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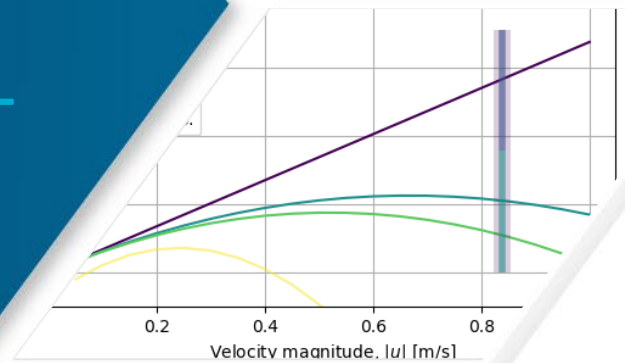
A VISUAL EXPLORATION OF OPTIMAL CONTROL IN HEAVING WECS



Daniel Gaebele, Giorgio Bacelli, Ryan Coe, Jeff Grasberger, Carlos Michelen Strofer

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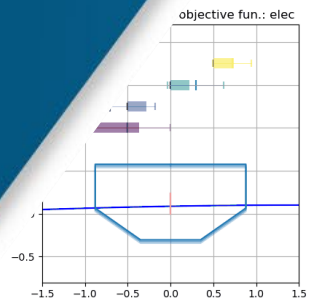

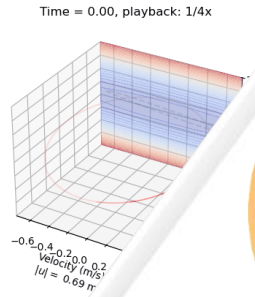

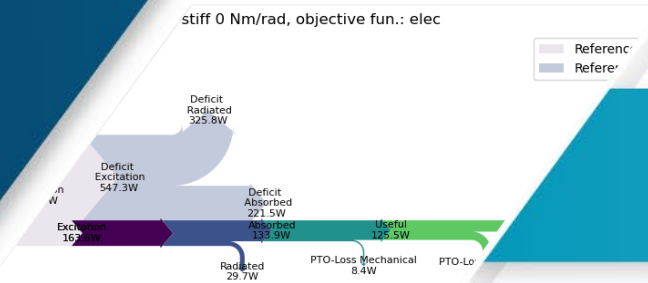

umerc + OREC 2025

UMERC 2025, Corvallis, OR

U.S. DEPARTMENT of ENERGY NNSA

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SAND2025-09884C

POWER CURVES

Theory behind power absorbed as function of velocity (thus control)

Hydro dynamic

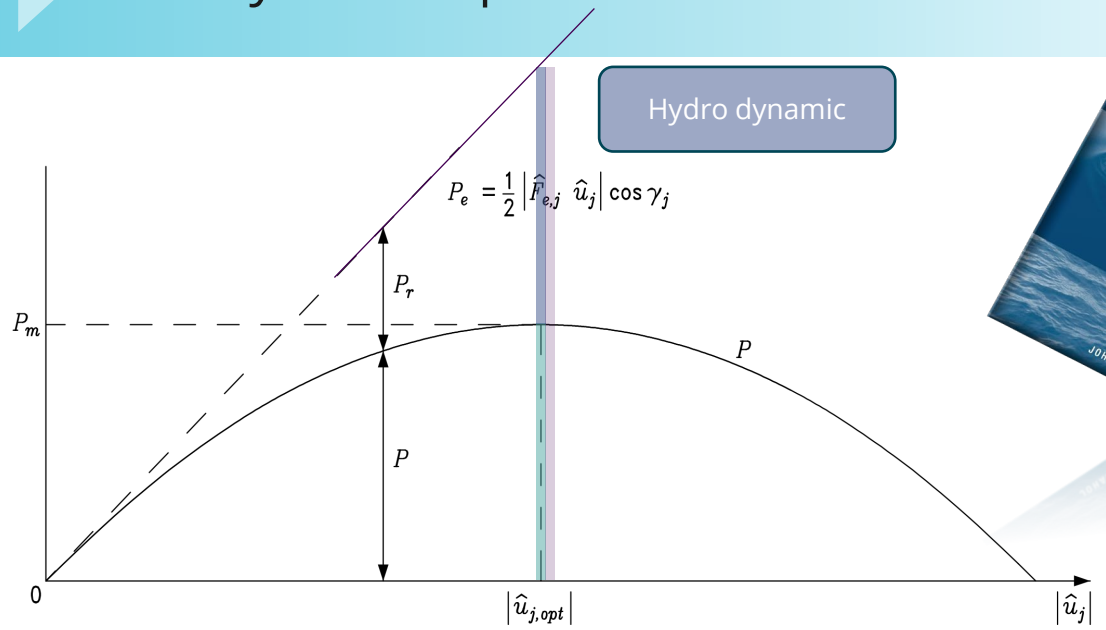
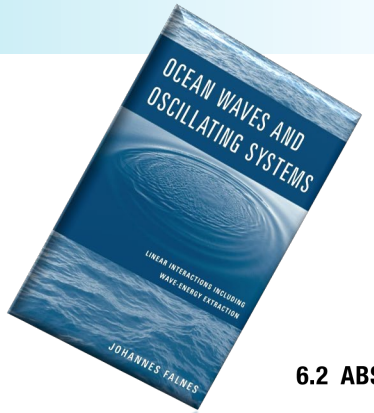


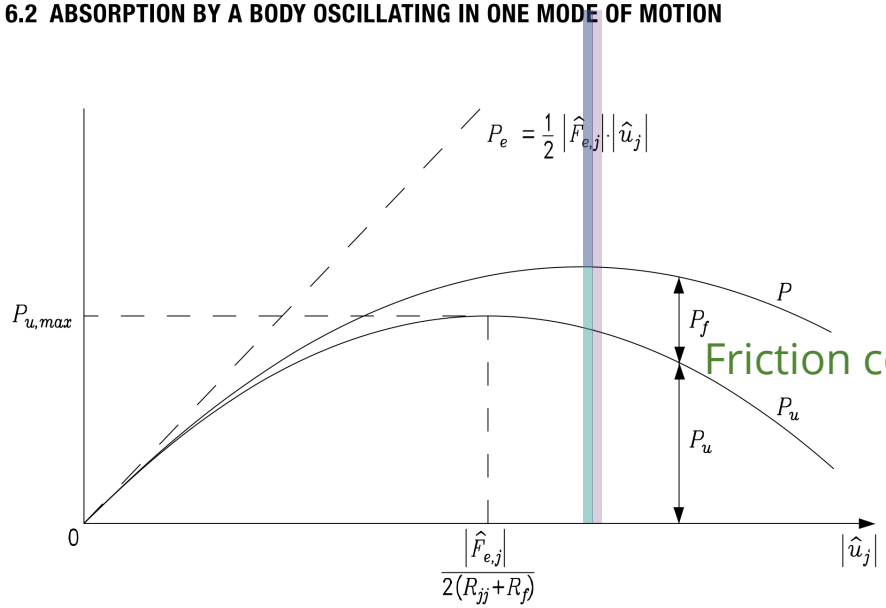
Figure 6.3: Power absorbed (solid curve) versus velocity amplitude. Radiated power P_r is the difference between excitation power P_e (dashed line) and absorbed power P.



Hydro dynamic

PTO friction

6.2 ABSORPTION BY A BODY OSCILLATING IN ONE MODE OF MOTION 203



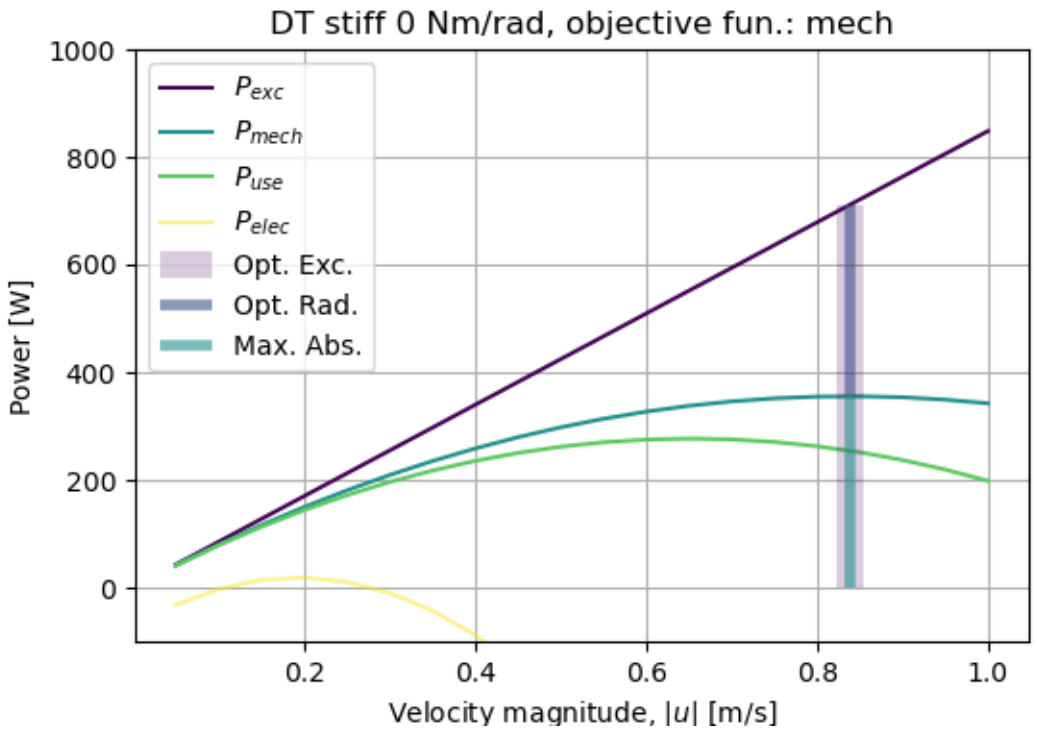
Friction considered

Figure 6.5: Curves showing absorbed power P, useful power P_u and excitation power P_e versus velocity amplitude $|\hat{u}_j|$ at optimum phase.

POWER CURVES

Power curves of an experimental WEC, the WaveBot

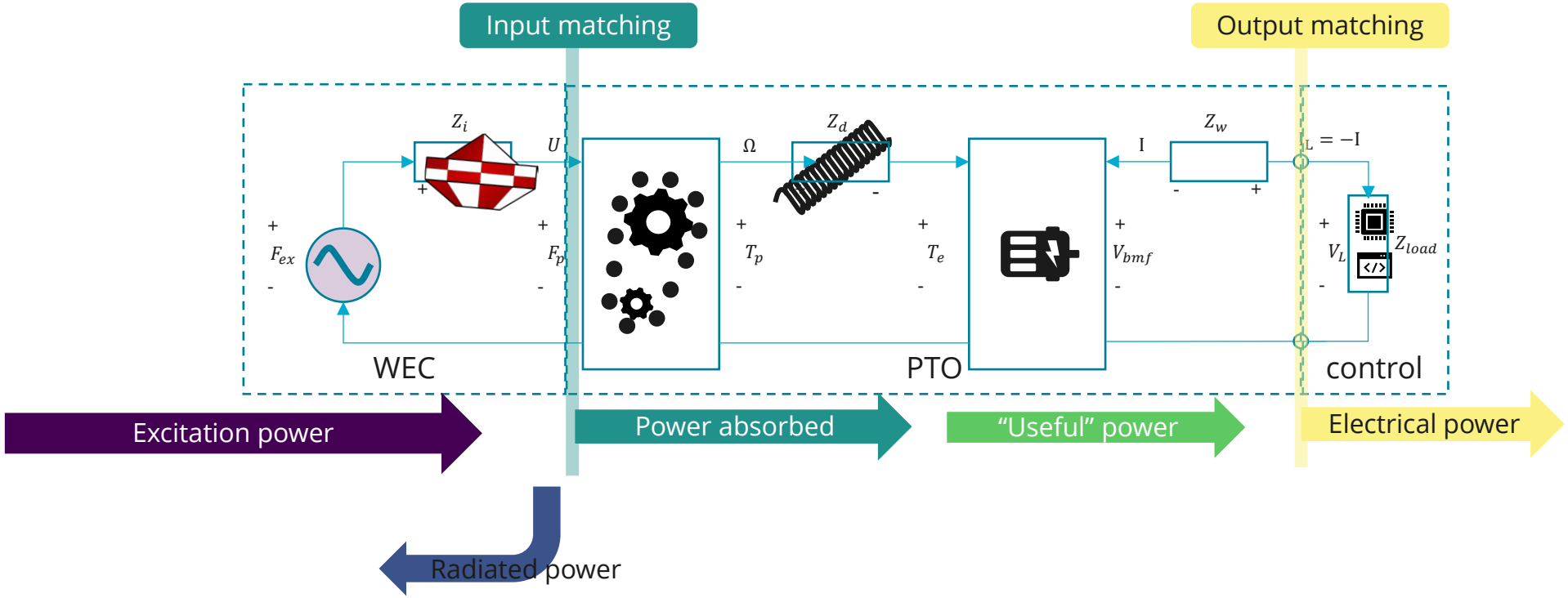
- Hydro dynamic
- PTO friction + dynamics
- Electrical losses



Where is the electrical power?!

WAVE ENERGY CONVERTER AS MULTI-PORT NETWORK

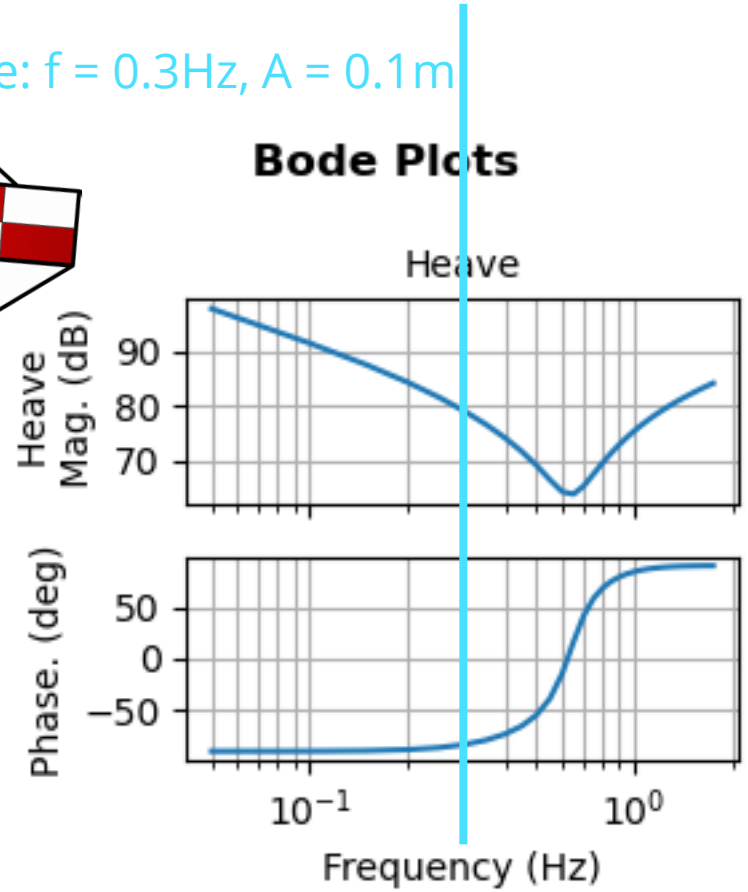
Bi-conjugate impedance matching as design framework



CASE STUDY

Regular wave, different objective functions for control optimization, different PTOs

Wave: f = 0.3Hz, A = 0.1m



Objective → Power absorbed

Objective → Electrical power

Regular PTO

PTO + negative spring

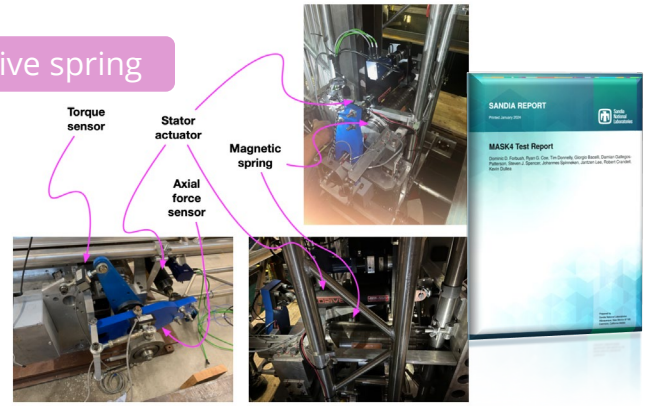


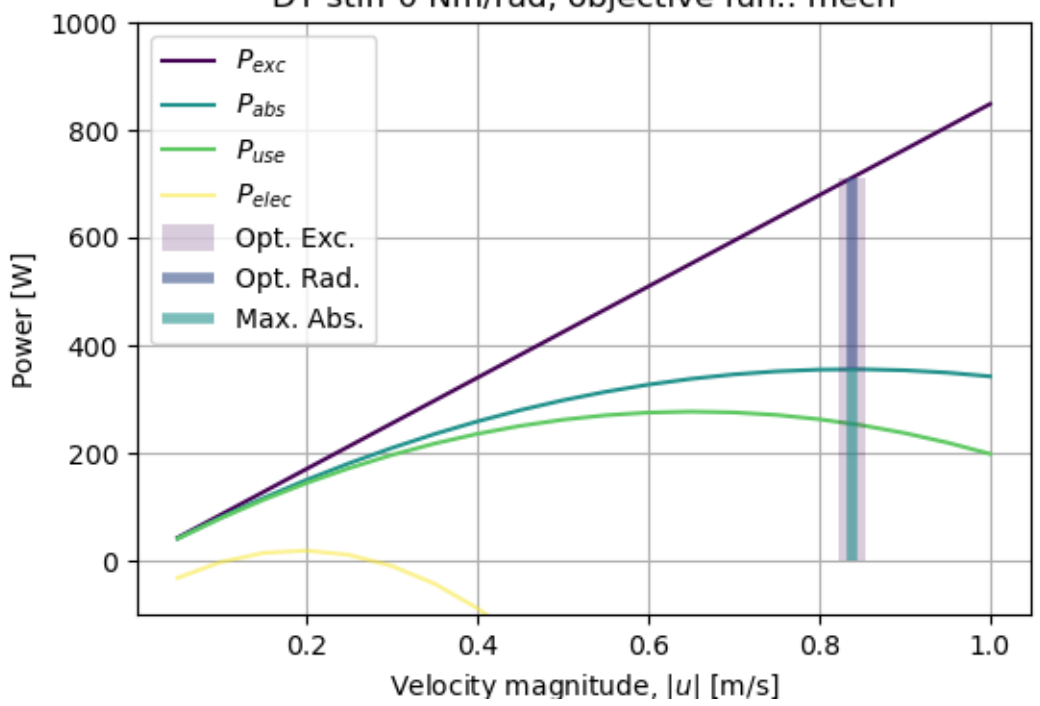
Figure 3-3. Magnetic spring installed with sensors.

WHERE IS THE ELECTRICAL POWER?

Let's optimize the controller for electrical power!

Objective

Power absorbed



Objective

Electrical power

Same velocity but different absorbed power => **different phase**

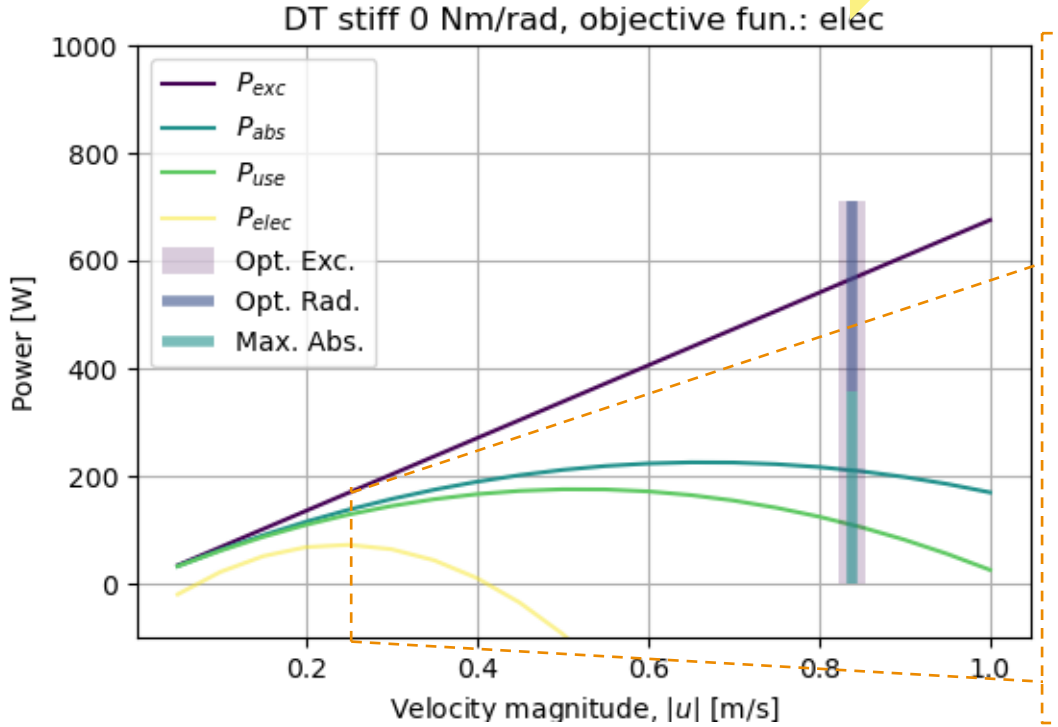
Better... but not good

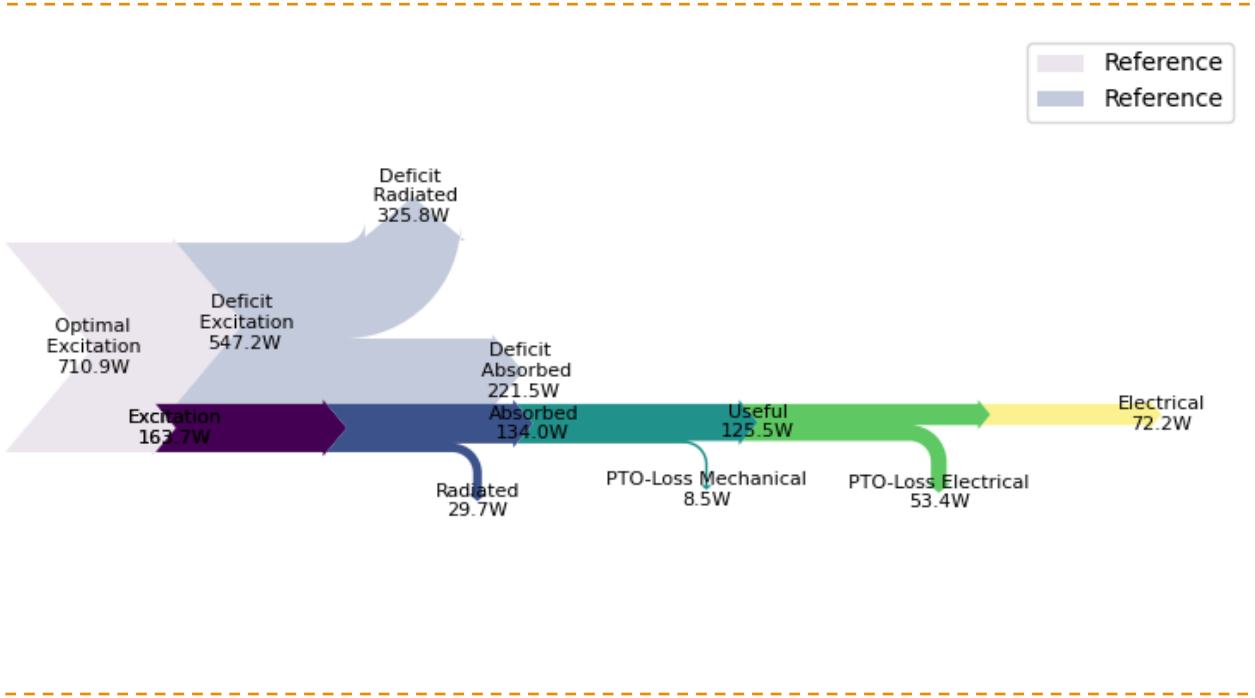
WHERE IS THE ELECTRICAL POWER?

The actual optimum for electrical power

Objective

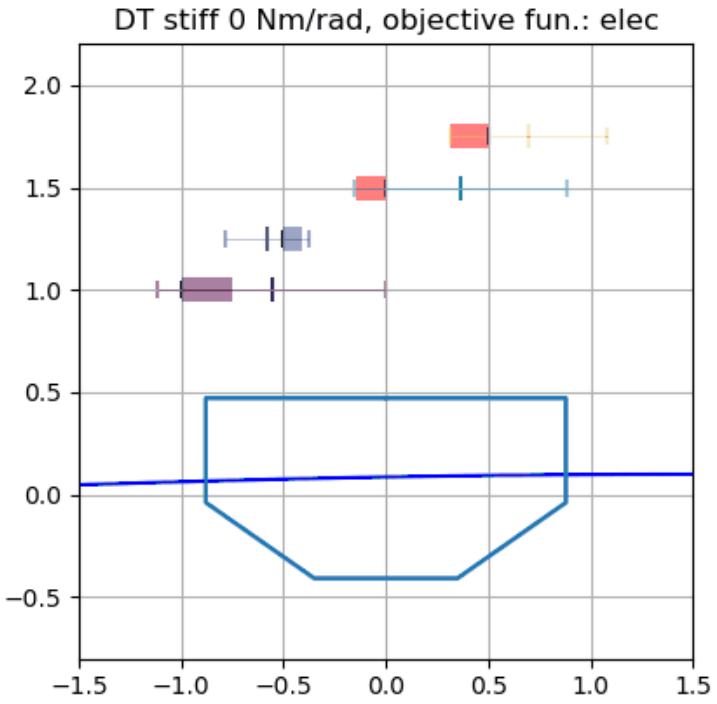
Electrical power

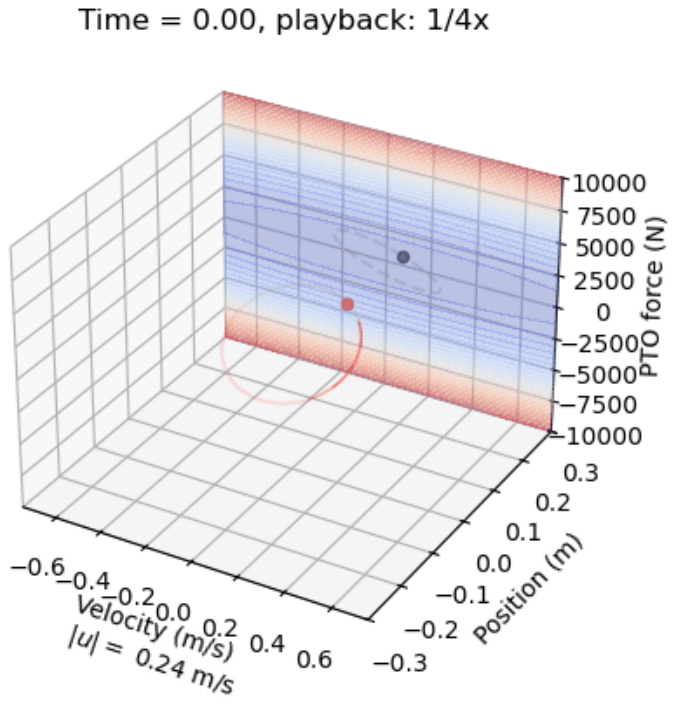


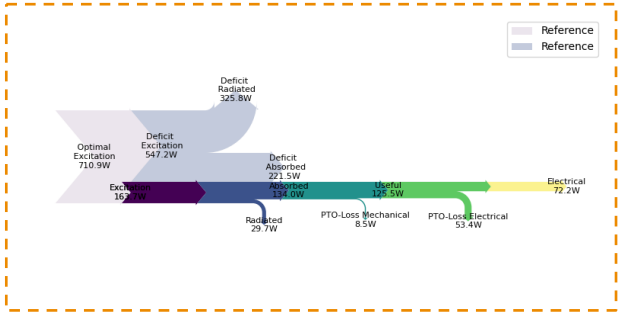


WHERE IS THE ELECTRICAL POWER?

The actual optimum for electrical power - dynamics





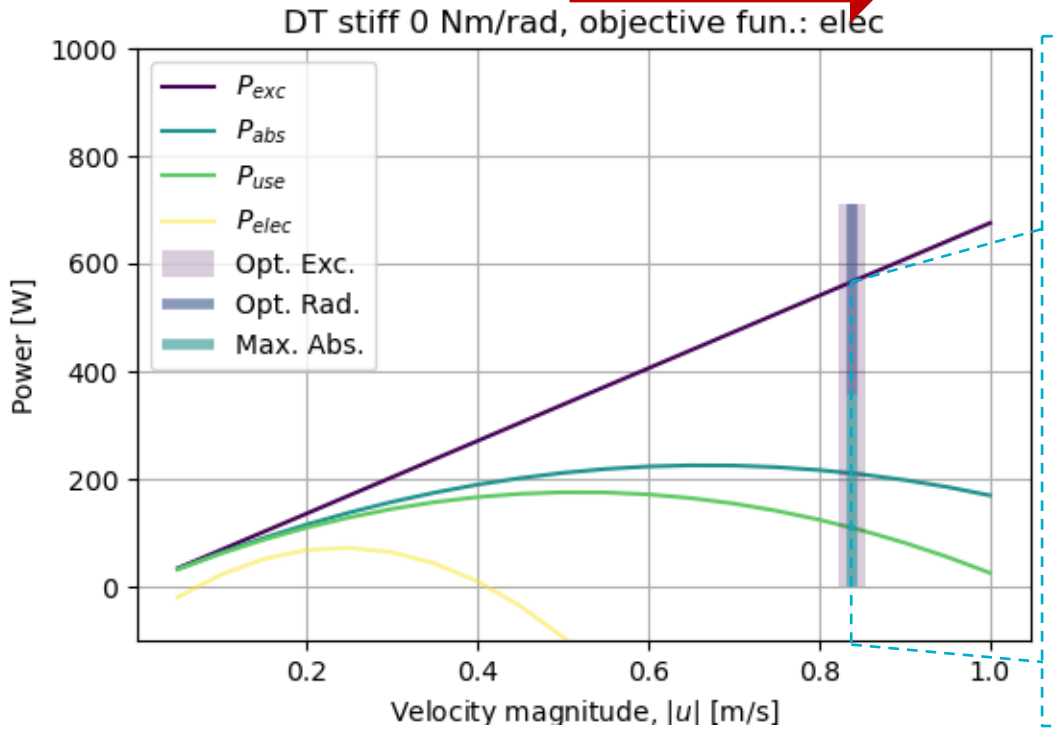


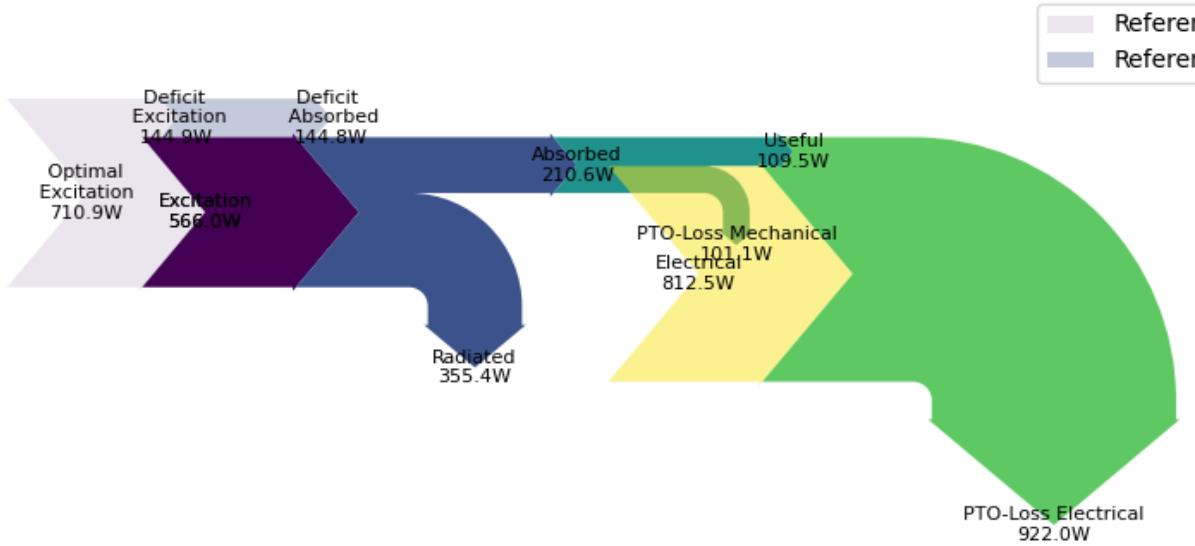
WHERE IS THE ELECTRICAL POWER?

What if we would have the enforced optimum velocity for max wave power absorbed?

Objective

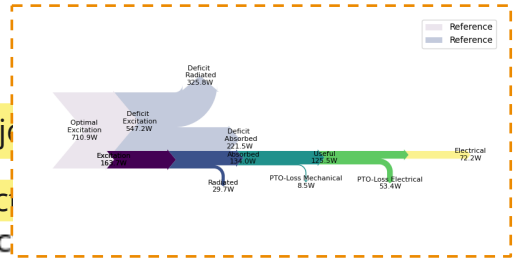
Electrical power





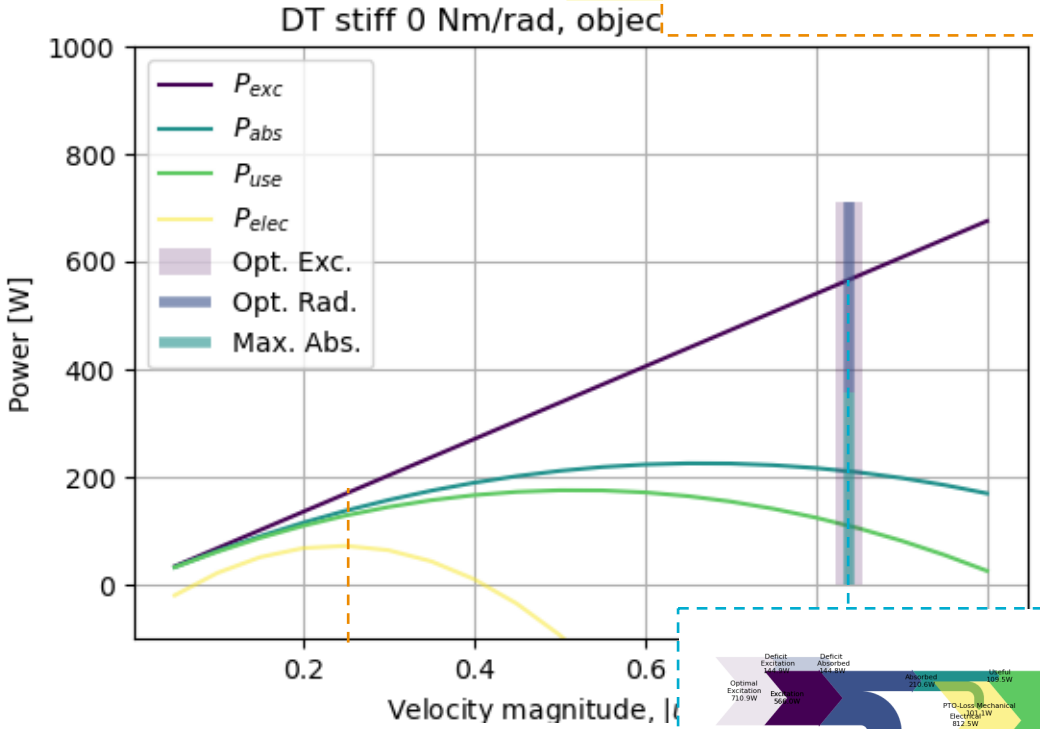
WHERE IS THE ELECTRICAL POWER?

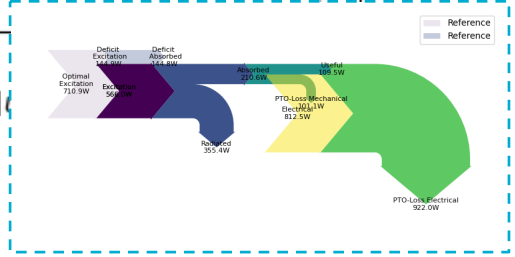
The device and PTO are identical, what could the difference possibly be?

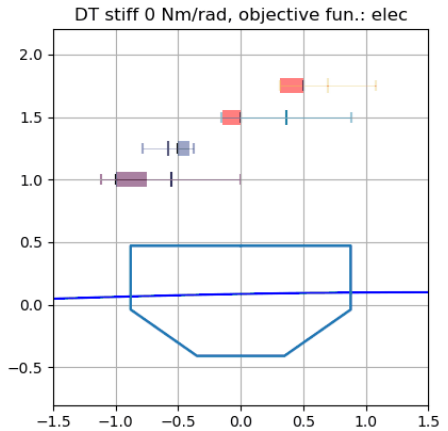


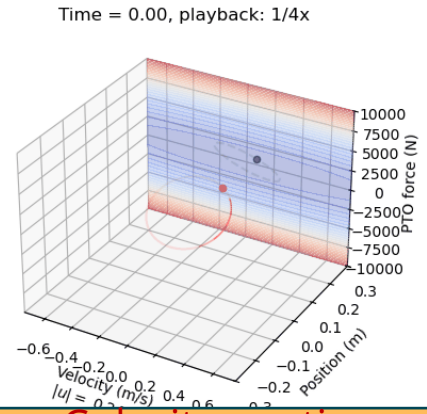
Obj

Elec

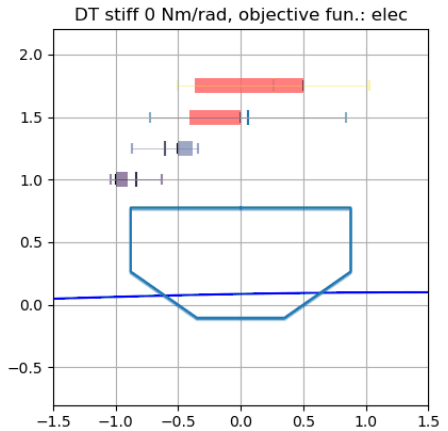


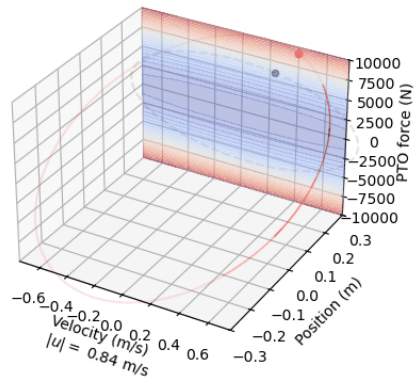






Culprit: reactive power provided to buoy and electrical losses



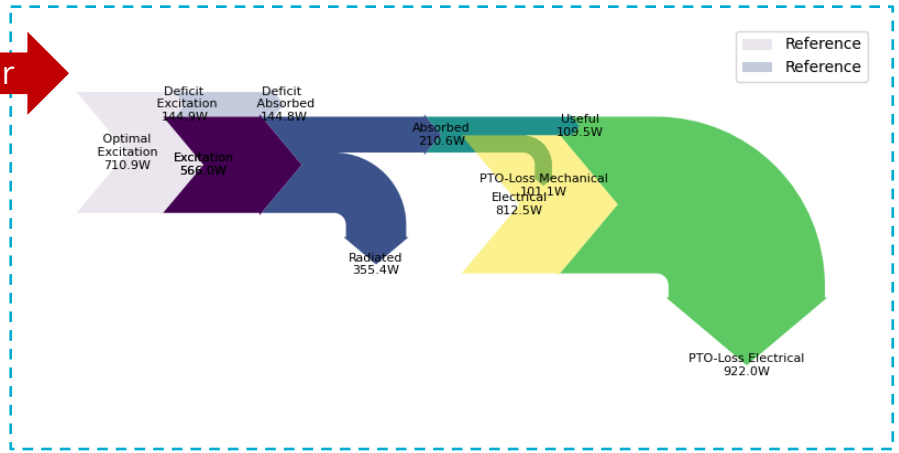


HOW DOES THIS COMPARE TO THE MAXIMIZING THE POWER ABSORBED?

Could it possibly be worse?

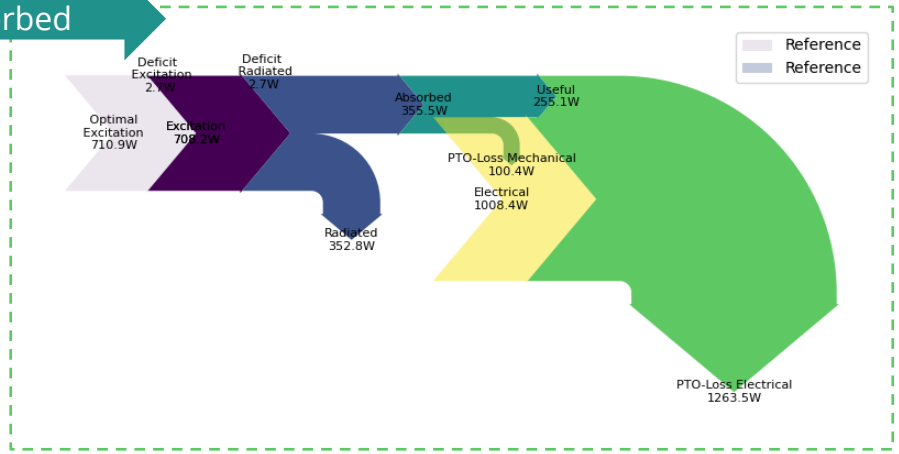
Objective

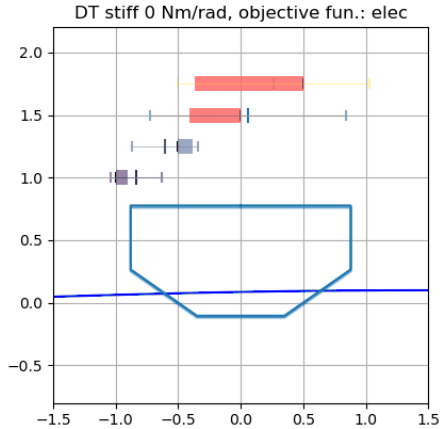
Electrical power

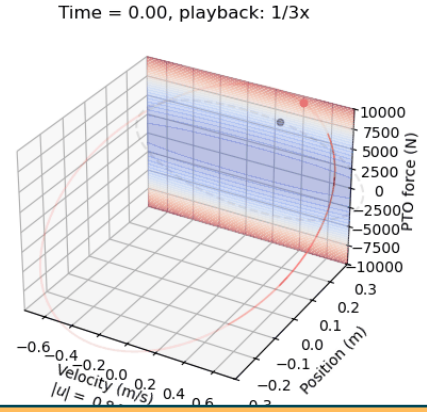


Objective

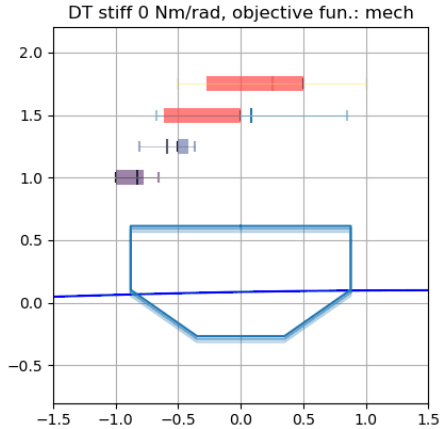
Power absorbed

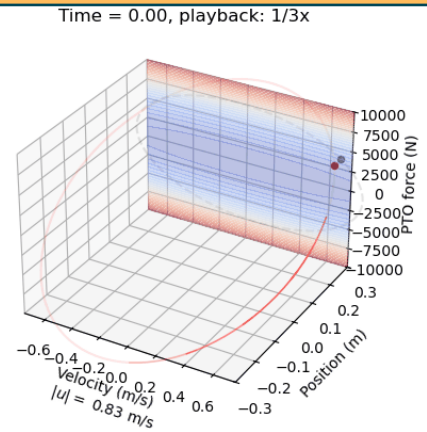






Yes, it requires even more reactive power to phase match





IS THERE NOTHING WE CAN DO?

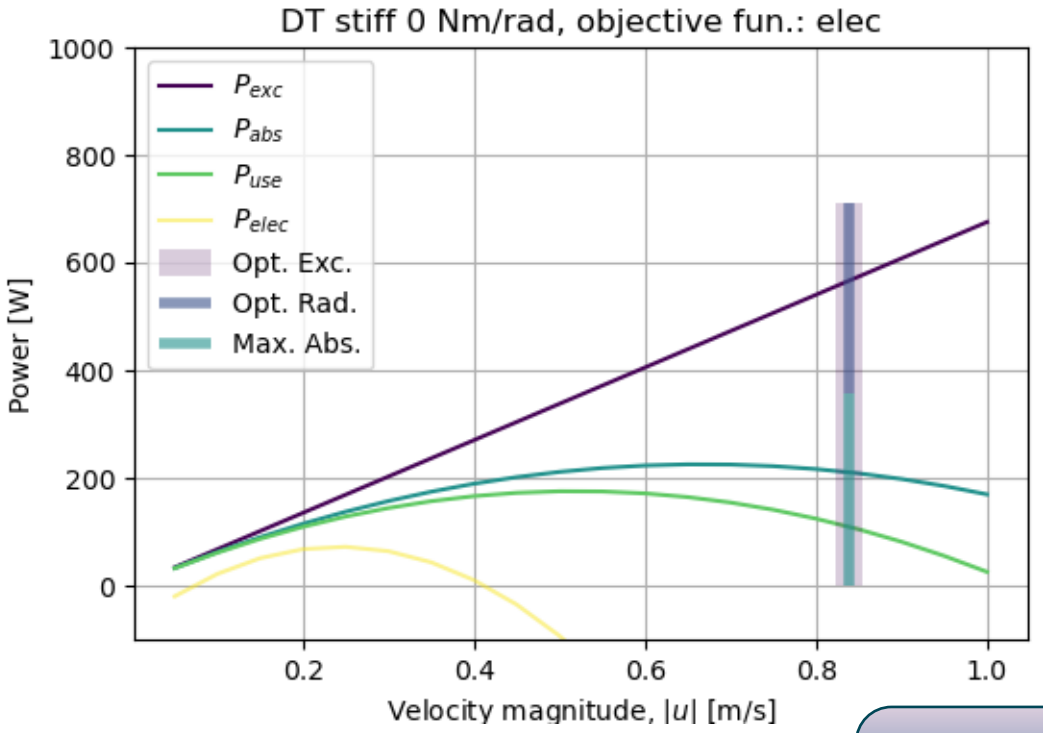
Quick recap

Given wave

Given hardware

Controller is the only knob to tune

Even optimal control for electrical power is disappointing



Increasing the WEC velocity could yield higher absorbed power

But doing so with active control comes at a high price

This is the motivation for the concurrent design of hardware and controller

Look at WEC design as control co-design problem!

WEC CONTROL CO-DESIGN

“simple” solution for the WaveBot

PTO + negative spring

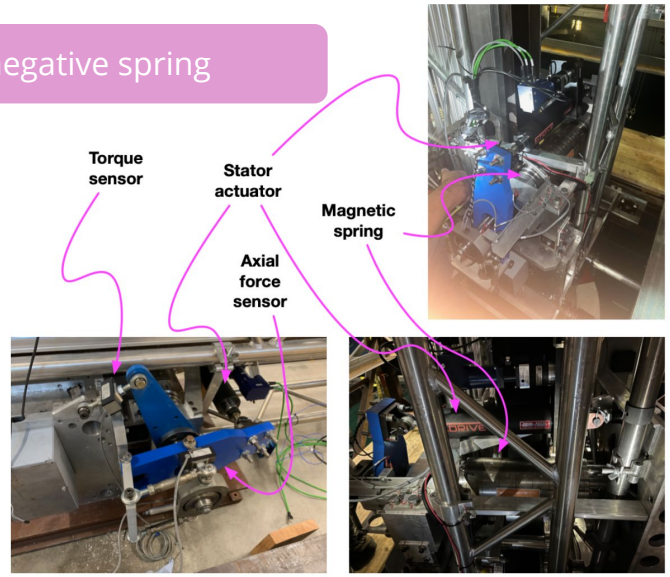


Figure 3-3. Magnetic spring installed with sensors.

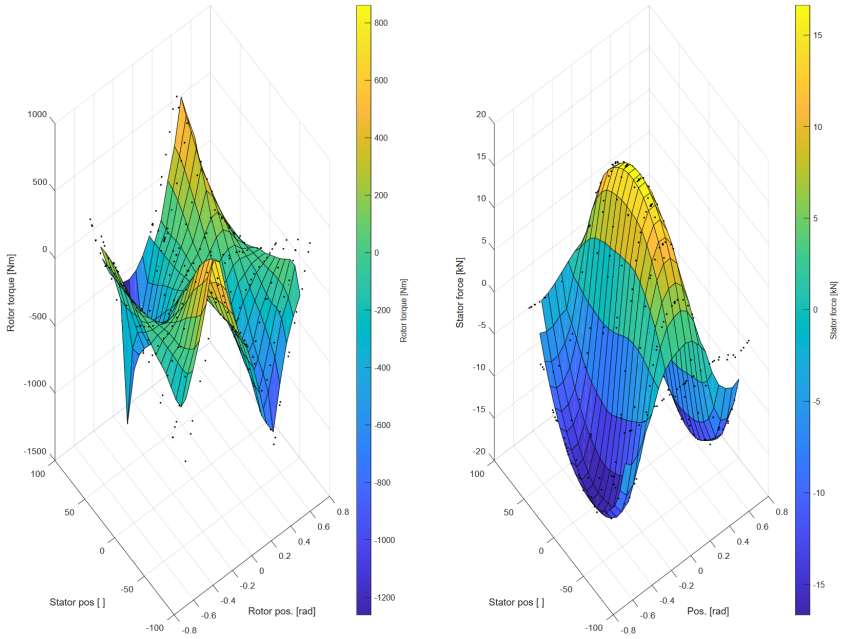
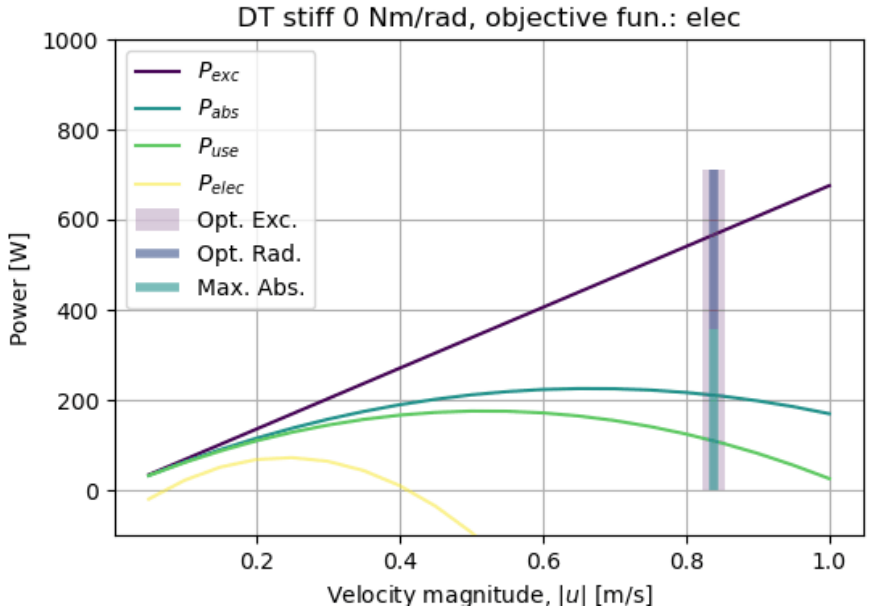


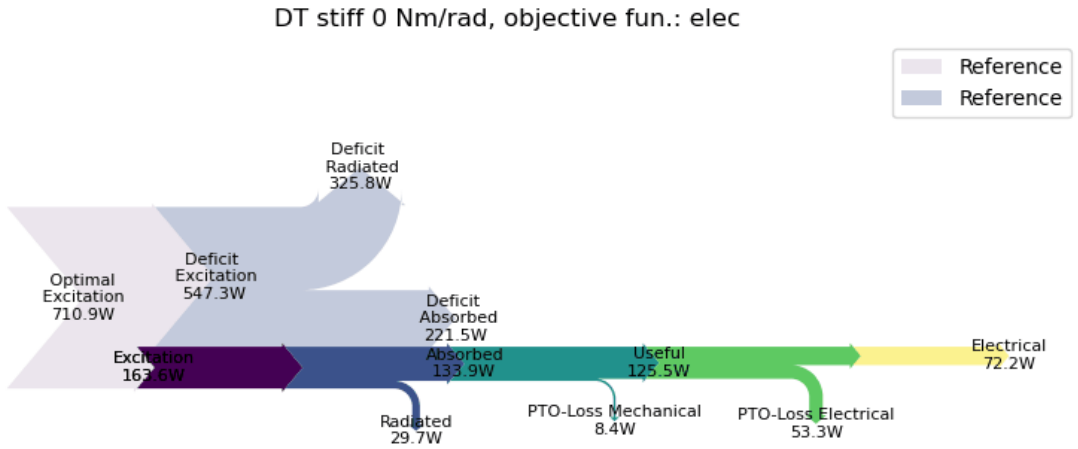
Figure 4-1. Surfaces for magnetic spring rotor torque (left) and stator force (right) as a function of rotor and stator position. Black dots show individual measurements. (MATLAB file: `MASK4_mag_spring_mapping.m`)

WEC CONTROL CO-DESIGN

“simple” solution for the WaveBot

PTO + negative spring



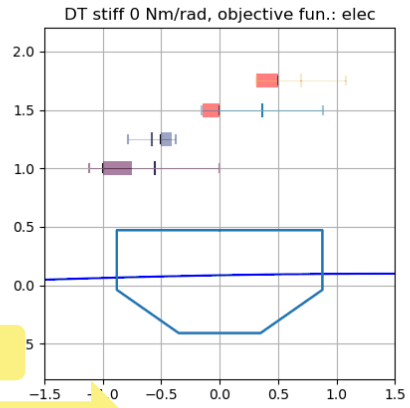


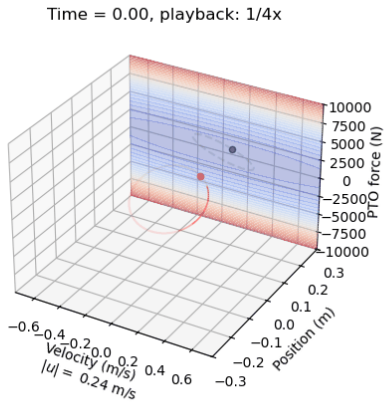
Negative spring helps match the phase
By *passively* providing reactive power without the electrical losses

THINGS ARE LOOKING UP

We can get the power in and through the PTO! (still need peak2mean)

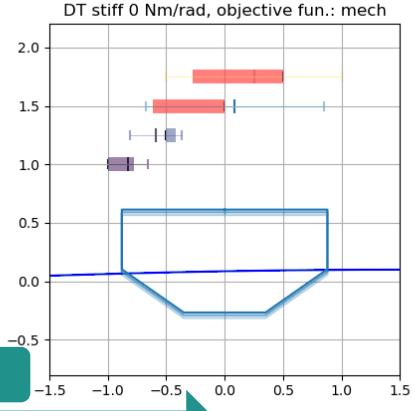
Regular PTO

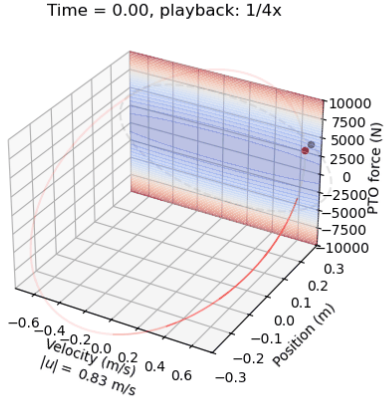




Objective

Electrical power

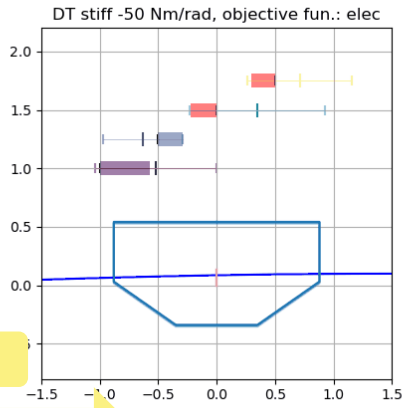


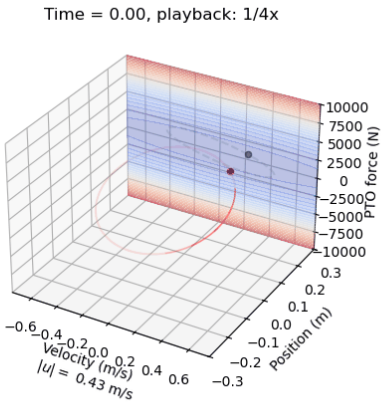


Objective

Power absorbed

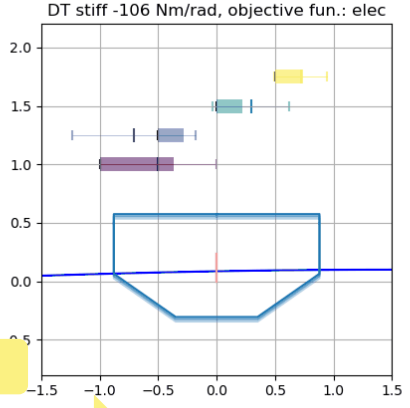
PTO + negative spring

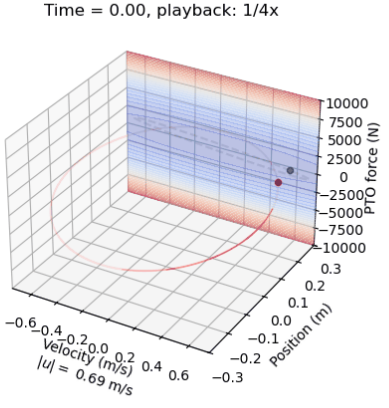




Objective

Electrical power



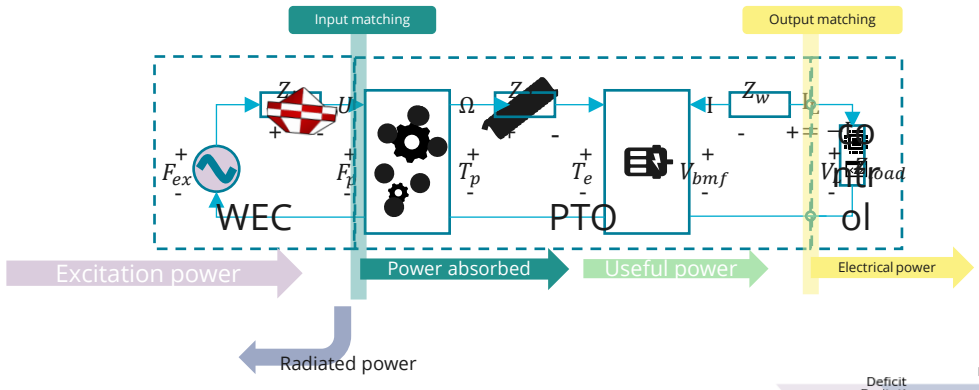


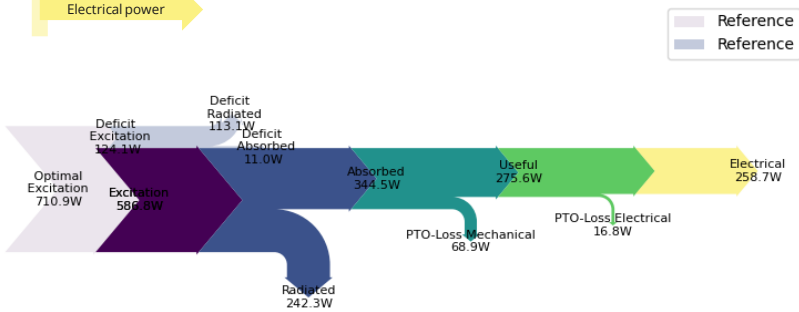
Objective

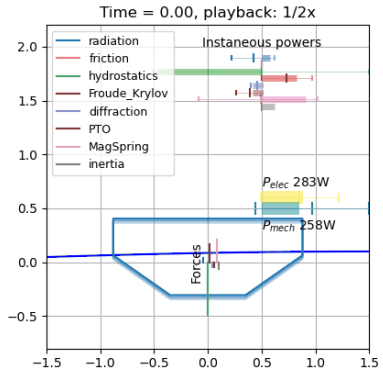
Electrical power

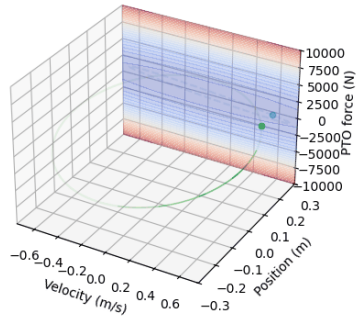
THINGS ARE LOOKING UP

Framework helps to understand where the power goes (or doesn't)









THANK YOU!

Q?&A!