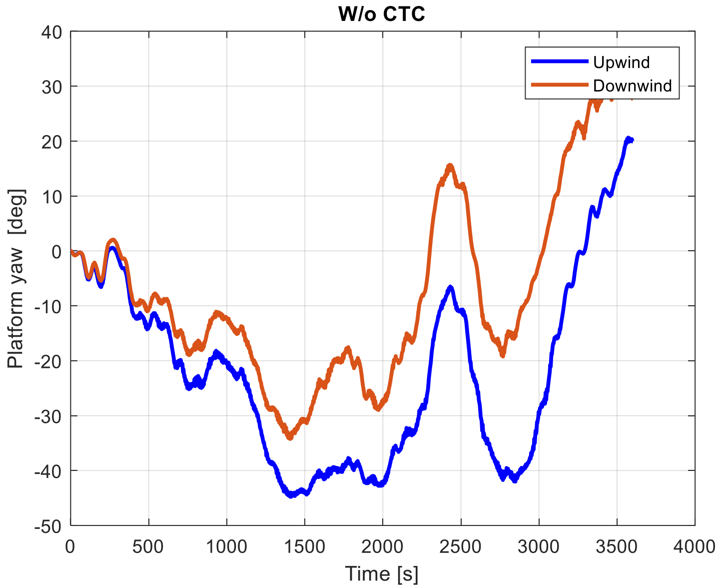
- CTC + Yaw-by-IPC

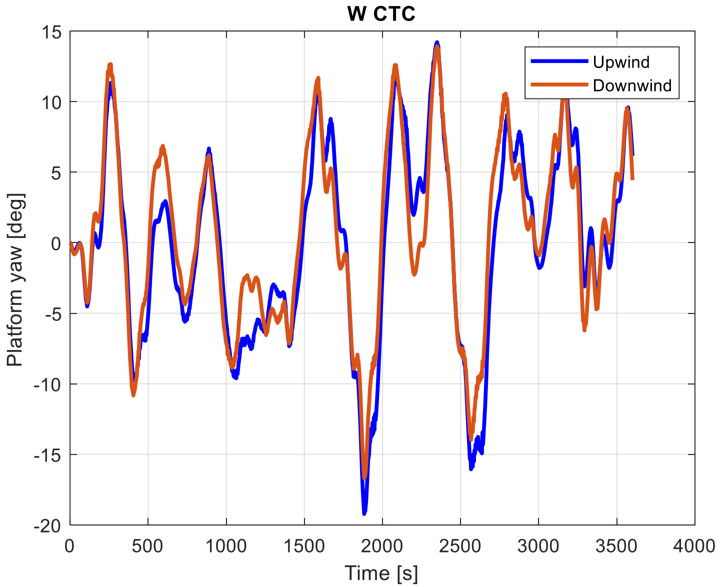


Control co-design

Downwind configuration

- Moment in Z direction that causes the yaw drift is attenuated
- Disadvantages:
  - Tower and nacelle shadow can affect the blades
  - Limited yaw drift correction in analysed bi-rotor wind turbine

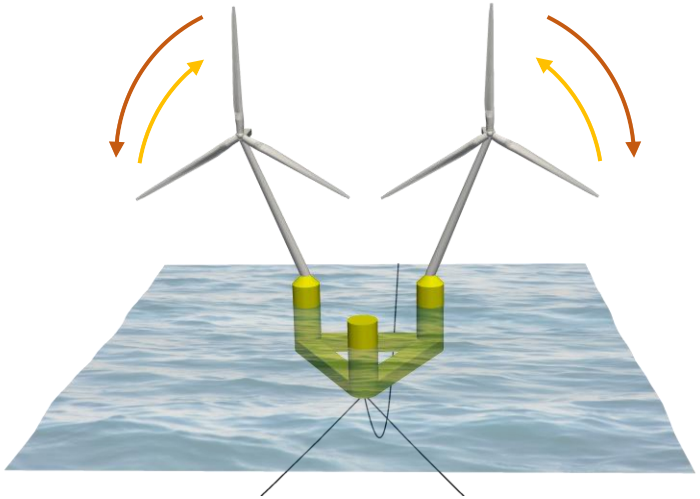


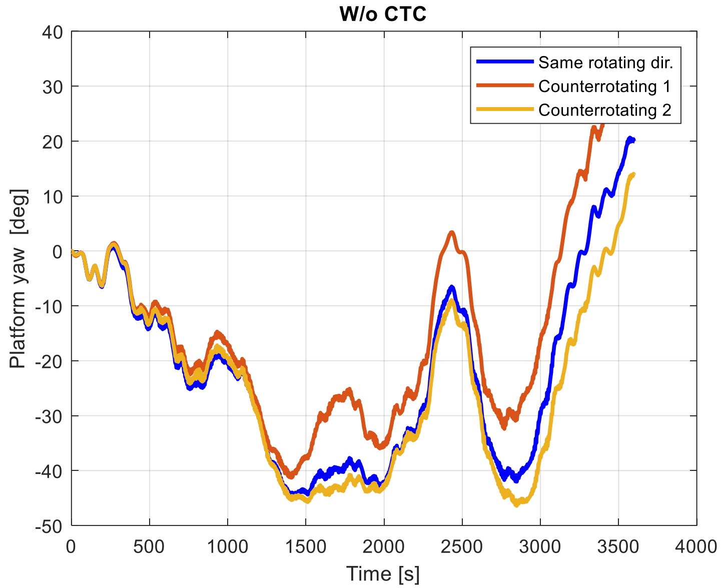


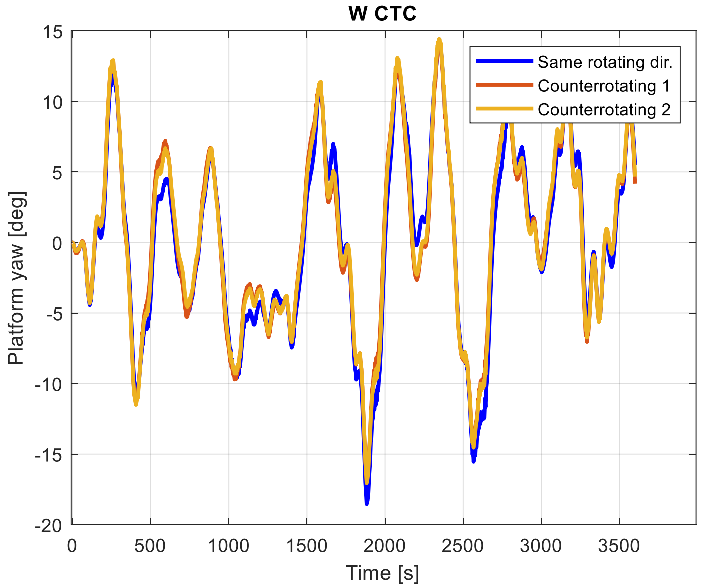
Control co-design

Counter-rotating rotors

- Moment in Z direction produced by each one of the rotors is compensated
- Disadvantages:
  - Some components (i.e. gearbox, blades) of each one of the wind turbines must be different
  - Limited yaw drift correction in analysed bi-rotor wind turbine







Control co-design

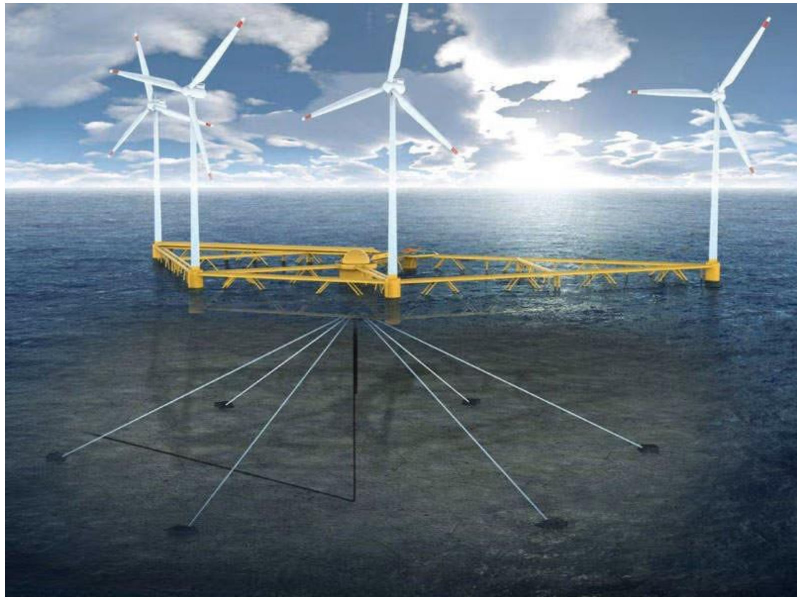
Aerodynamic tower

- Lift and drag forces in the tower can compensate yaw moment
- Disadvantages:
  - Tower must be re-designed (more complex geometry)
  - Higher fabrication costs

Control co-design

Advanced SPM configuration

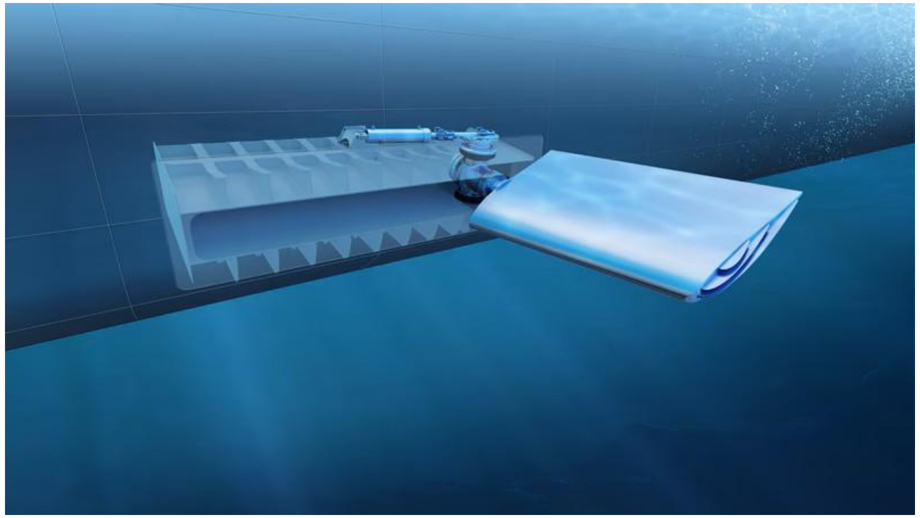
- Increasing friction in the fairlead bearing components to minimise yaw drift
- Disadvantages
  - More complex and expensive mooring system
  - More fatigue in the bearing



Control co-design

Active elements in floating platform

- Add motors or hydrodynamic profiles to the platform to control yaw drift
- Disadvantages
  - More complex and expensive floating platforms
  - Energy consumption
  - Fatigue in moving elements



To wrap up

Control co-design is necessary to ensure the feasibility of multi-rotor floating wind energy systems, but there is still a way to go

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Thank you.

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