WEC-Sim Technical Training Course

for users and developers

9/8/2023

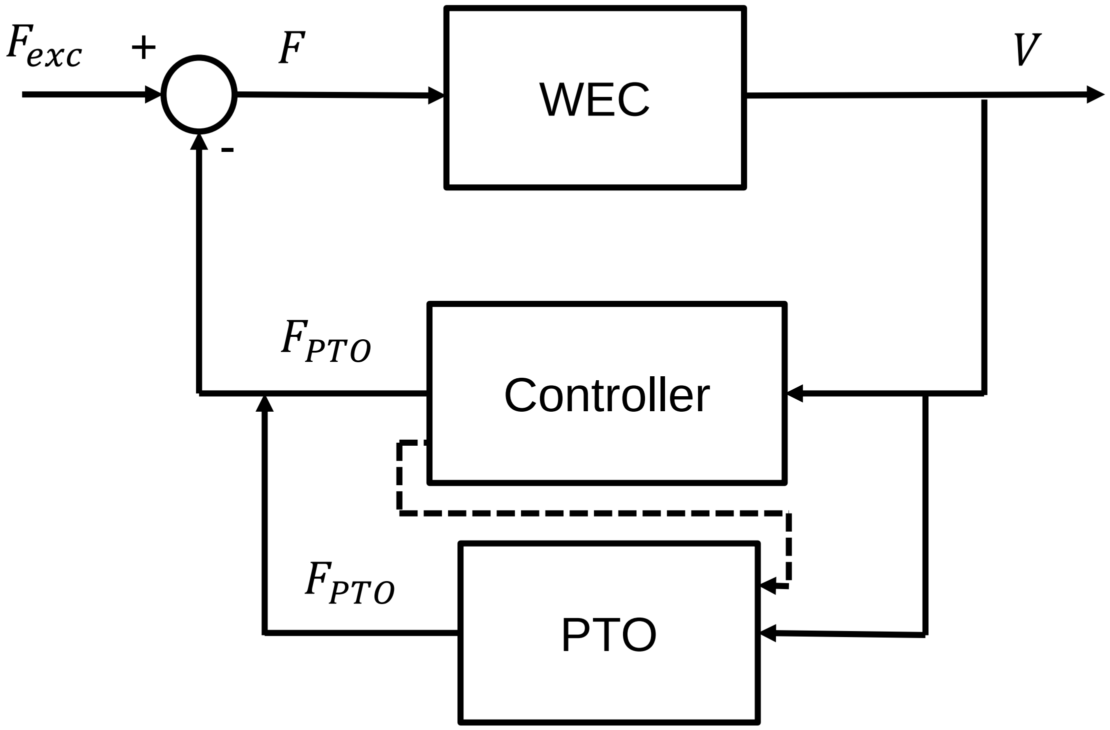
PRESENTED BY

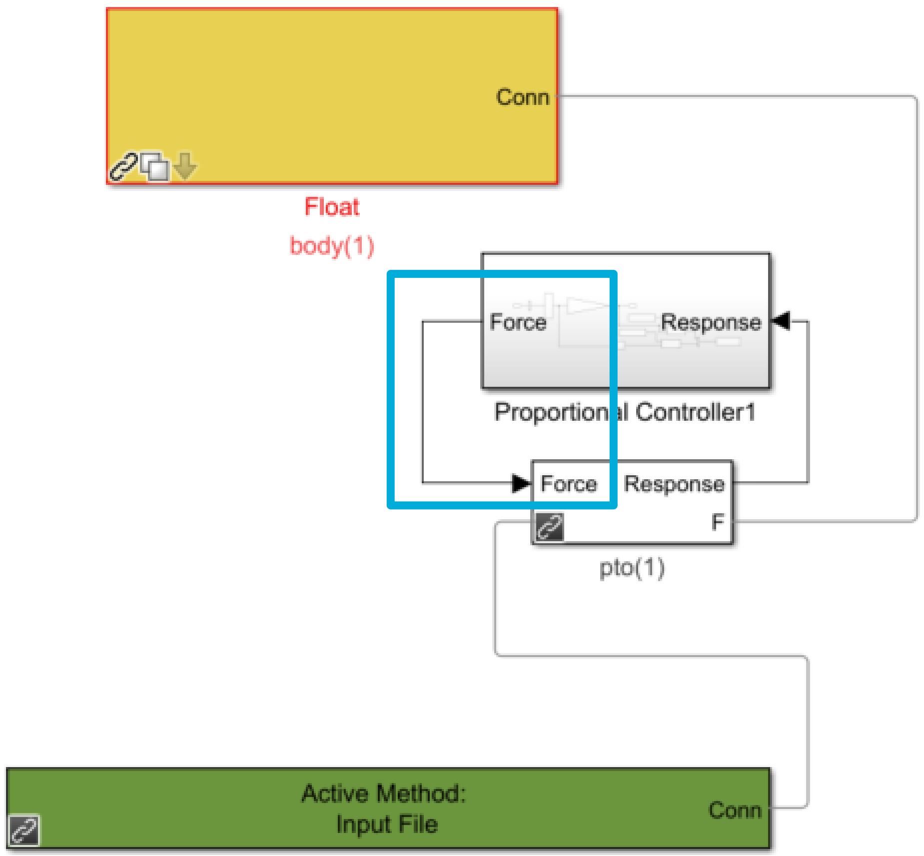
Jeff Grasberger

WEC-Sim Controls

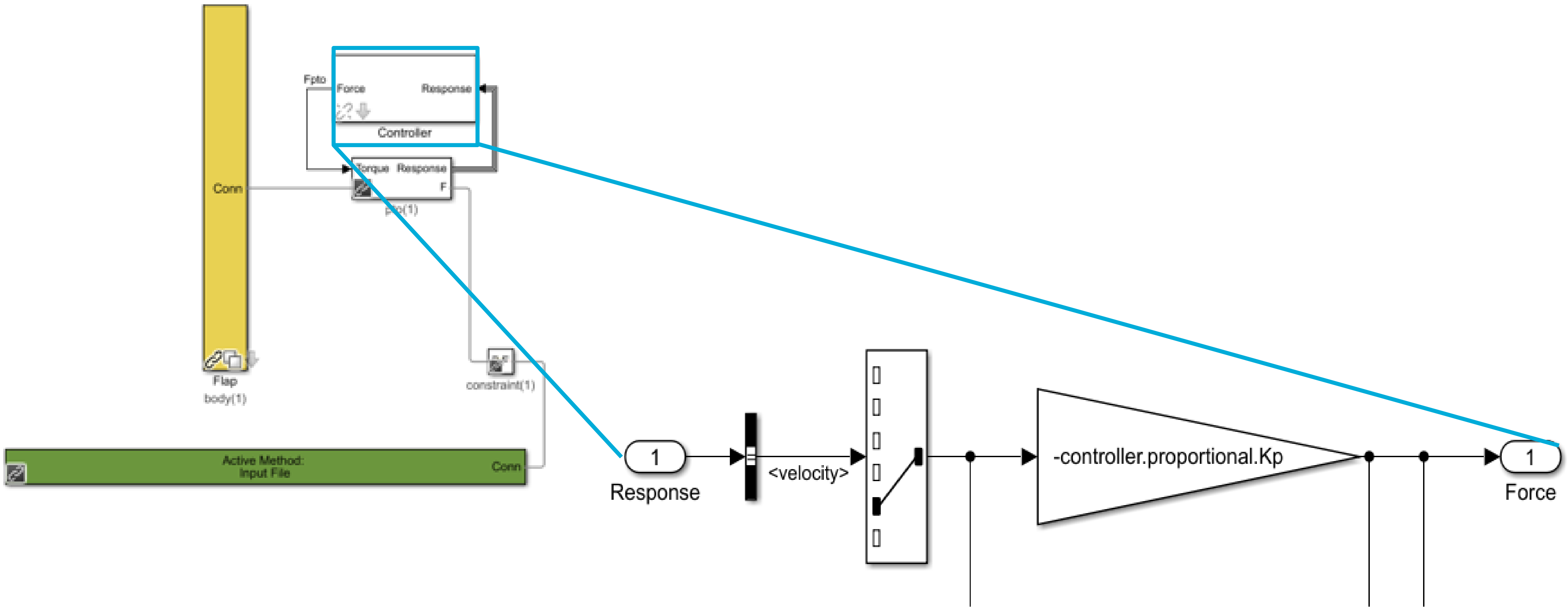
WEC Control Background – PTO Force

WEC controls prescribes PTO force: $u = F_{PTO}$





WEC-Sim Control Implementation



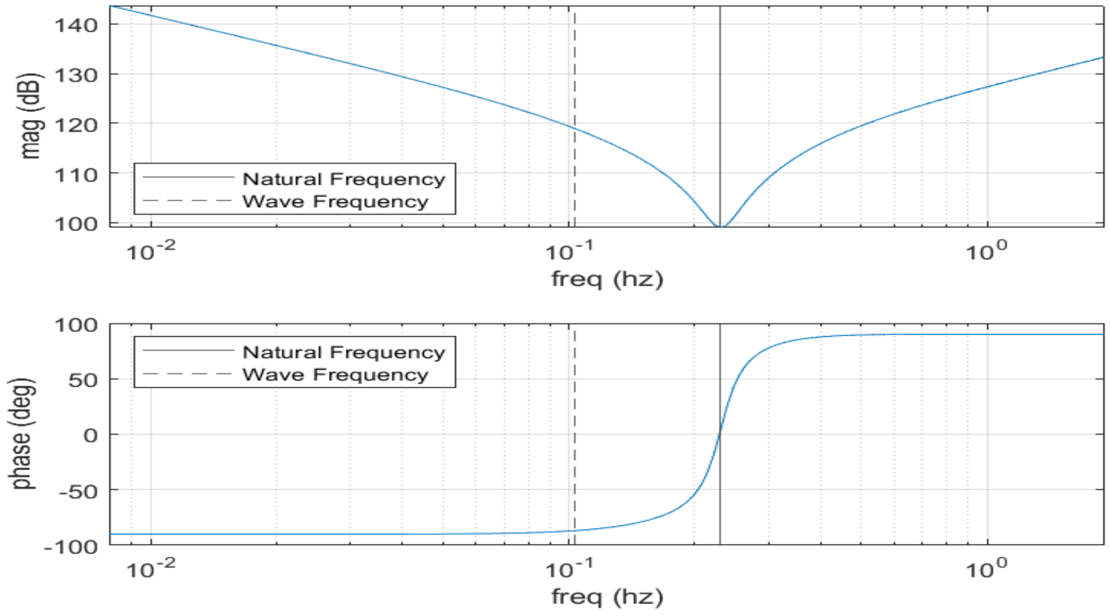
WEC Control Background – Complex Conjugate Impedance Matching

- Optimal control maximizes harvested power
- Power transferred to the WEC can be maximized through complex conjugate impedance matching
  - WEC Intrinsic Impedance:

$$Z_i(\omega) = j\omega\big(m + A(\omega)\big) + B(\omega) + \frac{K_{hs}}{j\omega}$$

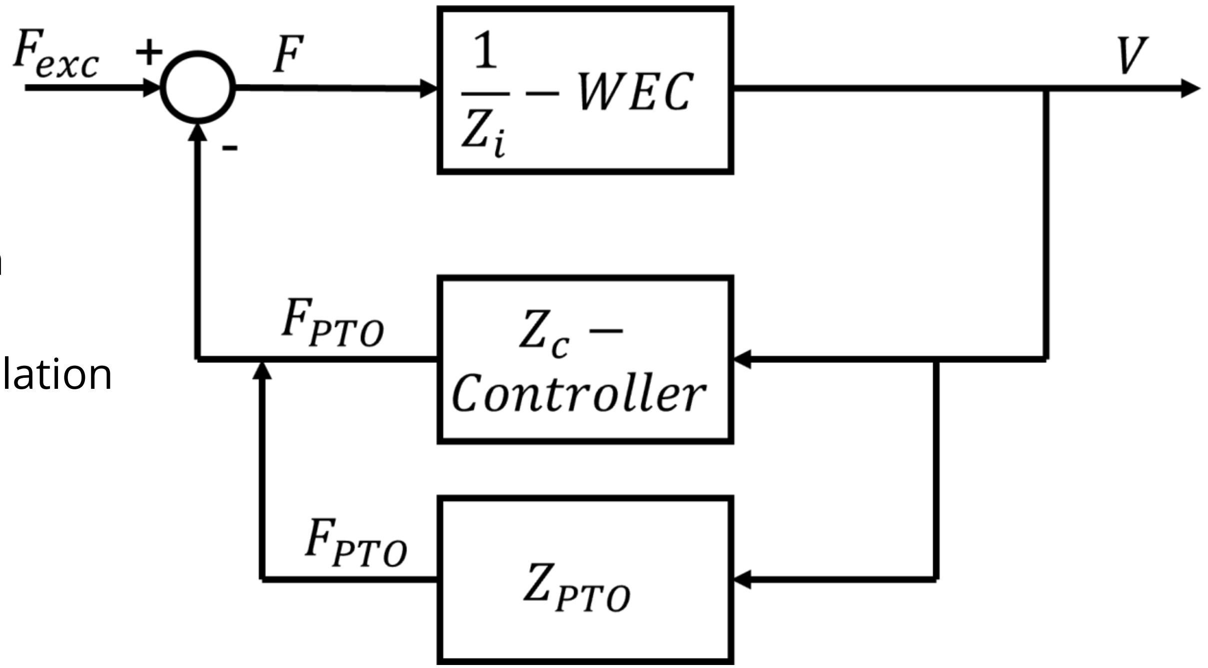
  - Complex Conjugate Controller Impedance:

$$Z_C(\omega) = -j\omega\big(m + A(\omega)\big) + B(\omega) - \frac{K_{hs}}{j\omega}$$



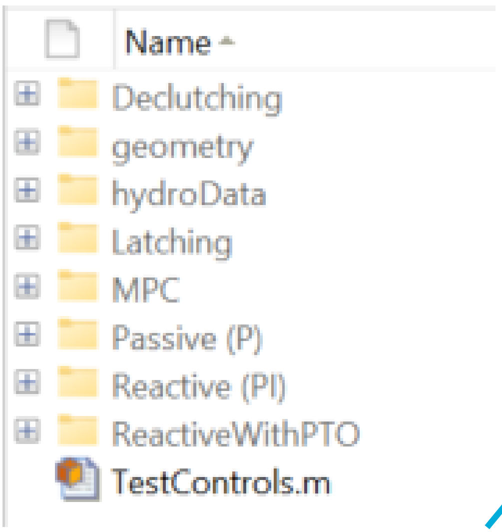
WEC Control Types

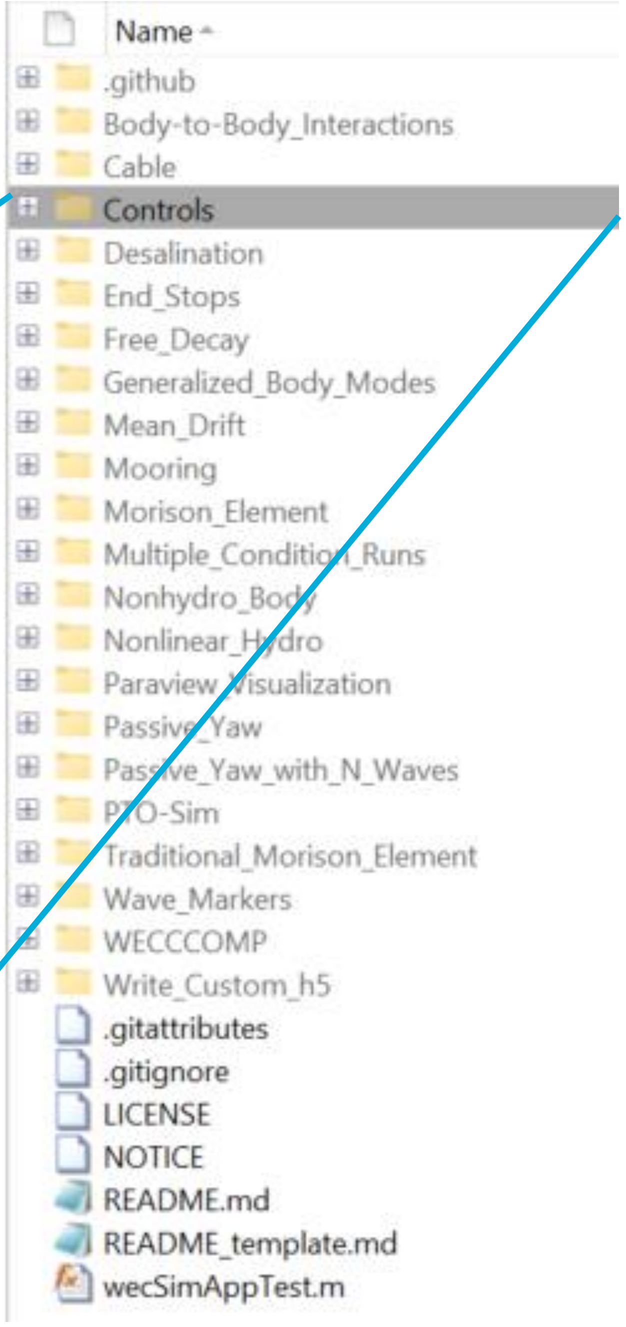
- **Passive** (proportional: P) – Damping Force
- **Reactive** (proportional-integral: PI) – Damping and Spring Force
- Phase Control:
  - **Latching** – Locking device for part of oscillation
  - **Declutching** – Releasing device for part of oscillation
- **Model Predictive Control** - Predicts and optimizes dynamics for maximum power



WEC Control Examples

- WEC control examples are available on the WEC-Sim Applications repository: https://github.com/WEC-Sim/WEC-Sim_Applications





WEC Control – Passive (P)

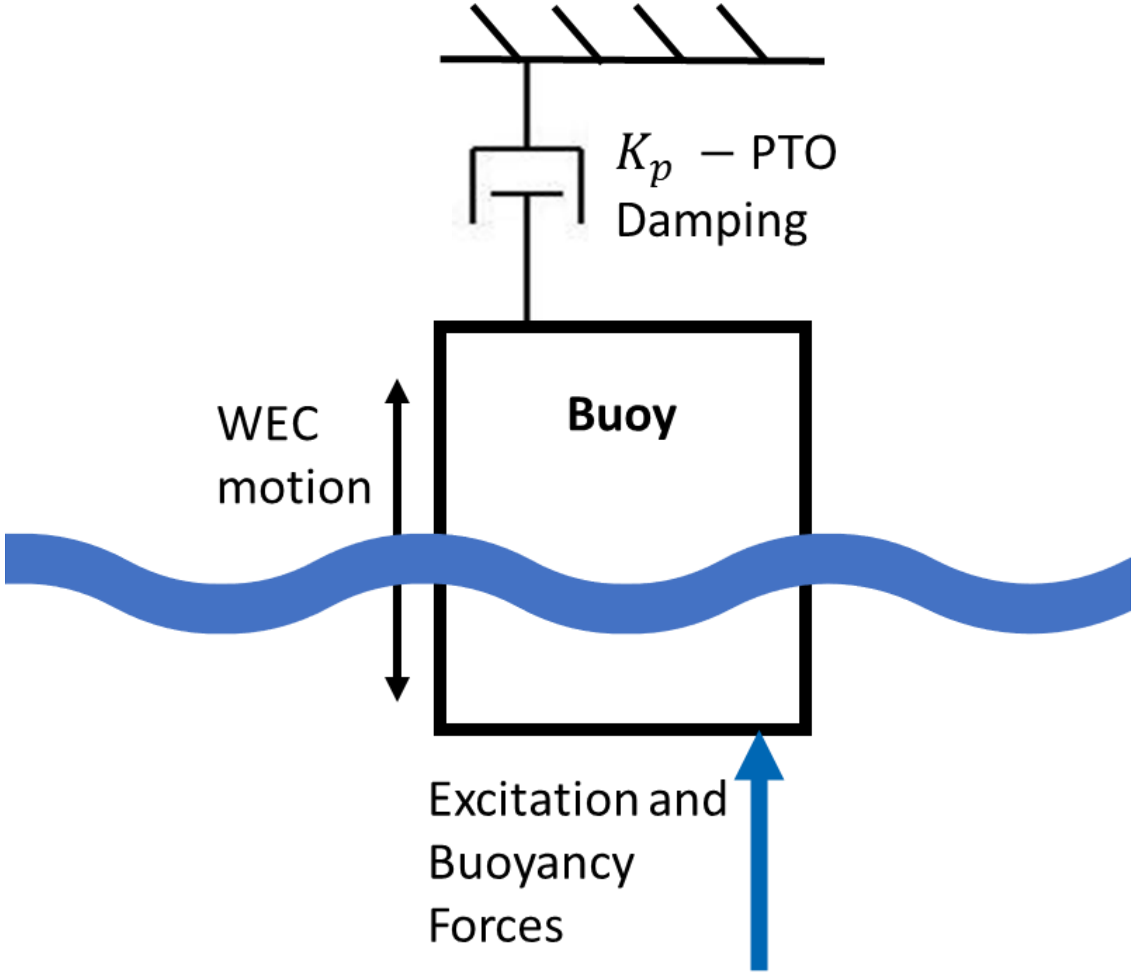
- Applied PTO force is proportional to velocity:

$$F_{PTO} = K_p \dot{X}$$

- Damping force
- Theoretical optimal gain:

$$K_{p,opt} = \sqrt{B(\omega)^2 + \left(\frac{K_{hs}}{\omega} - \omega\big(m + A(\omega)\big)\right)^2}$$

- Requires no input power



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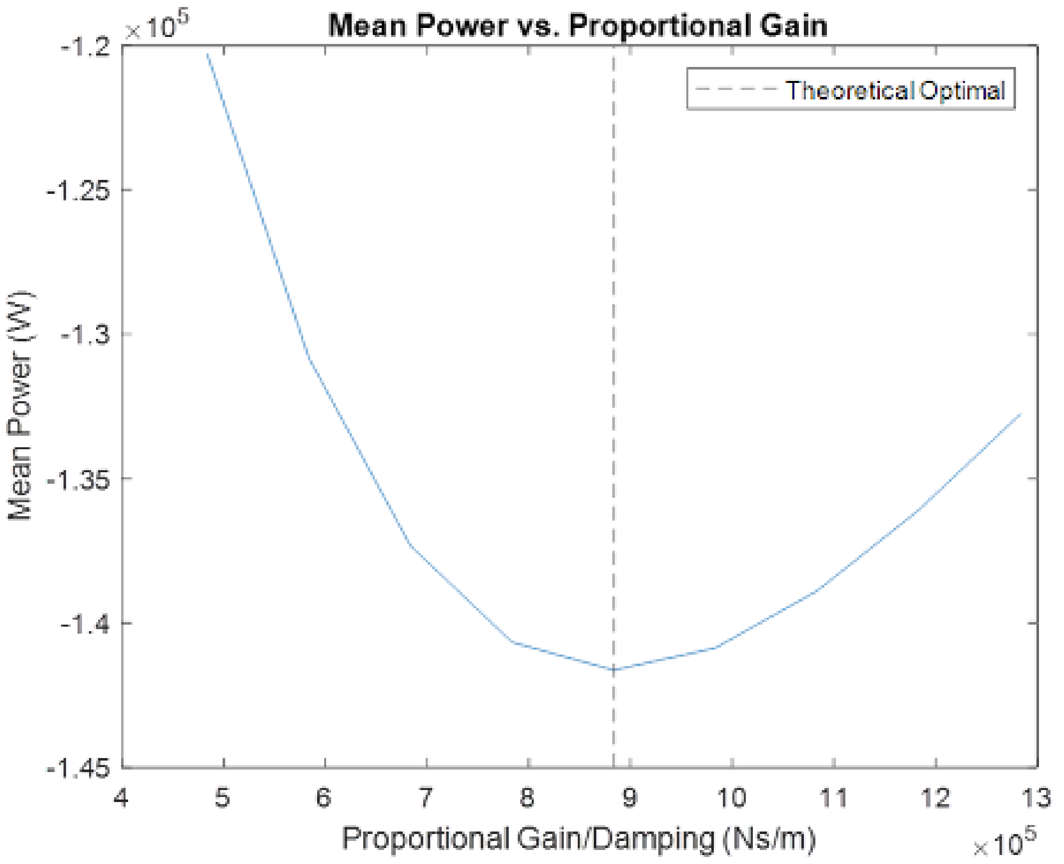
Note: negative power is power harvested



WEC Control – Reactive (PI)

- Applied PTO force is proportional to position and velocity:

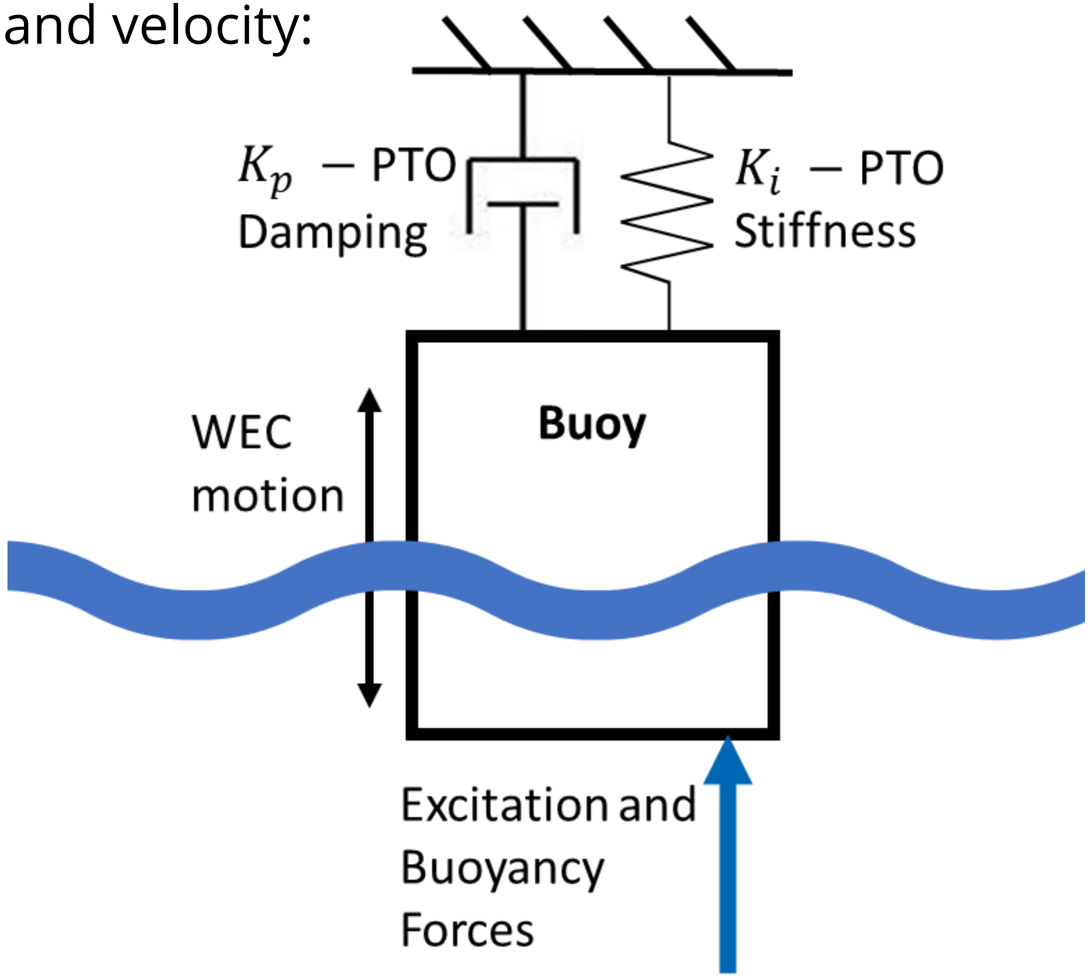
$$F_{PTO} = K_p\dot{X} + K_i X$$

- Damping and spring force
- Theoretical optimal gains:

$$K_{p,opt} = B(\omega)$$

$$K_{i,opt} = \left(m + A(\omega)\right)\omega^2 - K_{hs}$$

- Reactive component requires input power



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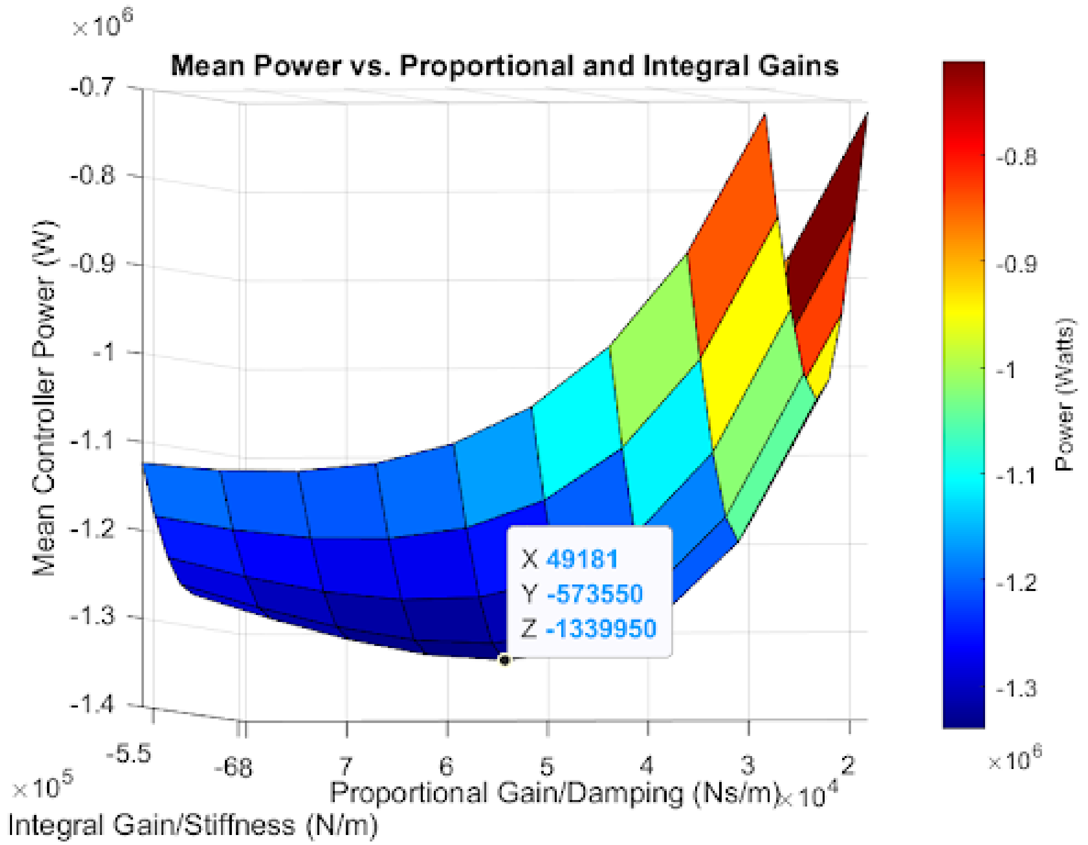


WEC Control – Latching

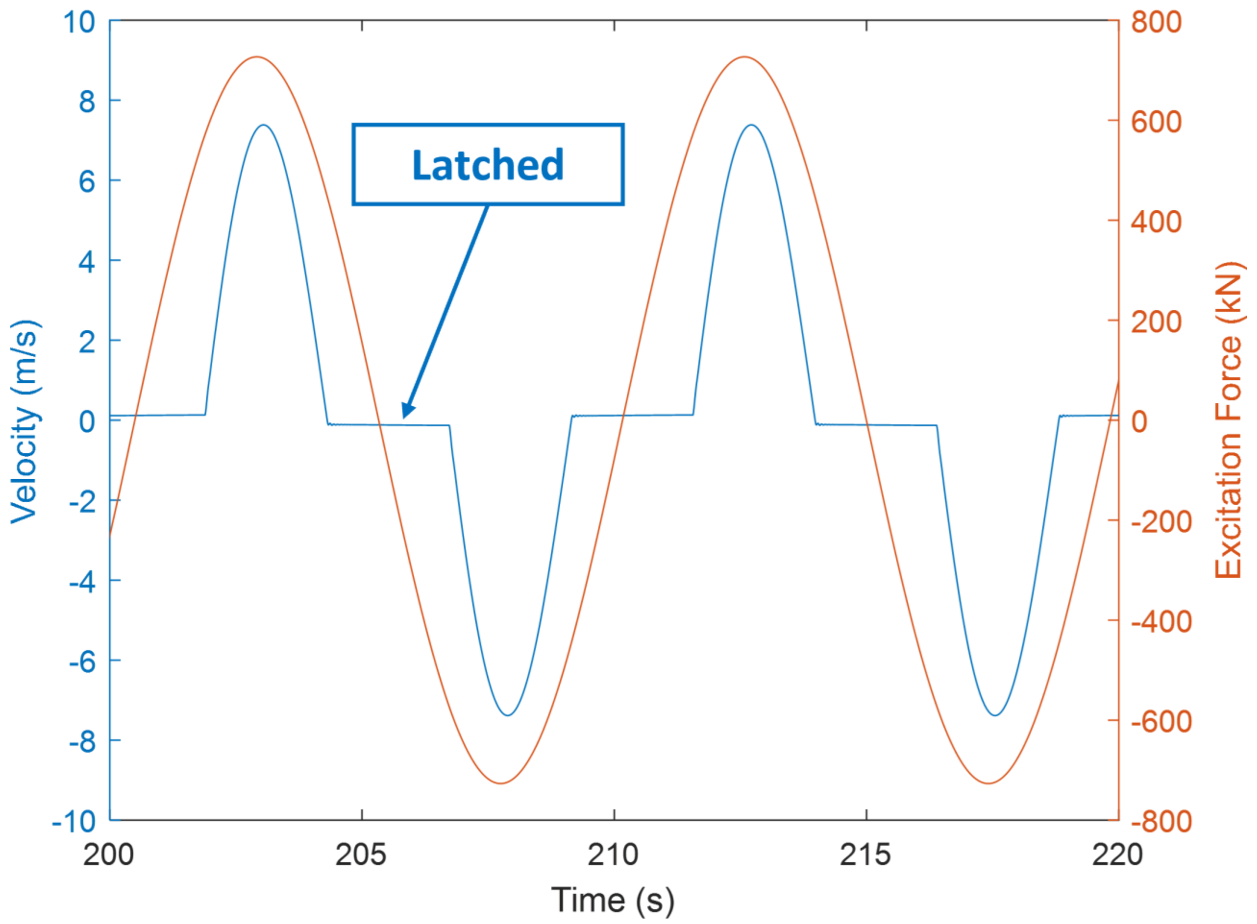
- Passive controller + locking device
- Braking force:

$$G = 80(m + A(\omega))$$

- Theoretical optimal latch time:

$$t_{latch} = \frac{1}{2}(T_{wave} - T_{nat})$$

- No input power required



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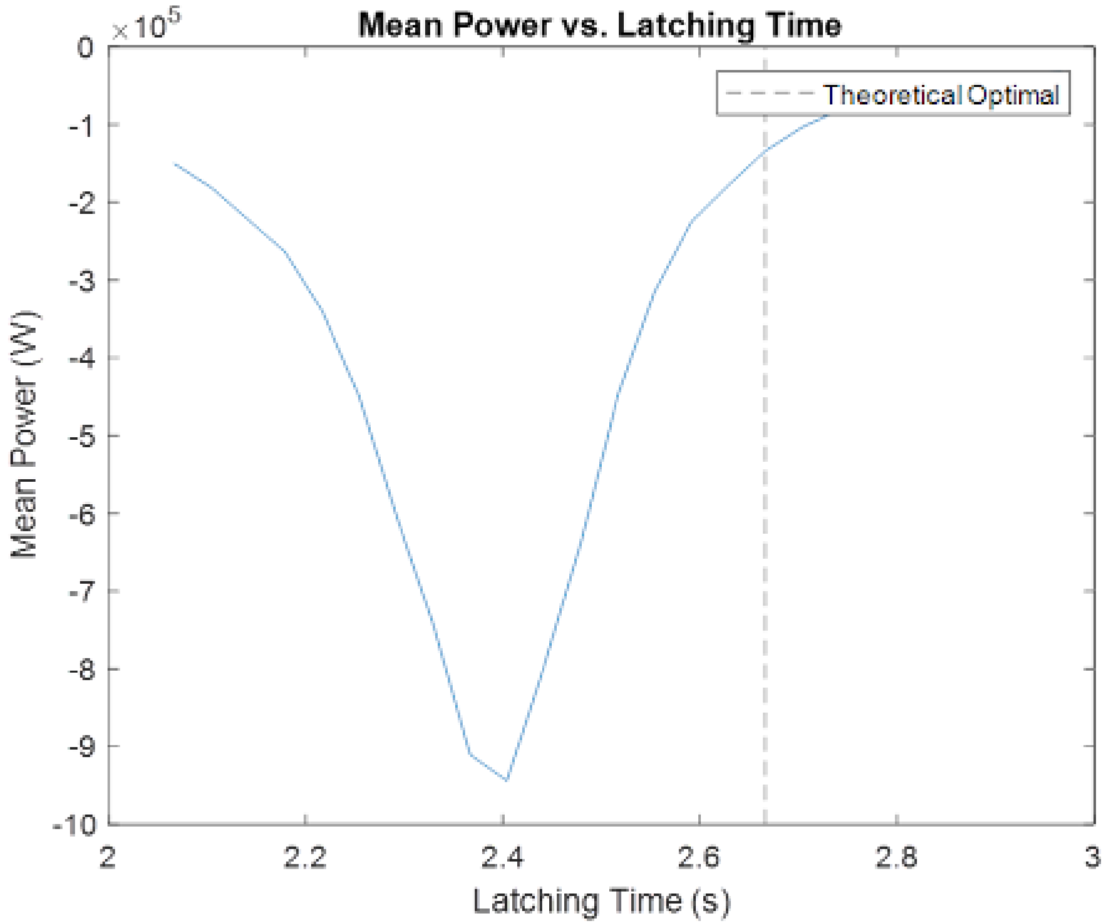
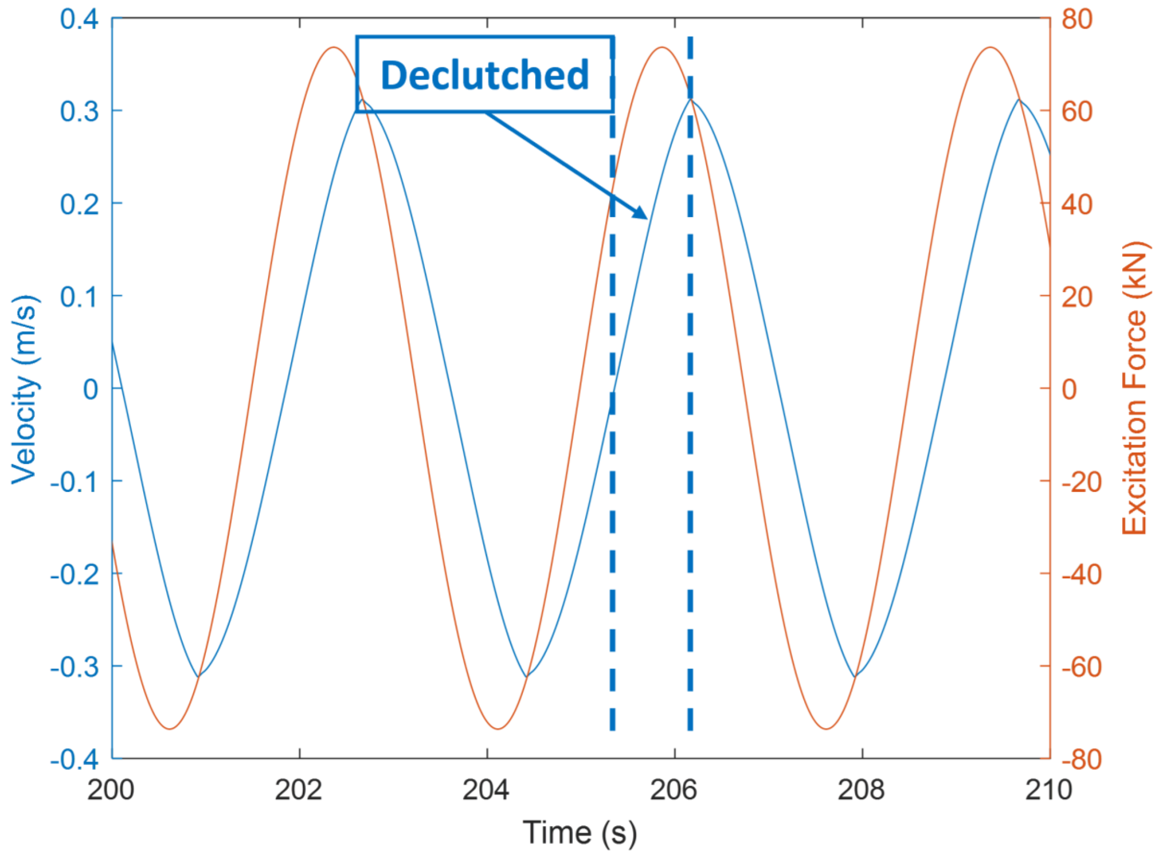


WEC Control – Declutching

- Passive controller + releasing device
- Allow device to move without damping force for part of oscillation
- Theoretical optimal declutch time:

$$t_{latch} = \frac{1}{2}(T_{nat} - T_{wave})$$

- No input power required



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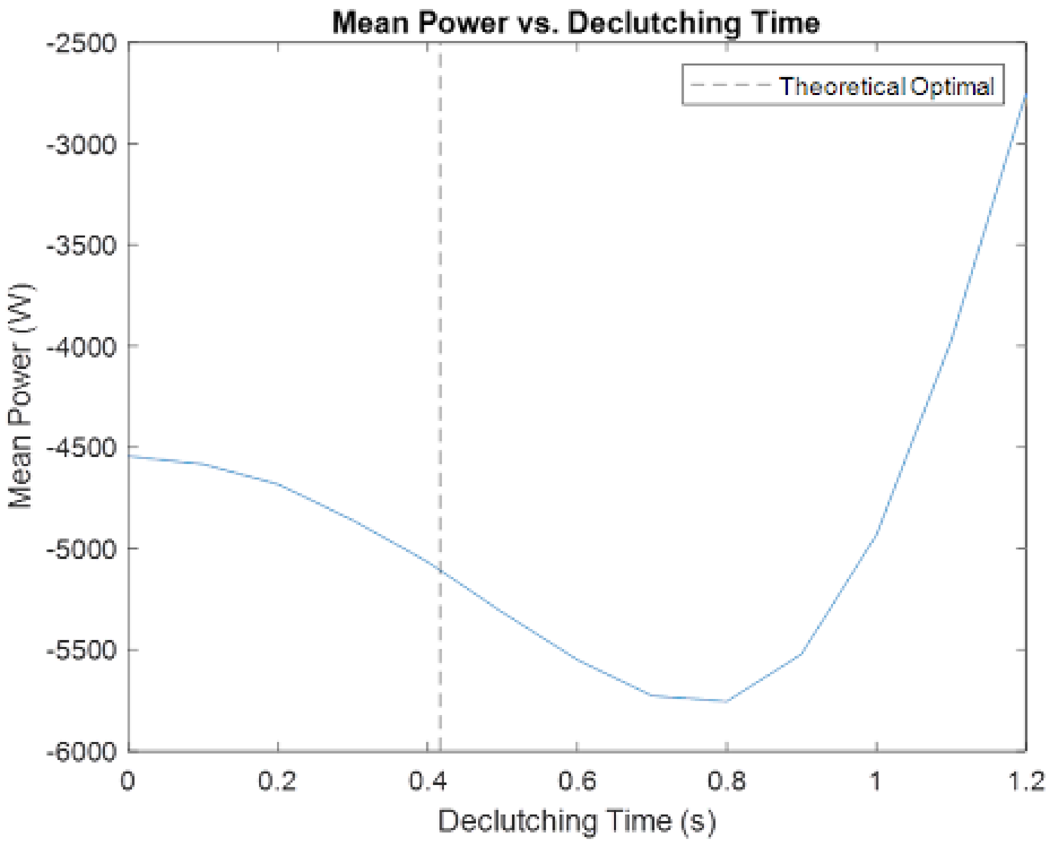
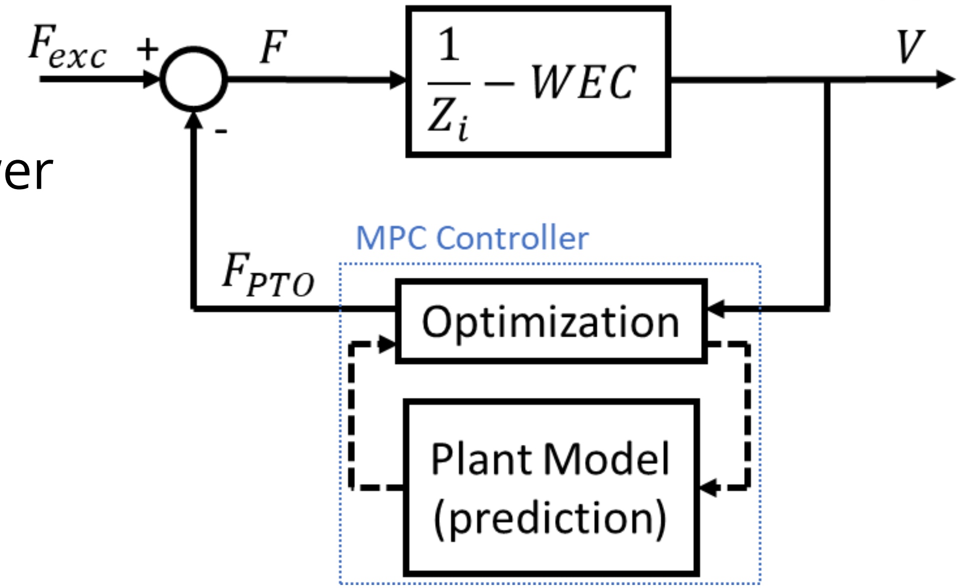
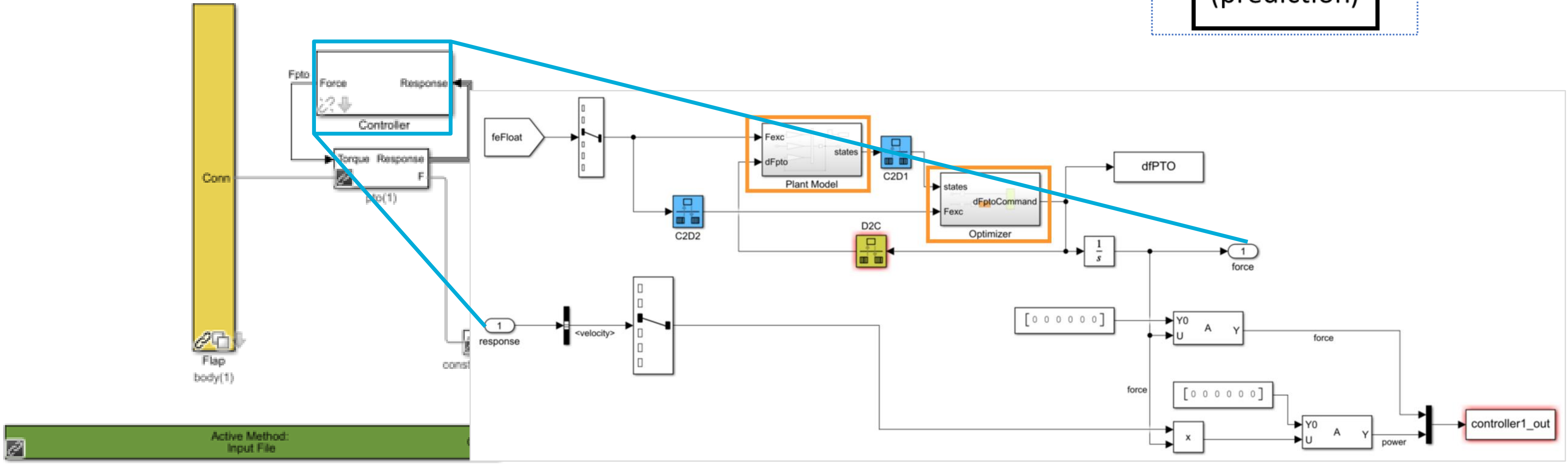


WEC Control – Model Predictive Control (MPC)

- Predicts and optimizes dynamics for maximum power
- State space plant model used to predict dynamics
- Quadprog() used to optimize for maximum power
- Can apply time-domain constraints





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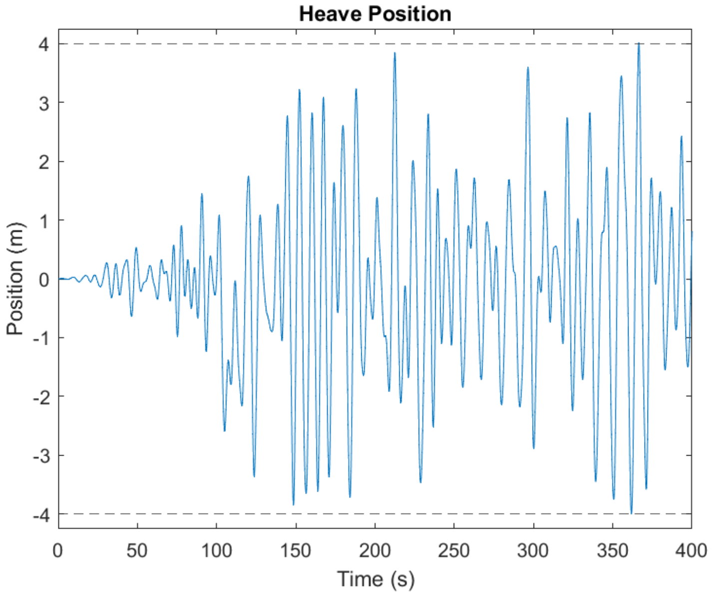
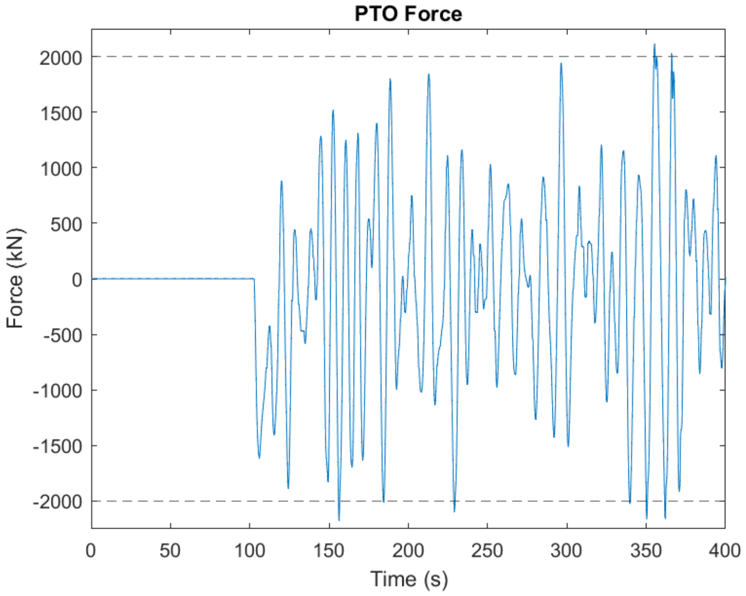
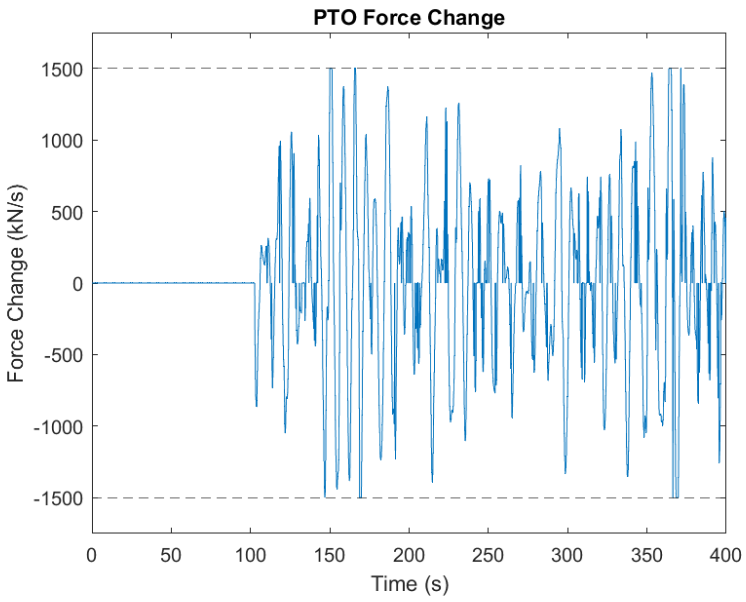
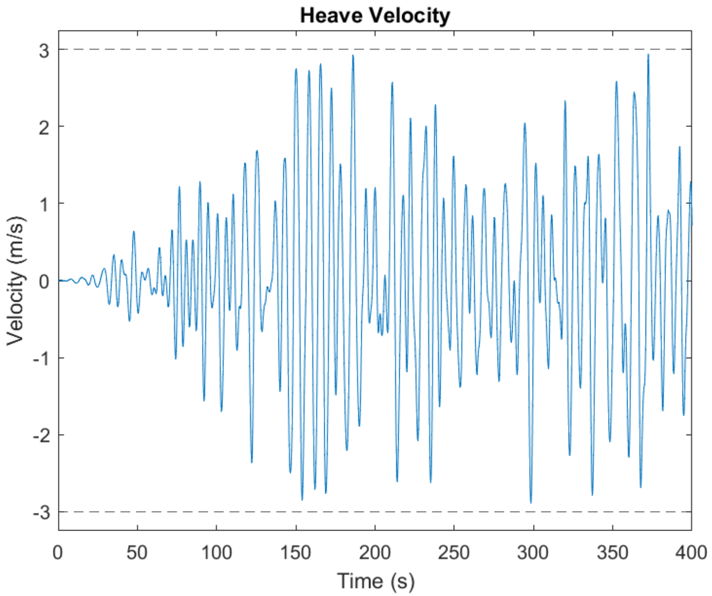






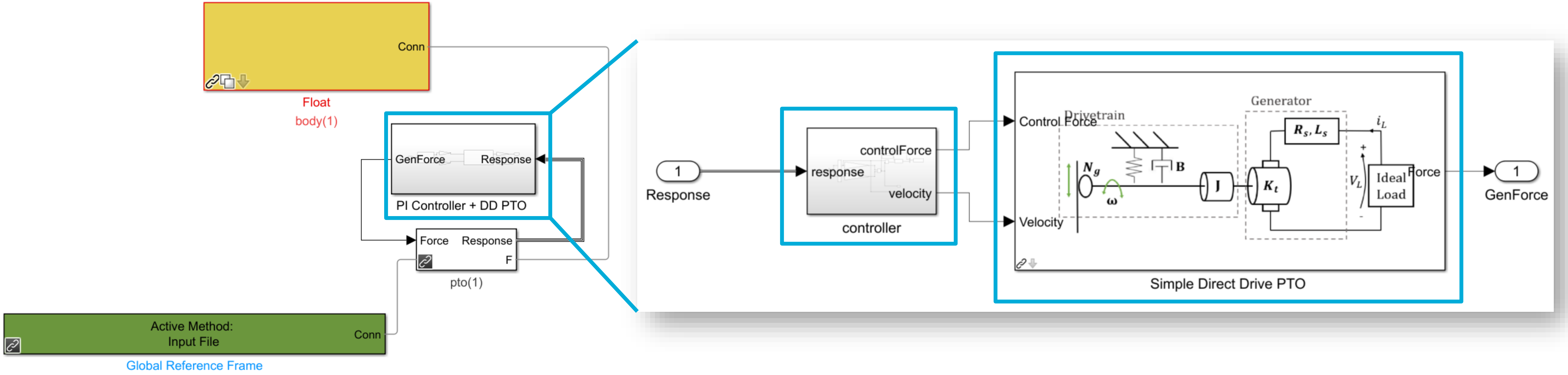


Parameter	*Constraint*	*MPC*	*Reactive*
Max Heave Position (m)	4	4.02	8.06
Max Heave Velocity (m/s)	3	2.95	5.63
Max PTO Force (kN)	2,000	2,180	4,630
Max PTO Force Change (kN/s)	1,500	1,500	3,230
Peak Mechanical Power (kW)	N/A	4,870	13,700
Avg Mechanical Power (kW)	N/A	300	241

WEC Control – Integration with PTO-Sim

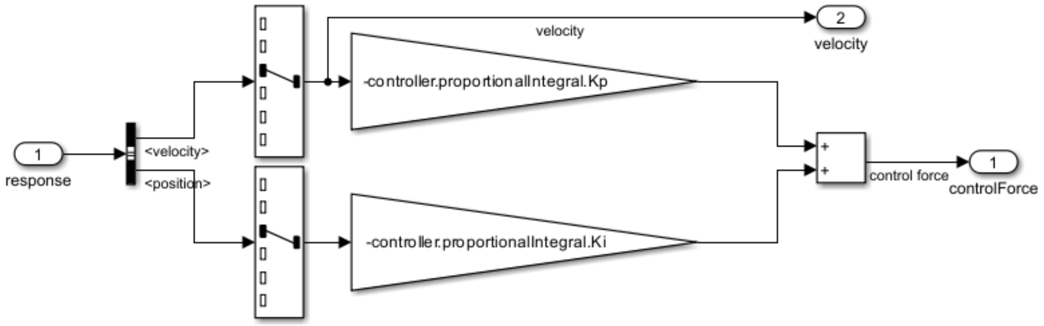
- Effective WEC control NEEDS to be linked with a power take-off system to calculate electrical power
- Optimal mechanical power ≠ optimal electrical power
- Complex conjugate control often leads to conditions that are inefficient for PTO power extraction

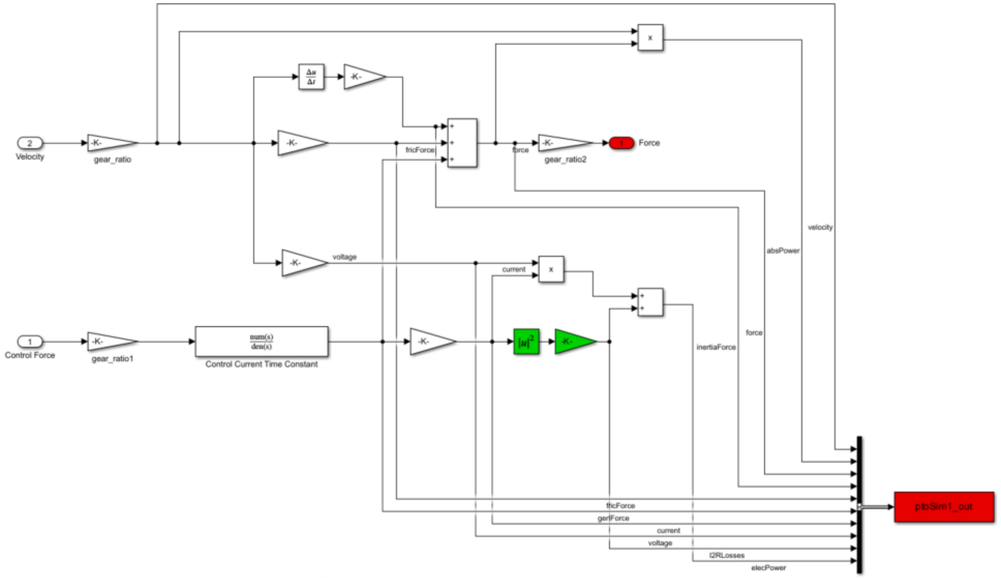
- Controller determines desired force which is fed into PTO to apply force and calculate electrical power



WEC Control – Integration with PTO-Sim

Reactive controller + simplified direct drive PTO





PTO Parameters		
Parameter	**Value**	**Unit**
Torque Constant (Kt)	7.186	Nm/A
Gear Ratio (N)	100	
Inertia (J)	2	kg/m^2
Mechanical Shaft Damping (B)	1	Nms
Resistance (R)	0.483	Ω
Inductance (L)	5.223	mH

Allied Motion Megaflux™ Frameless Direct Drive Torque Motors

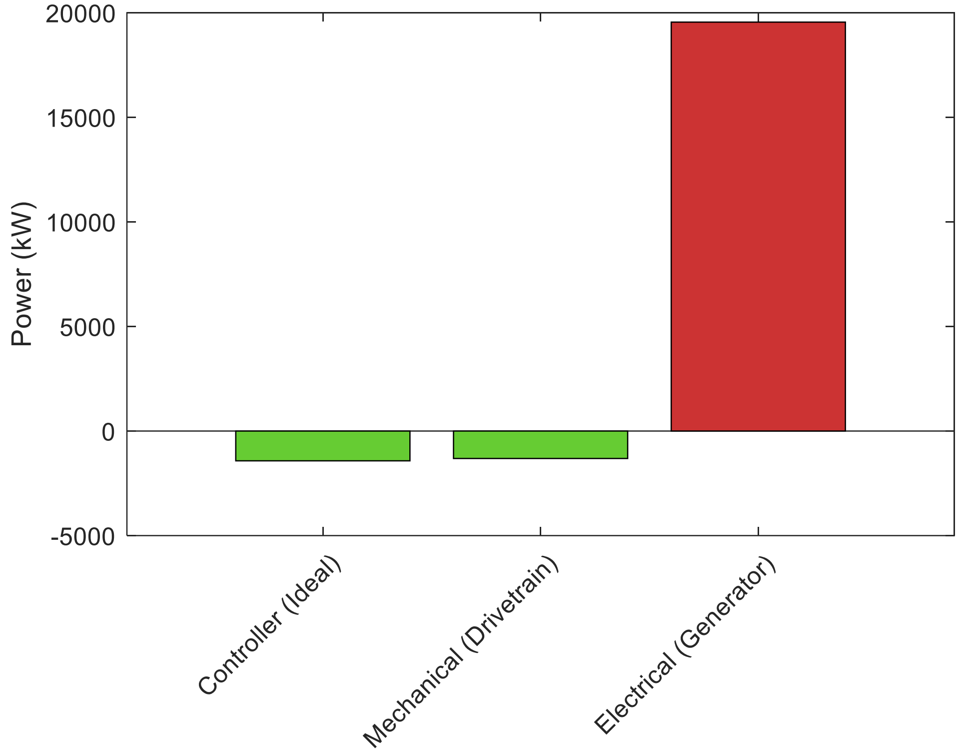
https://www.alliedmotion.com/d/?h=1e48f0c

WEC Control – Integration with PTO-Sim

- Maximization of mechanical power (aka complex conjugate control) requires significant input electrical power
- Kp = 49,200 N/m, Ki = -573,000 Ns/m

Note: negative power is power harvested

Component	Power (kW)
Controller (Ideal)	**-1,400**
Mechanical (Drivetrain)	**-1,300**
Inertia	0
Damping	300
Generator Mechanical	-1,600
Electrical (Generator)	**19,600**
Current*Voltage	-1,600
Electrical Power Loss (I^2*R)	21,200

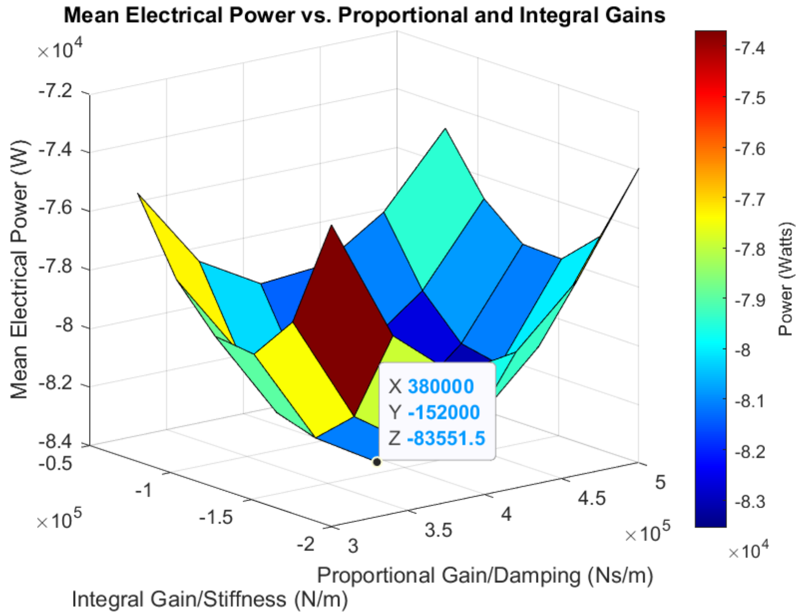


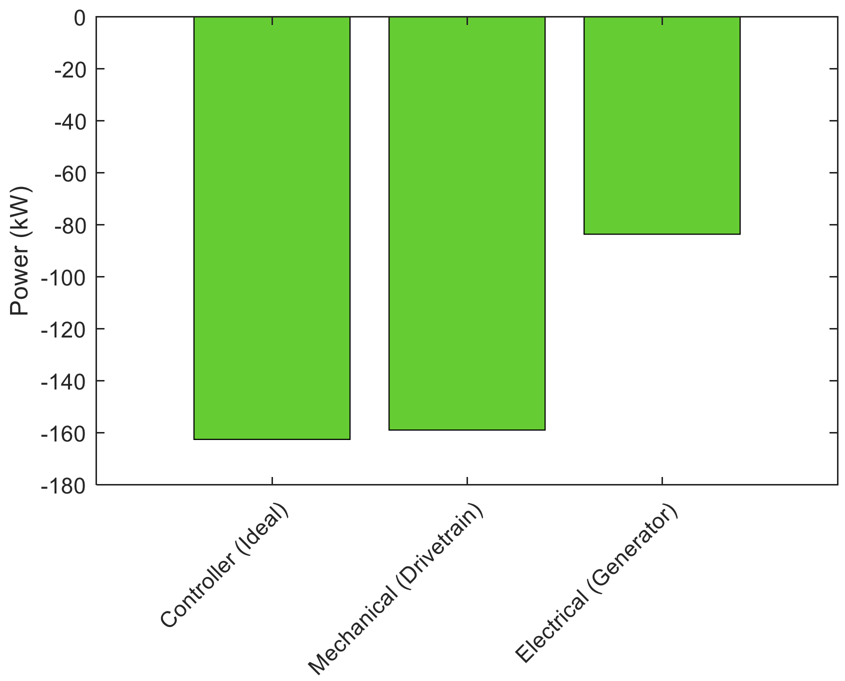
WEC Control – Integration with PTO-Sim

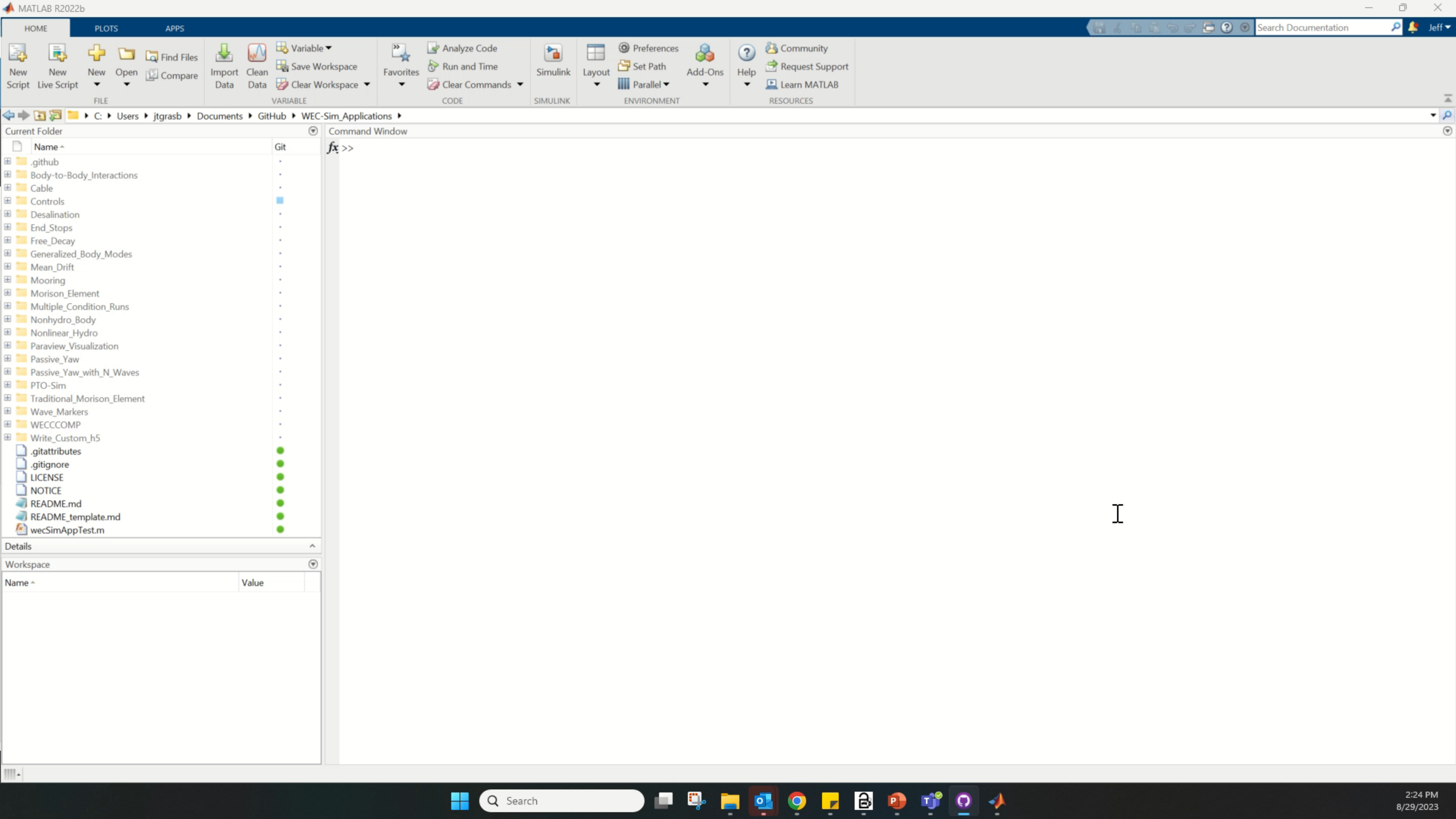
- Larger proportional (Kp) and smaller integral (Ki) gains support optimal electrical power
- Kp = 380,000 Ns/m, Ki = -152,000 N/m

Note: negative power is power harvested

Component	Power (kW)
Controller (Ideal)	**-162**
Mechanical (Drivetrain)	**-159**
Inertia	0
Damping	4
Generator Mechanical	-163
Electrical (Generator)	**-84**
Current*Voltage	-163
Electrical Power Loss (I^2*R)	80



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README_template.md
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Thank you

For more information please visit the WEC-Sim website:

http://wec-sim.github.io/WEC-Sim

If you have questions on this presentation please reach out to any of the WEC-Sim Developers on GitHub:

https://github.com/WEC-Sim/WEC-Sim

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