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Evaluation of control methods for floating offshore wind turbines

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Background & Motivation

Upper tank

It consists of an upper concrete floating body connected by tendons to a heavy lower ballast tank. It is compartmented to meet standardized stability requirements and allow water ballast transfer.

Telescopic tower

The telescopic tower system consists of tubular tower levels built of precast concrete elements, one steel section and a tower self-lift using heavy-lift strand jacks. This system is already developed for onshore and offshore fixed foundation application and is currently being developed from TRL3 to TRL7 in a separate project.

The application with a floating system gives added advantages for deep-water application and transportation: A lower wind turbine height for installation and transportation allows for a stable system.

Suspension tendons

The steel tendon configuration it is key to guarantee the solidary motions of the upper tank and lower tank.

Lower tank

The suspended ballast lowers the system's centre of gravity to stabilize the structure. The concrete structure is stable during transport partially filled with solid ballast. For installation purposes the lower tank is water ballasted until it gets the final location.

[esteyco]

EU Horizon 2020 project: TELWIND

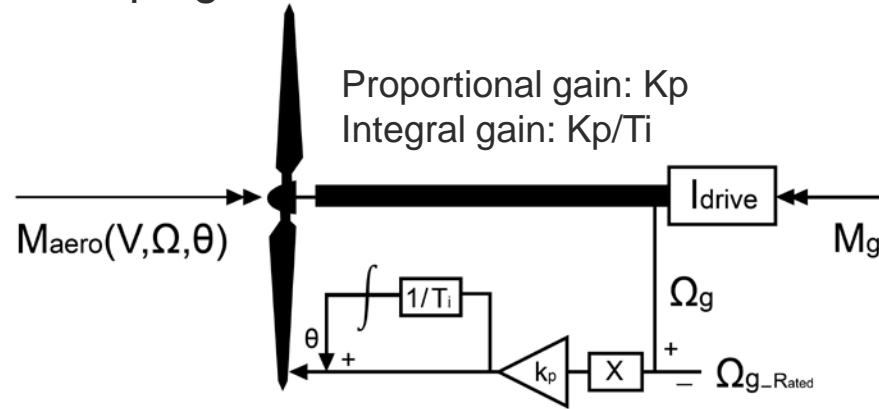
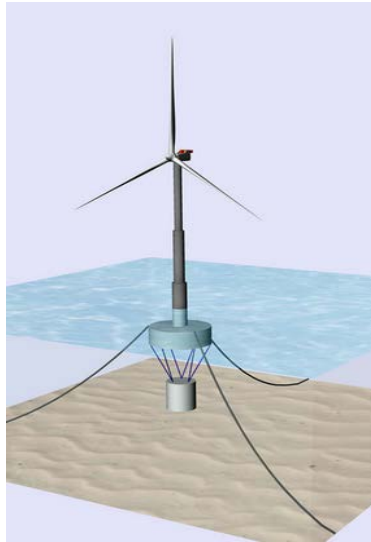
Cost reduction for floating offshore turbine

- Evolved spar concept
- Telescopic tower
- Local and low cost material usage: Concrete
- Simpler manufacturing and installation processes

- How great is the impact of controller on FOWTs?
- What makes controlling FOWTs difficult ?
- How well do the state-of-art control methods work?

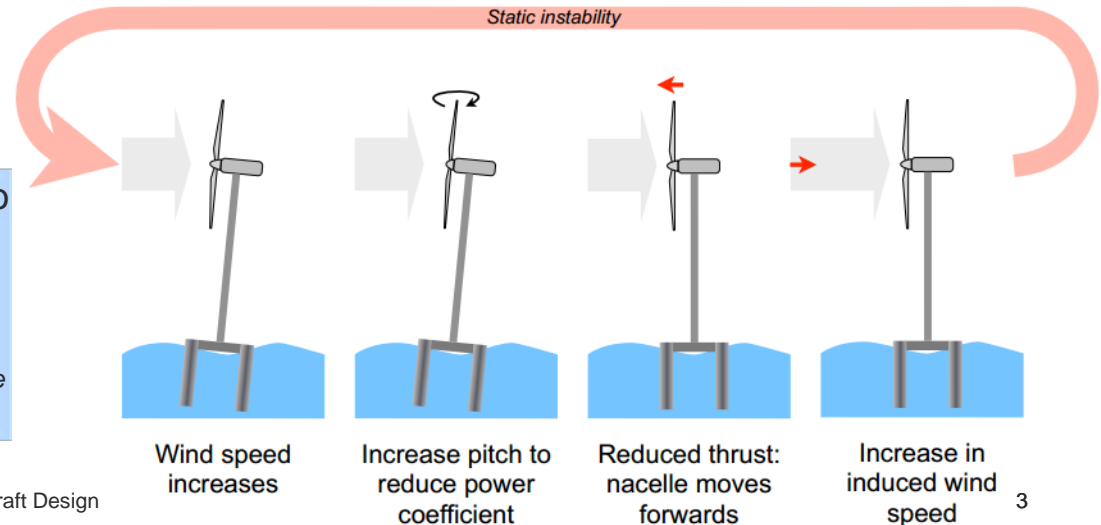
What makes controlling FOWTs difficult ?

Physical: Negative aerodynamic damping



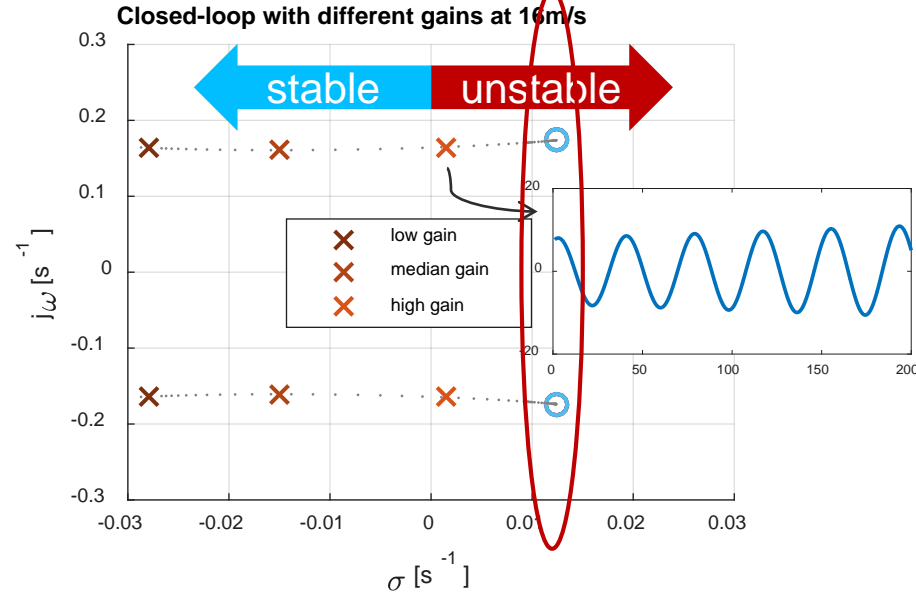
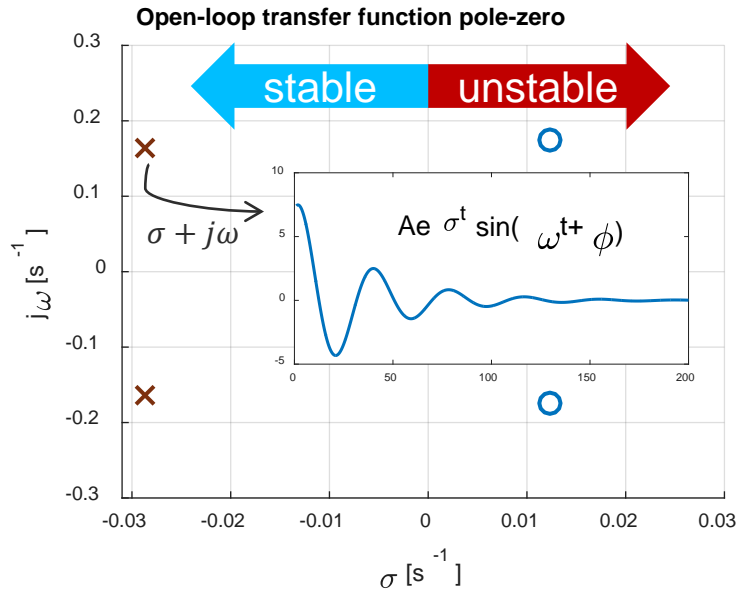
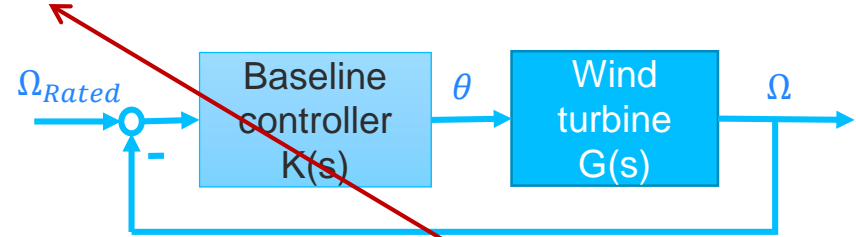
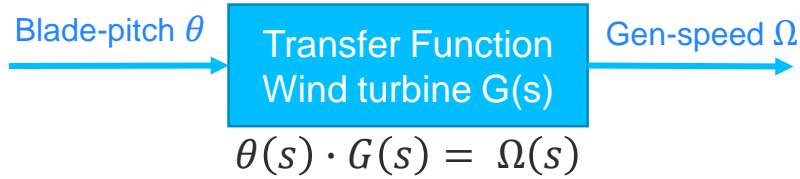
Applying conventional on-shore controller to FOWT leads to the instability problem

Larsen, T. J., and Hanson, T. D., 2007. "A method to avoid negative damped low frequent tower vibrations for a floating, pitch controlled wind turbine". *Journal of Physics: Conference Series*, **75**(1), p. 012073.



What makes controlling FOWTs difficult ?

Control theory: Right-half-plane-zero (RHPZ)



How good do the state-of-art controllers work?

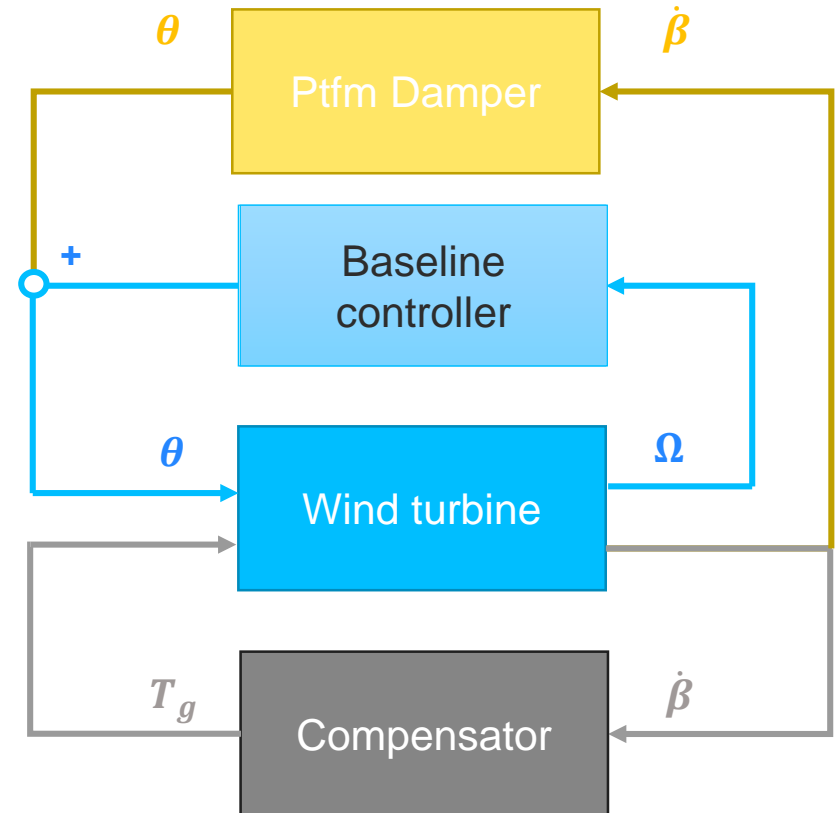
Selection of theoretical methods

Different control methods used for FOWT by modifying Baseline controller:

- **Single-input-single-output (SISO):**
Detuning / scheduled detuning
- **Multi-input-single-output (MISO):**
Ptfm damper - feedback of Ptfm-Pitch to Blade-Pitch
- **Multi-input-single-output (MIMO):**
Compensator - feedback of Ptfm-Pitch to Generator torque

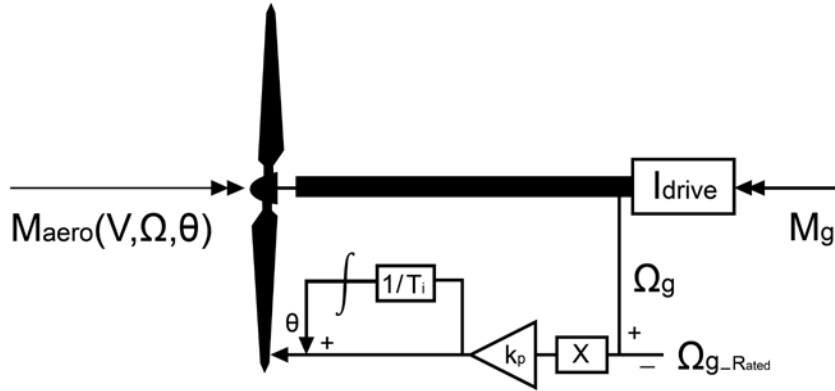
Evaluation tool:

- Linear analysis: simplified linear model with 5 DOF (SLOW)
- Coupled aero-hydro-servo-elastic nonlinear model (Bladed v4.7)



SISO: Detuning

Simple approach

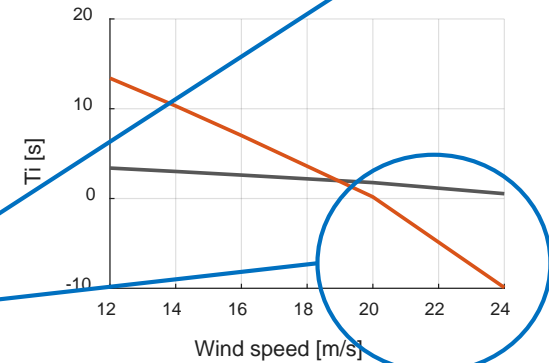
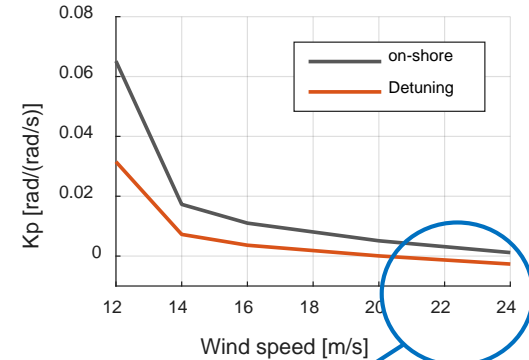
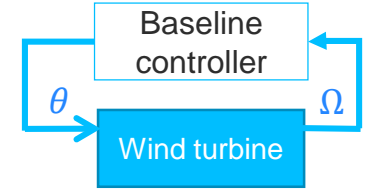


1DOF Drivetrain: second order differential system

$$I_{drive} \ddot{\varphi} + \left(-\frac{\partial M_{aero}}{\partial \theta} \right) K_P \dot{\varphi} + \left(-\frac{\partial M_{aero}}{\partial \theta} \right) \frac{K_P}{T_i} \varphi = 0$$

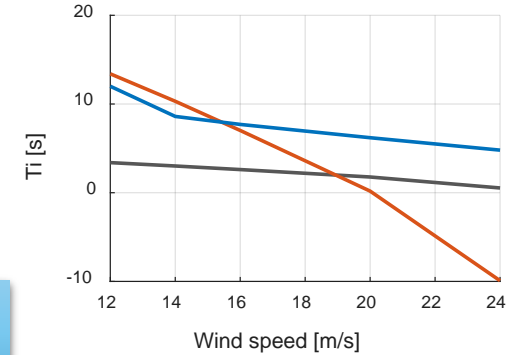
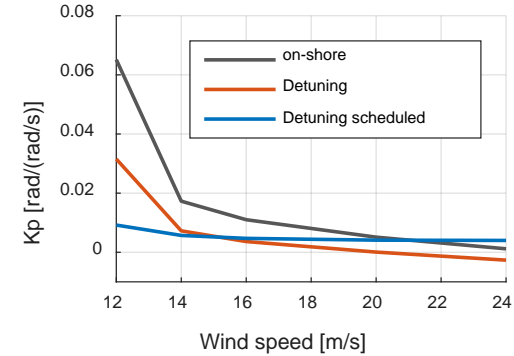
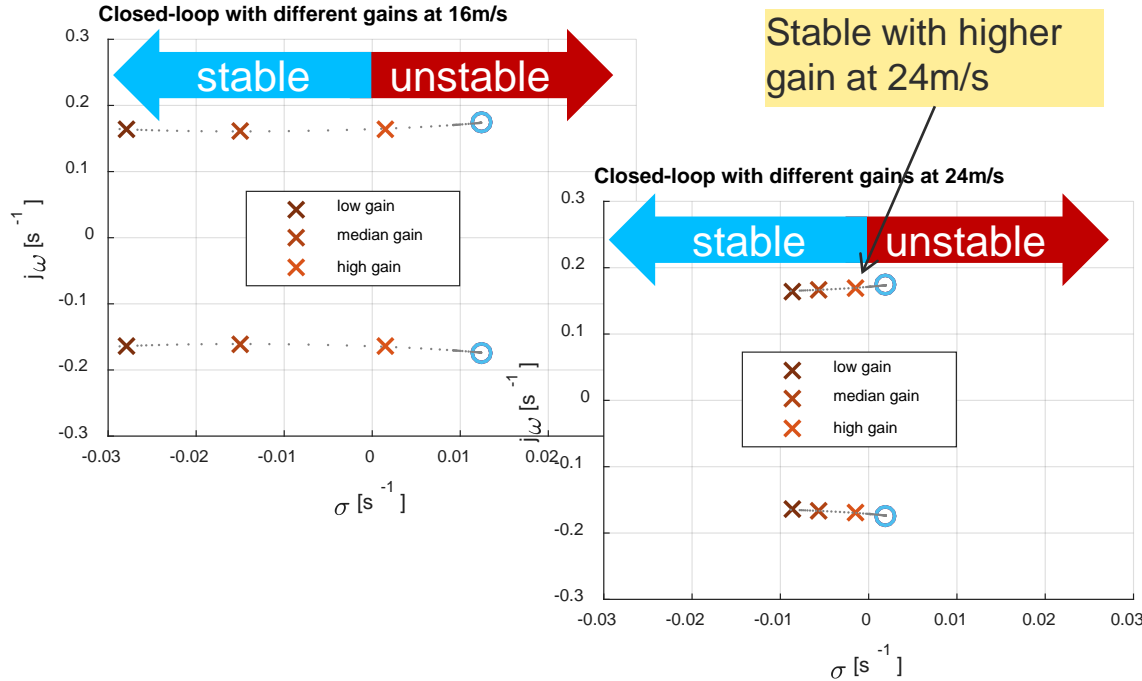
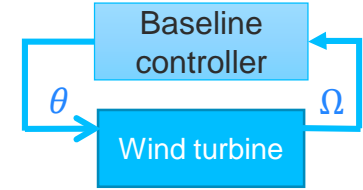
Eigen-frequency of the drivetrain motion should be lower than the Ptfm eigen-frequency

Detuning method could lead to negative gains at higher wind speed



SISO: Detuning

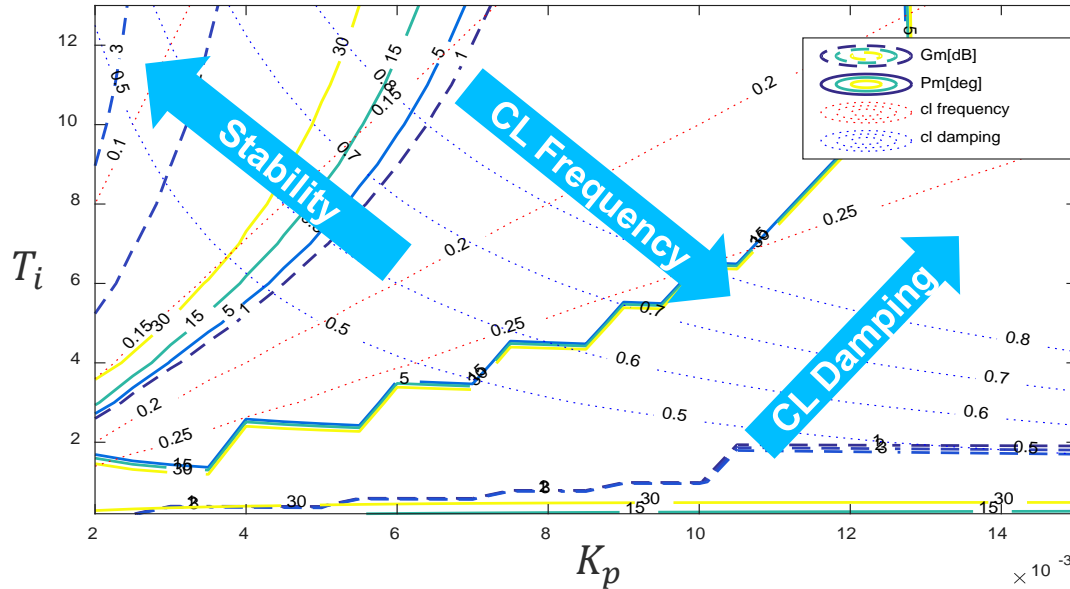
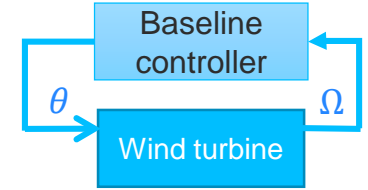
Scheduling at different wind speeds



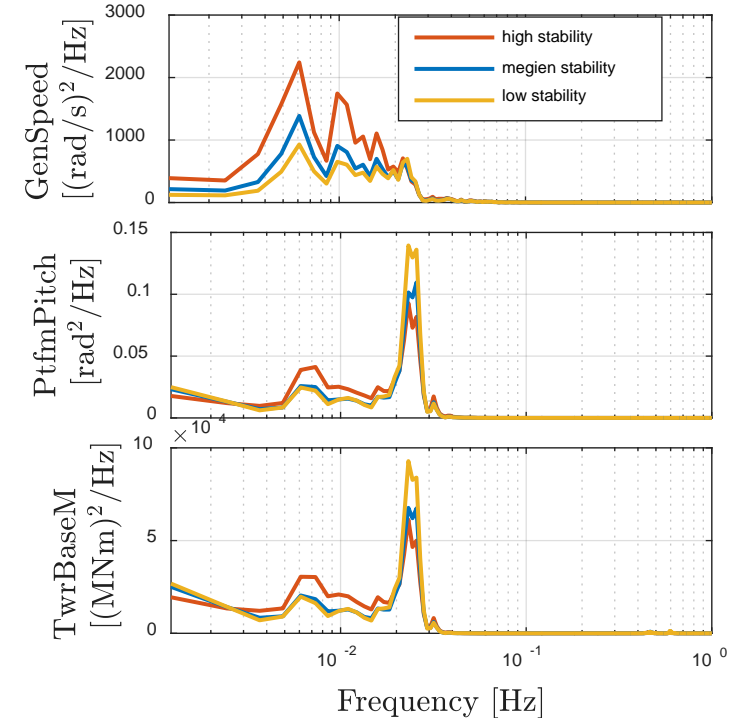
RHPZ problem differs from the operating wind speed, thus detuning should be applied according to the operating point

SISO: Detuning

Trade-off between system stability and control performance

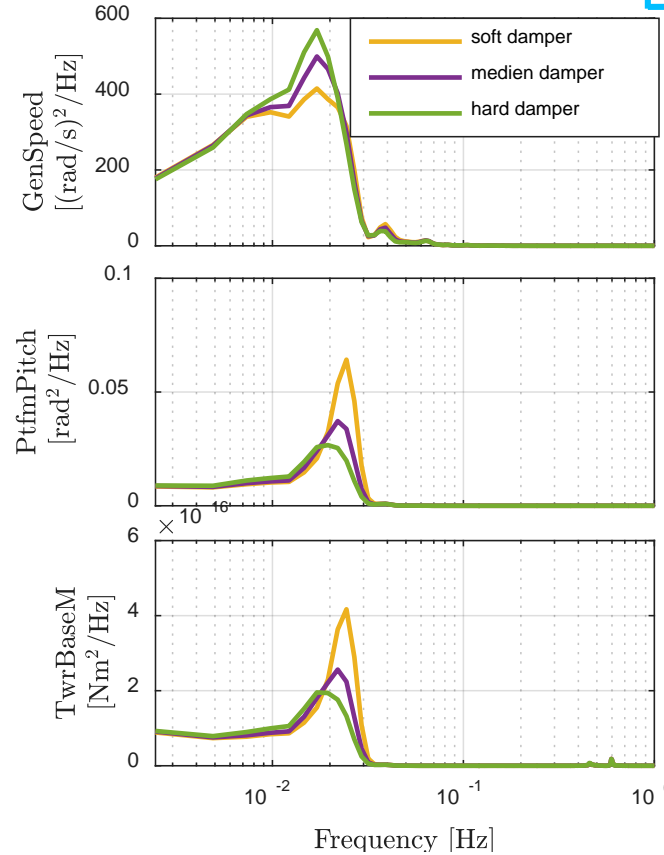
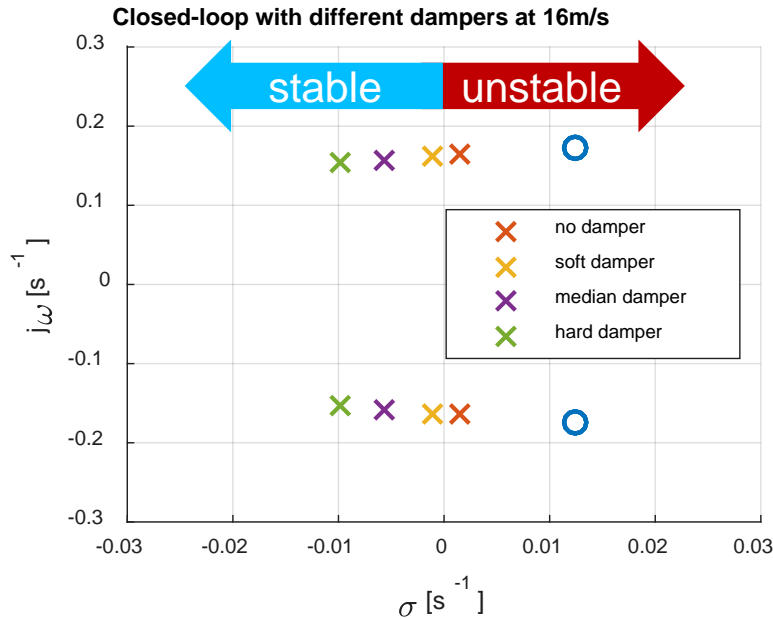
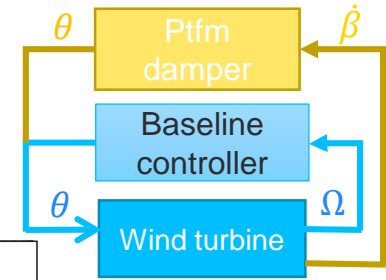


Higher stability is at the cost of the control performance.



MISO: Feedback of Ptfm-Pitch to Blade-pitch

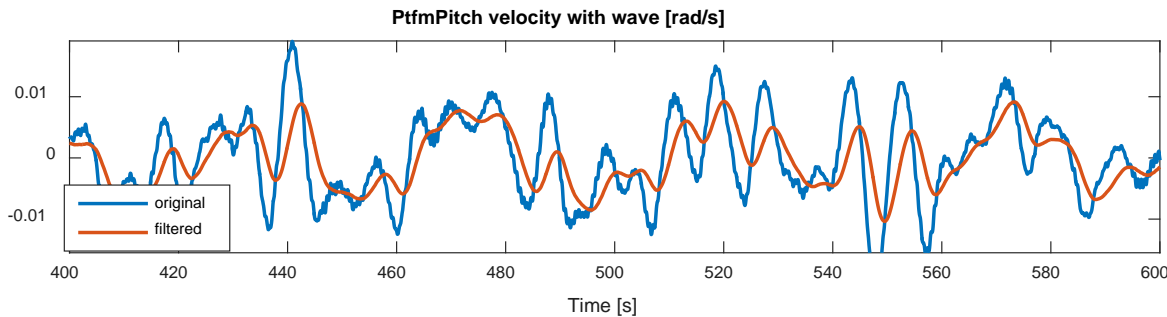
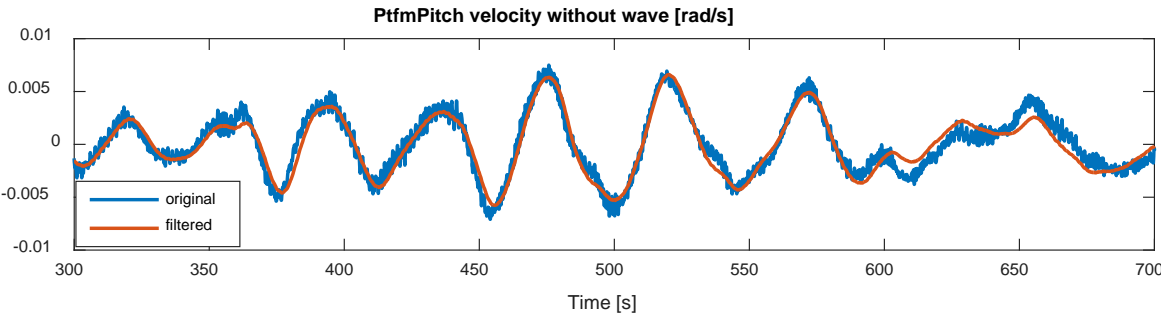
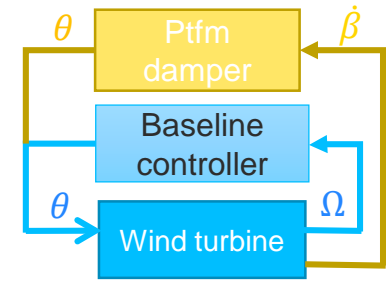
How does it work?



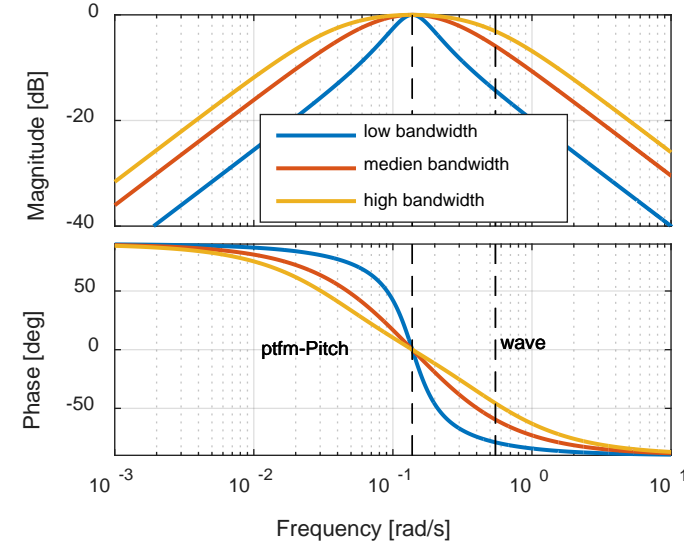
Ptfm-damper can increase the pitch stability, however the trade-off between stability and control performance still exist.

MISO: Feedback of Ptfm-Pitch to Blade-pitch

Problem with wave



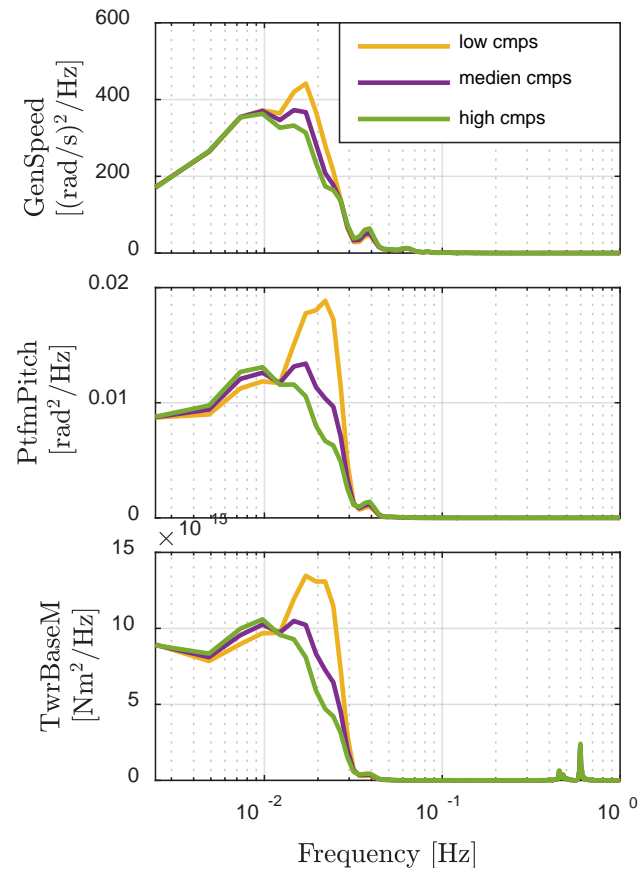
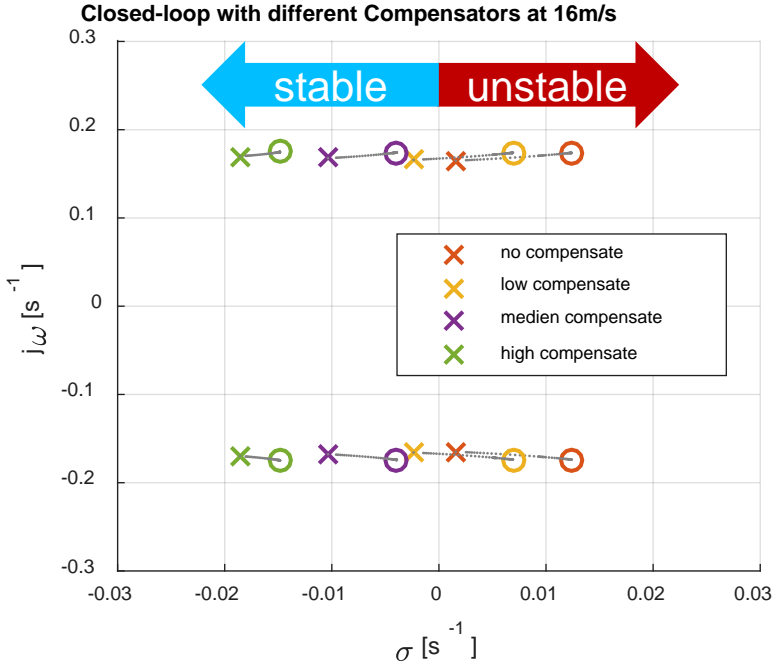
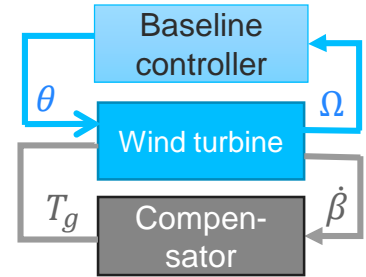
Bode plot of the Ptfm-pitch velocity filter



Due to the difficulty on filtering out the signal in wave frequencies, Ptfm Damper doesn't work well for Ptfms with pitch eigen-frequency close to the wave frequencies,

MIMO: Feedback of Ptfm Pitch to Gen Torque

How does it work?

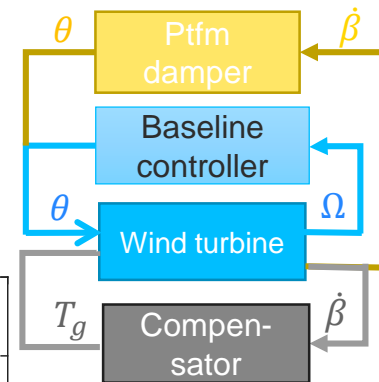
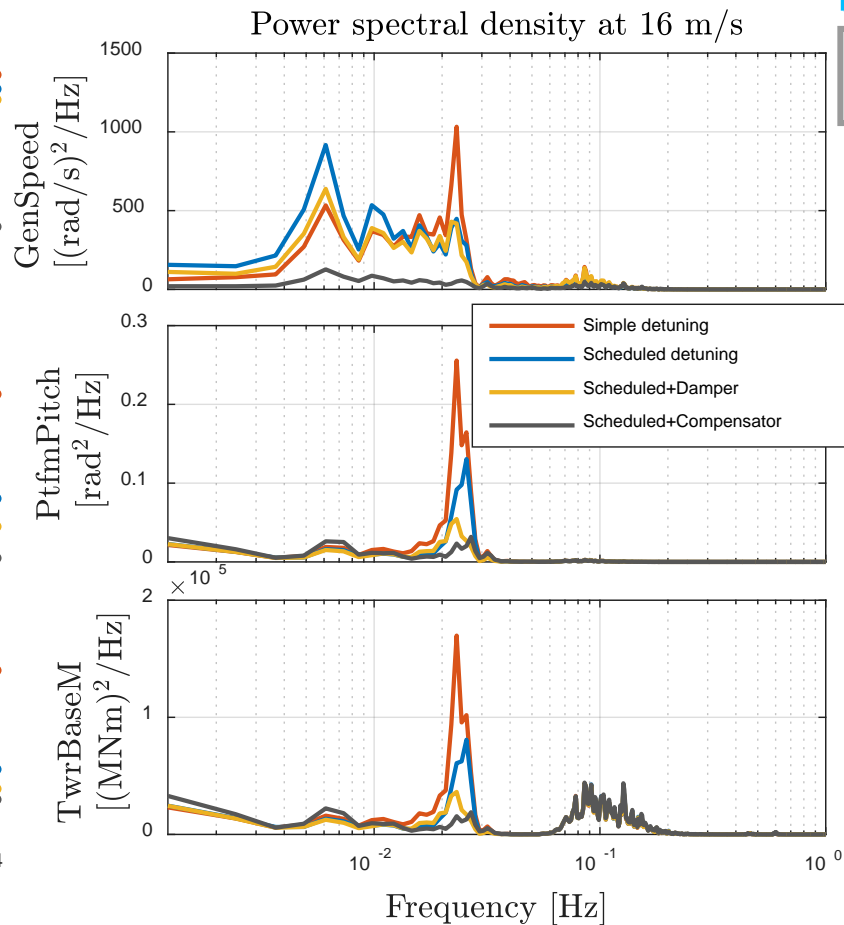
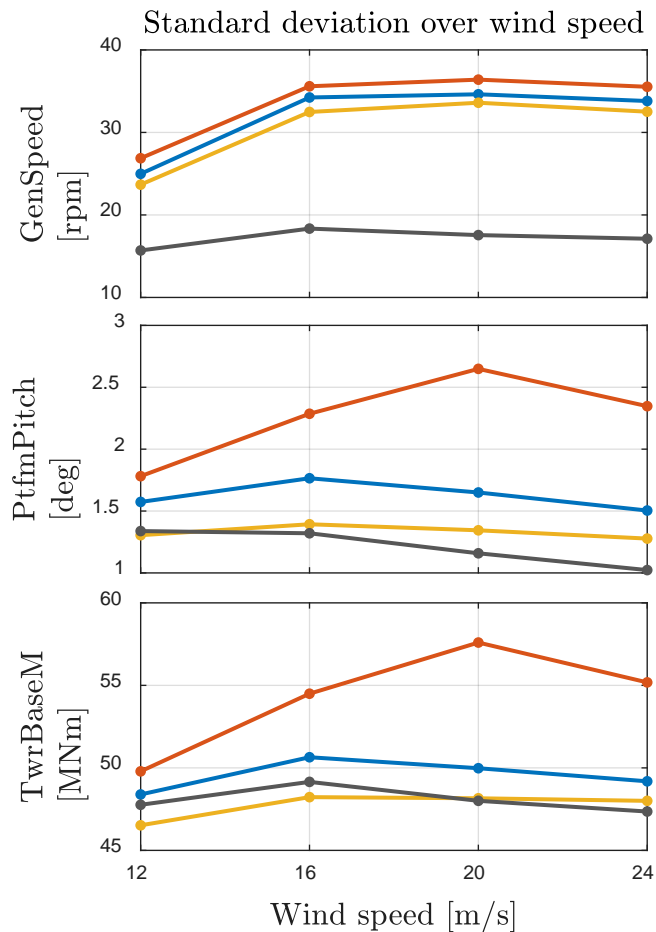


A RHPZ-Compensator can solve the trade-off problem by moving the positive zero to the left s-place, however will increase the maximum loads on the generator torque.

How great is the impact of controller on FOWTs?

Wind: [12, 16, 20, 24] m/s, IEC3-A class

Wave: Hs 5.7 [m], Tp 11.5 [s]



Conclusion

- System motions and loads are strongly influenced by the controller. These can be significantly reduced by a well designed controller.
- Additional loops can improve the control performance. However, all of the state-of-art approaches have drawbacks.
- Improvement of control performance in wave frequency region is difficult with current sensor and actuators.



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Thank you!



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