MDOcean: an Open-Source Software for Efficient Simulation and Optimization of WECs

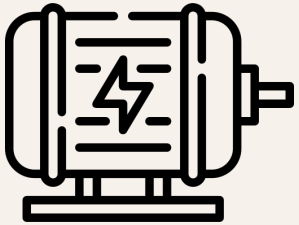
Rebecca McCabe, Madison Dietrich, Maha Haji

Symbiotic Engineering and Analysis Laboratory, Cornell University

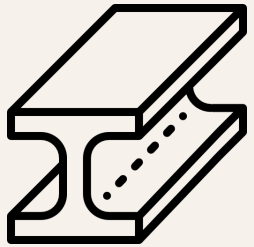
Wave Energy Converters are Multidisciplinary

Geometry

Hydrodynamics



Dynamics & Control



Structures

Economics

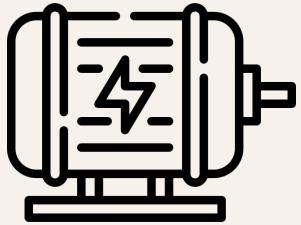
Problem 1: high computation time to optimize many interacting subsystems

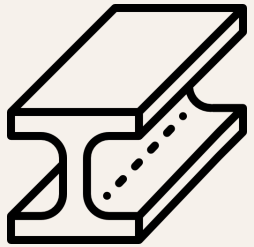
Solution 1: semi-analytical models, clever optimization formulation

Wave Energy Converters are Multidisciplinary

Geometry

Hydrodynamics


Dynamics & Control


Structures

Economics

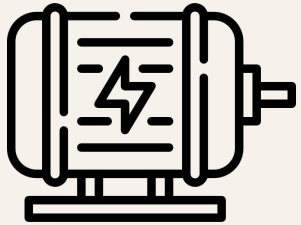
Problem 2: high uncertainty in cost model

Solution 2: multi-objective optimization and sensitivity analysis

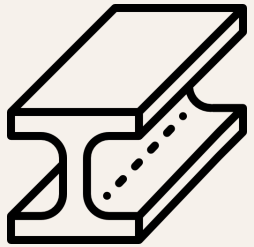
Wave Energy Converters are Multidisciplinary

Geometry

Hydrodynamics



Dynamics & Control



Structures

Economics

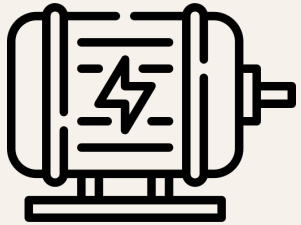
Problem 3: lack of replicability and comparison between models and designs

Solution 3: open source software with benchmarks, end-to-end tests, and CI

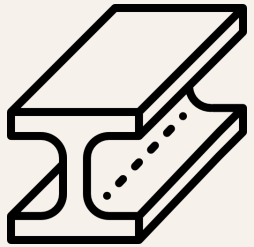
Wave Energy Converters are Multidisciplinary

Geometry

Hydrodynamics



Dynamics & Control



Structures

Economics

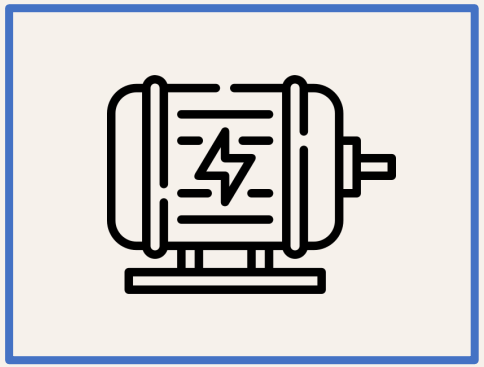
Matched Eigenfunction Expansion Method leverages cylindrical symmetry

Semi-analytical: complex derivation, fast execution

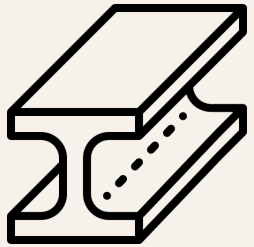
Wave Energy Converters are Multidisciplinary

Geometry

Hydrodynamics



Dynamics & Control



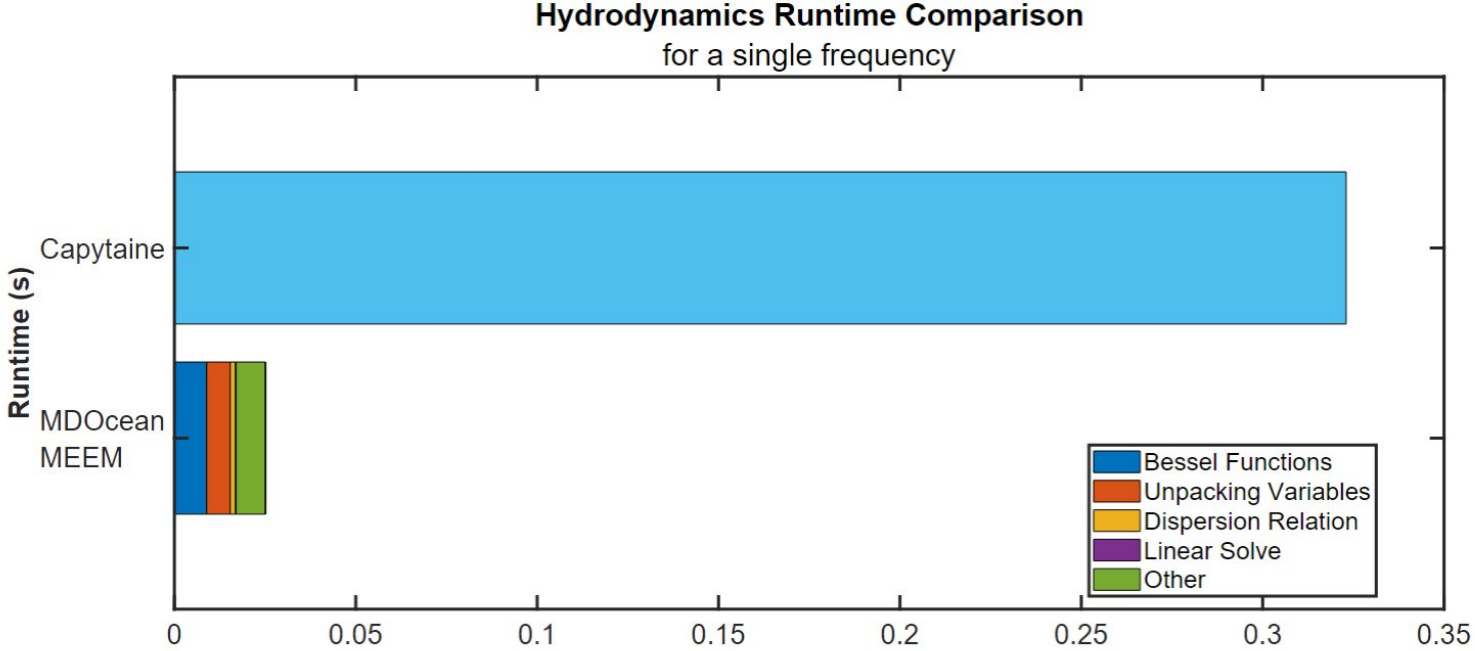
Structures

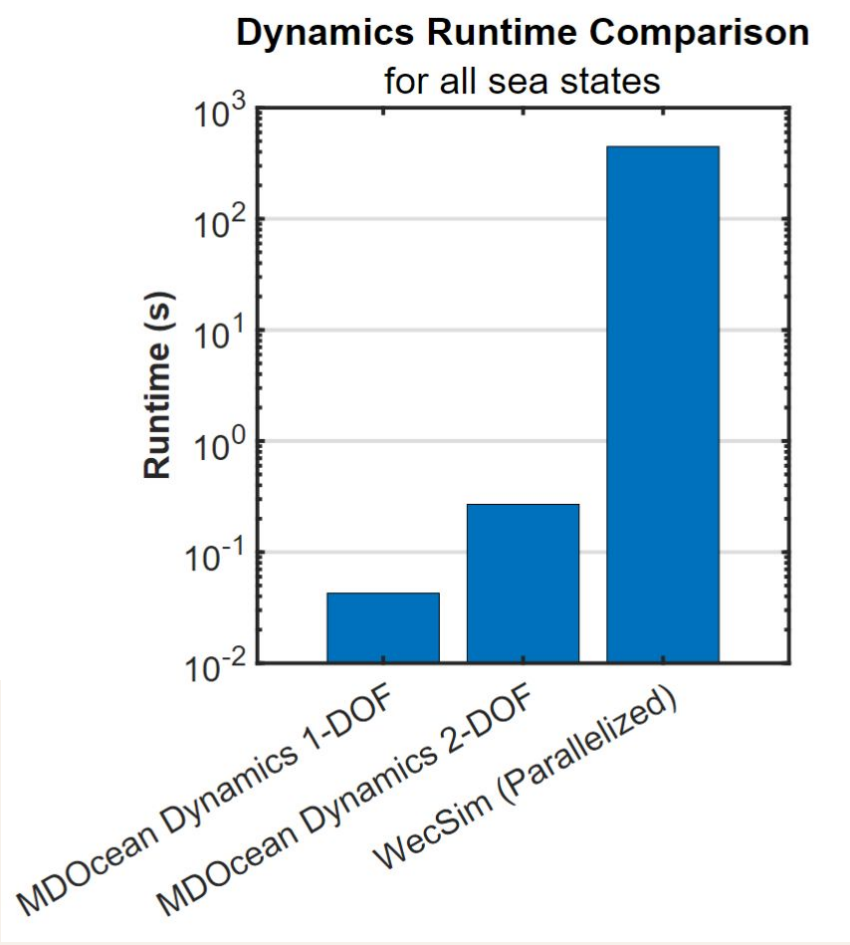
Economics

Quasi-linearize drag and saturation nonlinearities with **describing functions**

Solve in **frequency domain** while accounting for time domain peaks

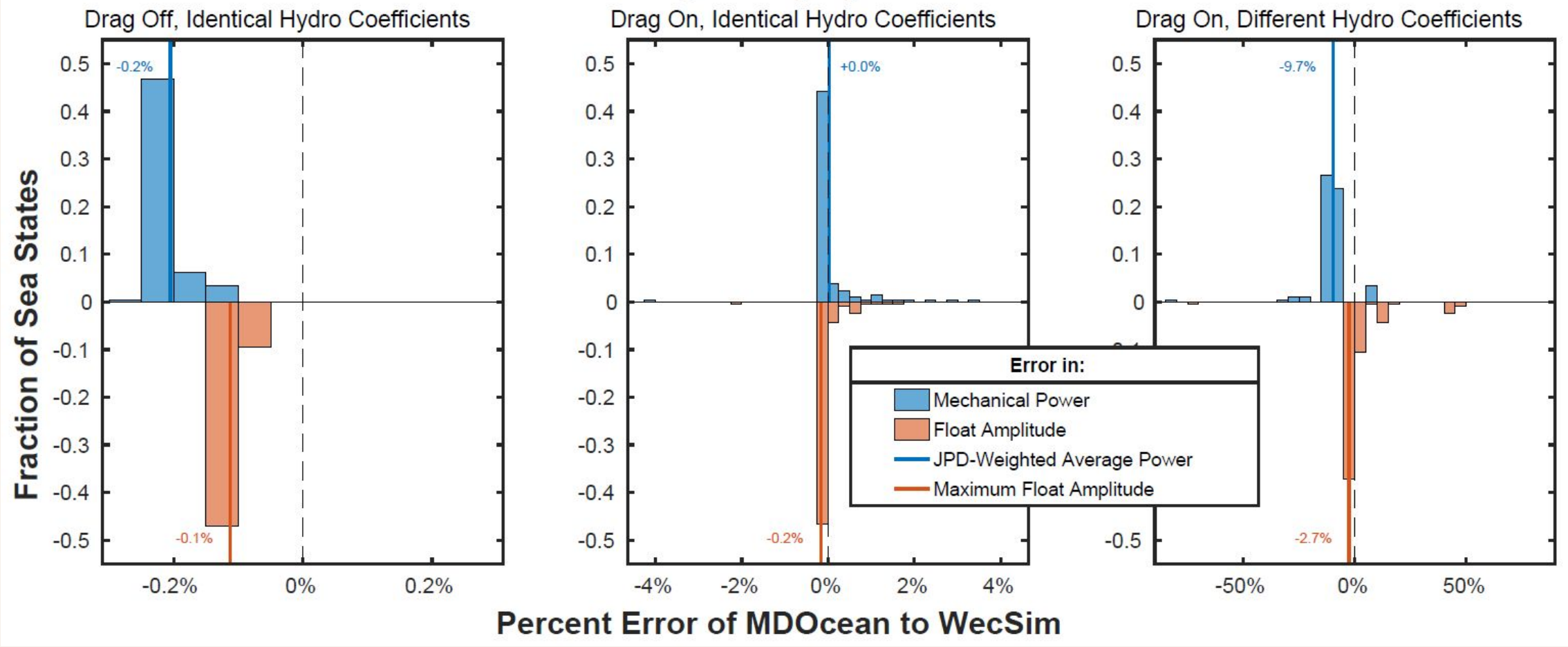
Both Models Achieve Significant Speedup





10x faster hydro, 1000x faster dynamics

Both Models are Accurate within 10%



Clever Optimization Formulation

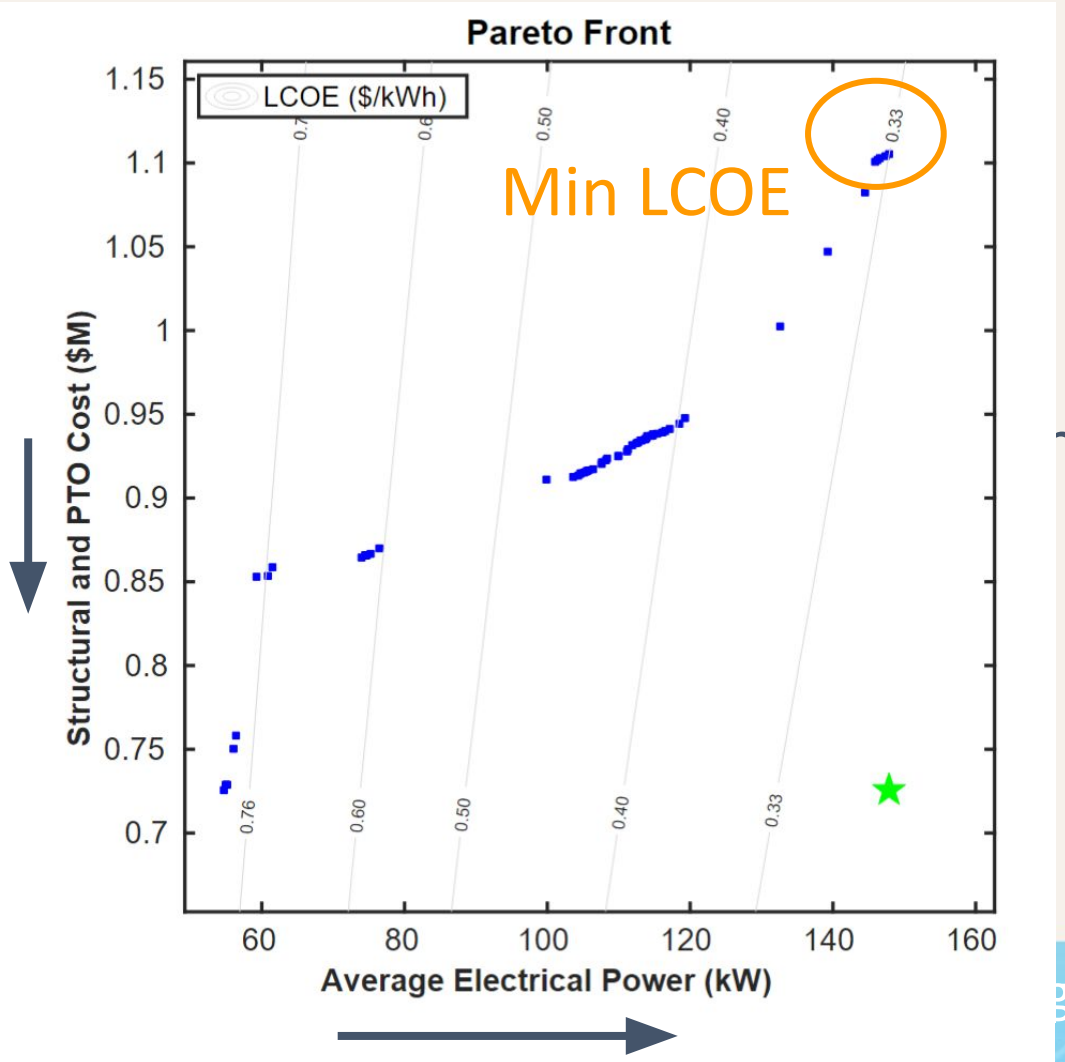
Prioritize requirements by model validity

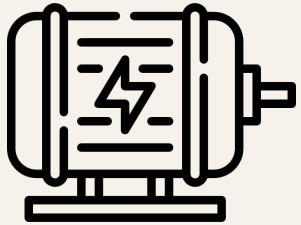
Enforce high-priority requirements with **bounds or linear constraints**

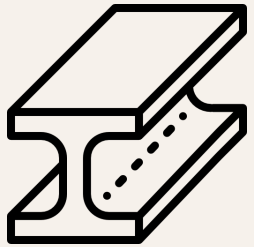
Automatic design variable scaling to keep hessian well-conditioned

Epsilon-constraint seeds to leverage gradients in multi-objective

Pareto Analysis to Address Economic Uncertainty



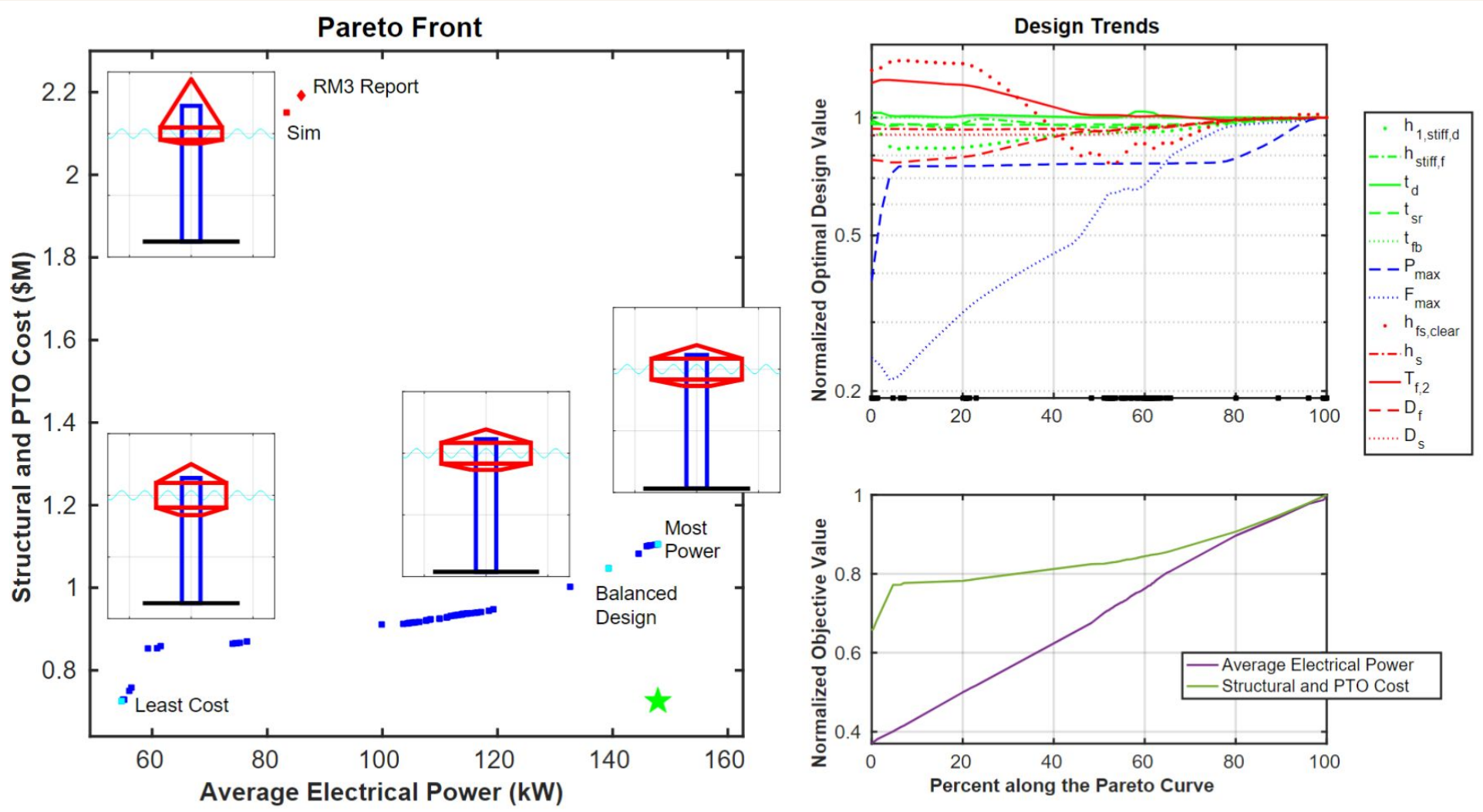




namics & Control Structures Economics

- Pareto front of structures + PTO cost vs average power (with LCOE contours)
- Visualize effect of changing constant cost and fixed charge rate

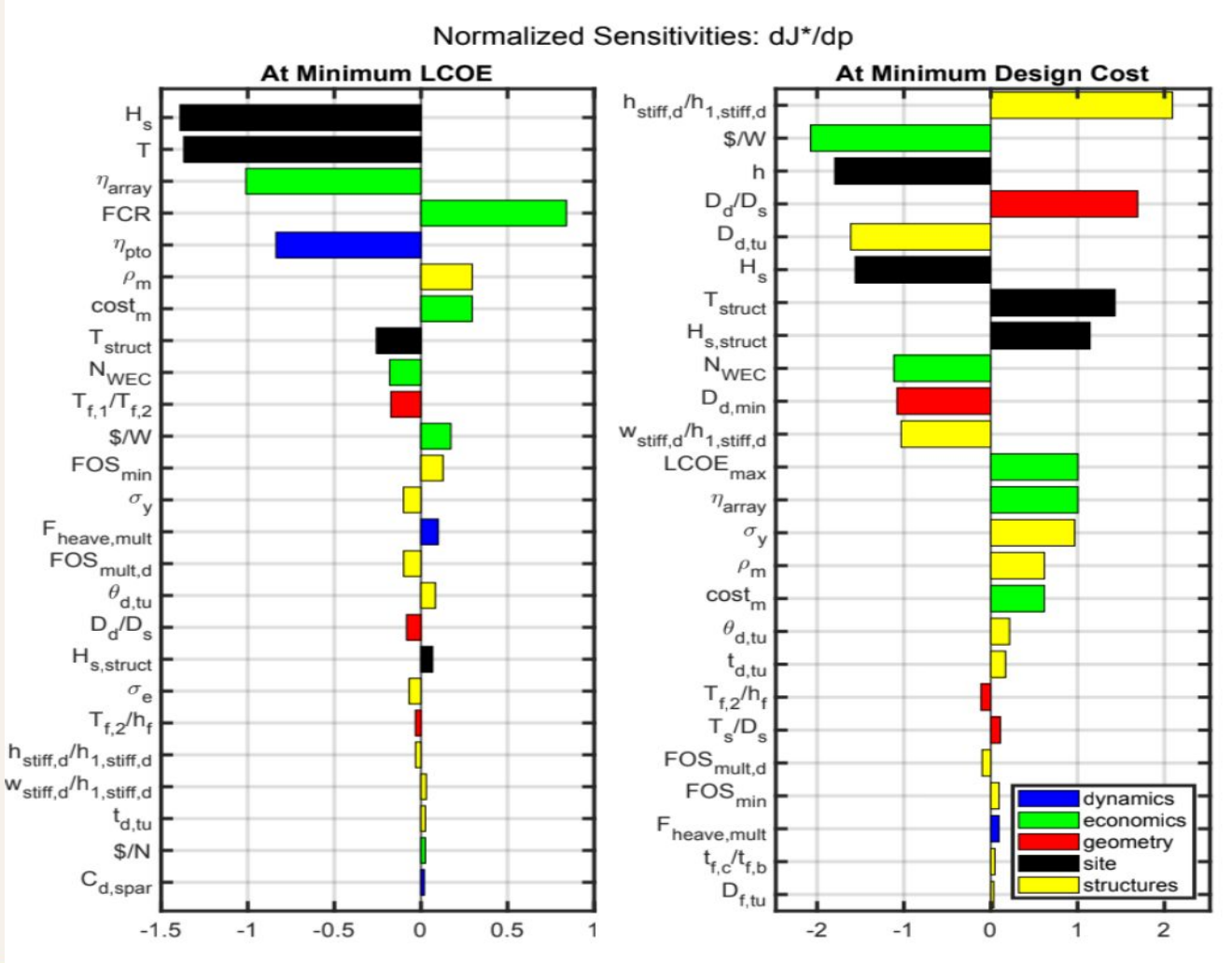
Pareto Analysis to Address Economic Uncertainty



Min LCOE design:

- 57% lower LCOE
- 37% lower structural / powertrain cost
- 89% higher power

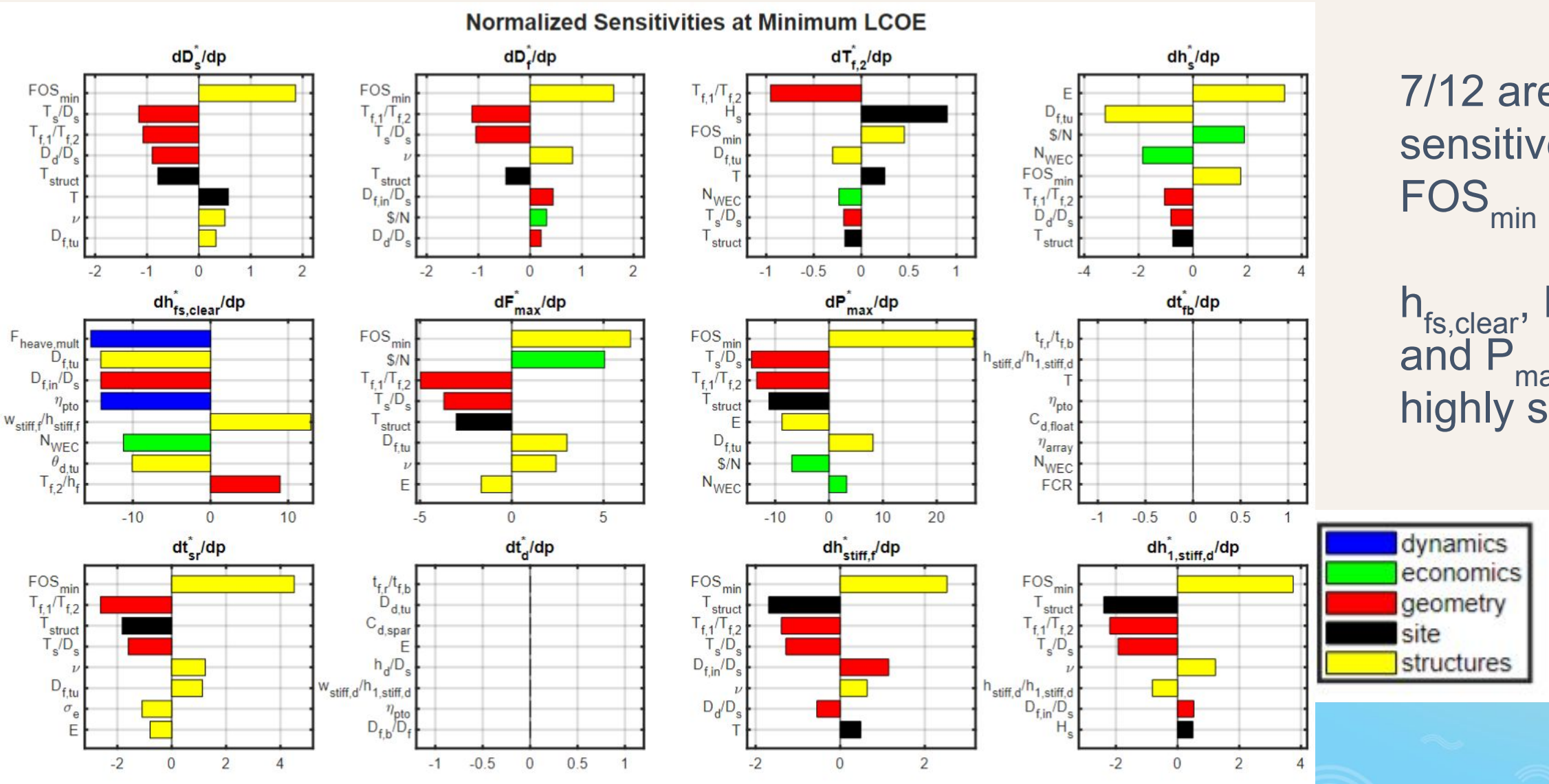
Sensitivity Analysis to Address Economic Uncertainty



H_s and T_{struct} (site wave conditions) are in top 10 for both objectives

Most sensitive parameter is structural in both cases

Sensitivity Analysis to Address Economic Uncertainty



7/12 are most sensitive to FOS_{min}

$h_{fs,clear}$, F_{max}, and P_{max} are highly sensitive

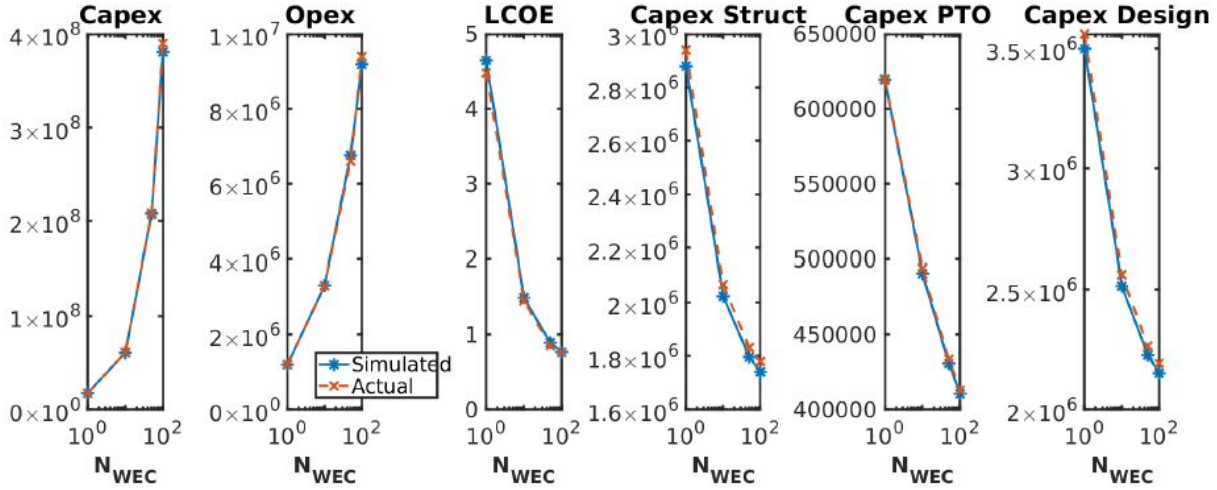
End to End Tests for Benchmark Comparison

validateNominalReport
Test Parameters: field_report=LCOE, rel_tol_report=0.25_2

The test passed.
Duration: 0.6740 seconds

Event:
Verification passed.
Test Diagnostic:

```
Figure saved to:
--> /home/becca/Documents/git/actions-runner/_work/MDOcean/MDOcean/MDOcean/test-results/2025-04-25_12.46.53/dfcb388c-bc25-4cc0-9161-a2f449c17929/econ_validation_report1afc1974-3169-4d25-be89-4c5f34f8b680.fig
--> /home/becca/Documents/git/actions-runner/_work/MDOcean/MDOcean/MDOcean/test-results/2025-04-25_12.46.53/dfcb388c-bc25-4cc0-9161-a2f449c17929/econ_validation_report1afc1974-3169-4d25-be89-4c5f34f8b680.png
```

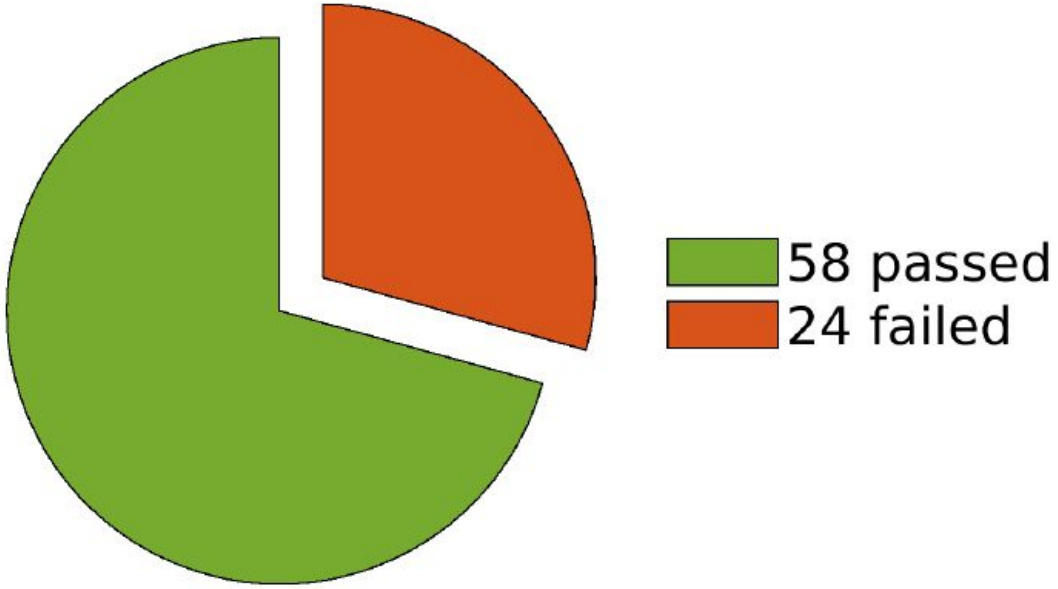


Framework Diagnostic:

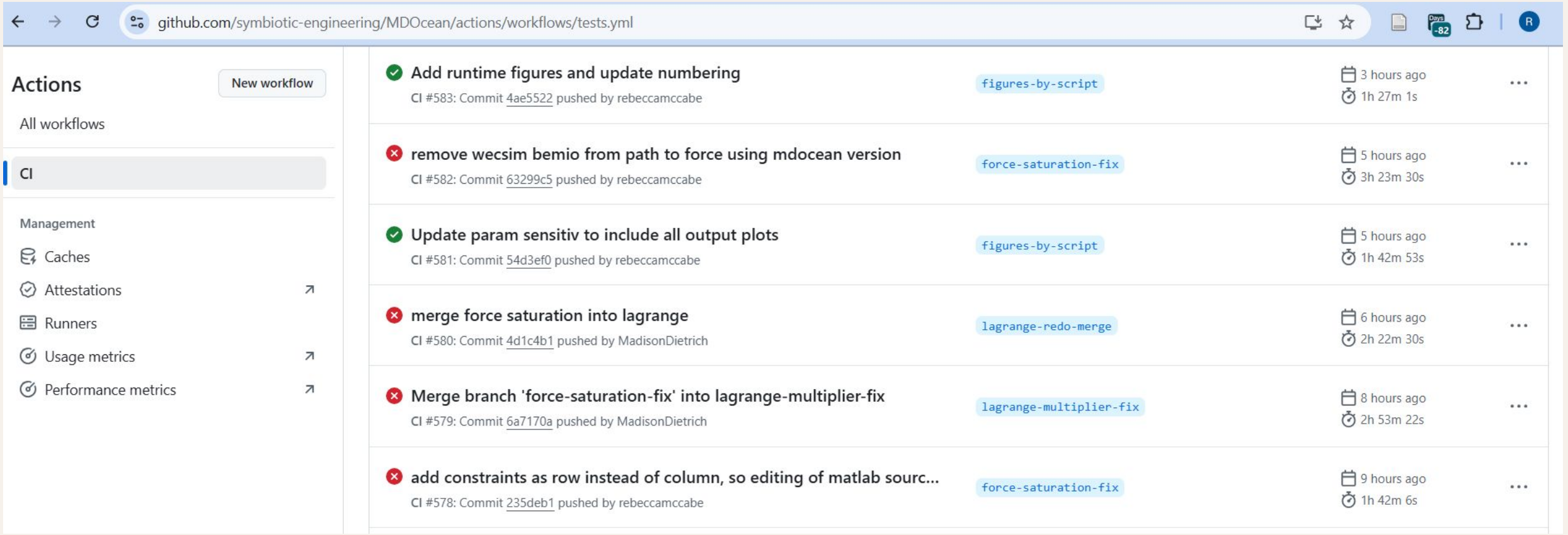
```
verifyEqual passed.
--> The error was within relative tolerance.

Actual Value:
   4.647303820626163   1.492688733308334   0.890516519108912   0.767758969576778
Expected Value:
   4.480000000000000   1.450000000000000   0.850000000000000   0.760000000000000
```

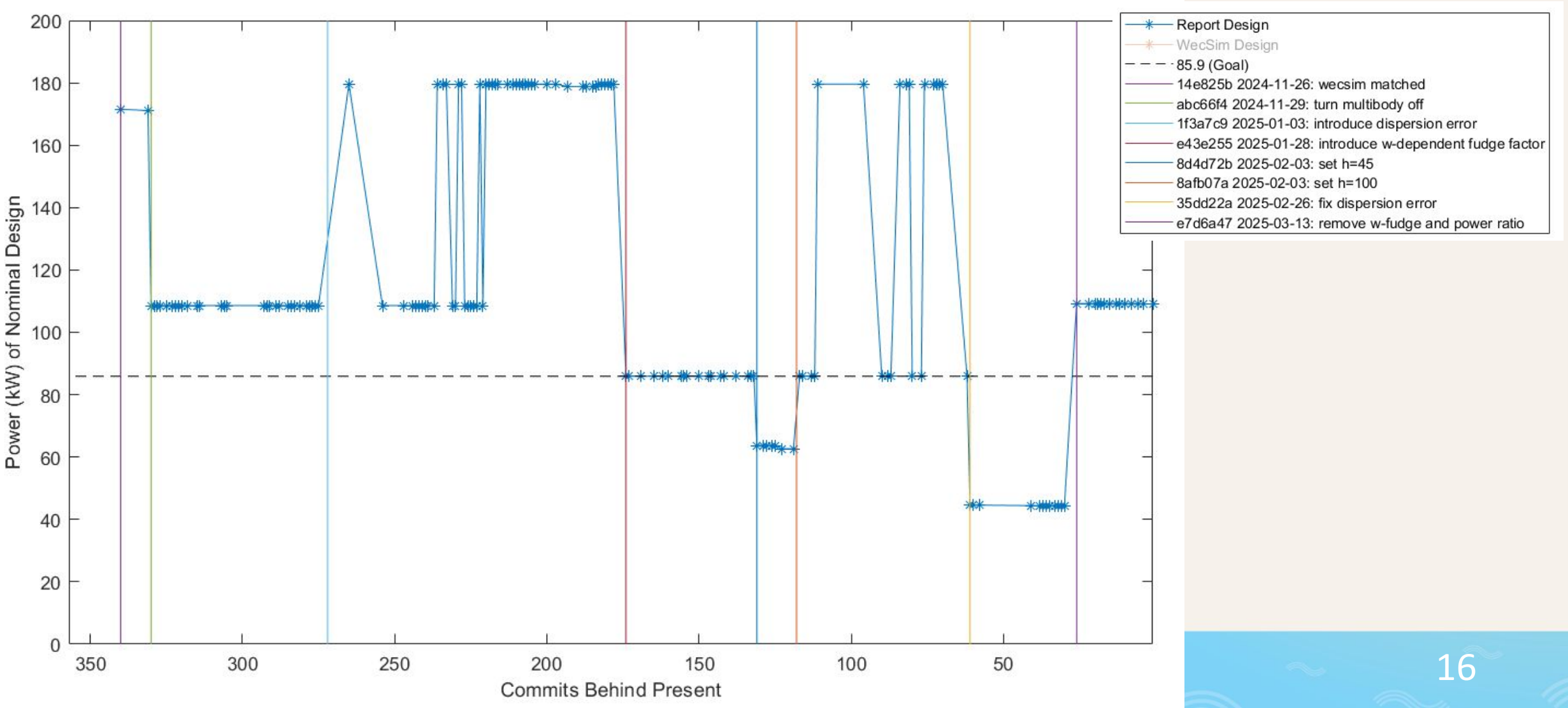
Comparison against **WEC-Sim** and **reference model report** facilitates validation and direct comparison of optimized designs



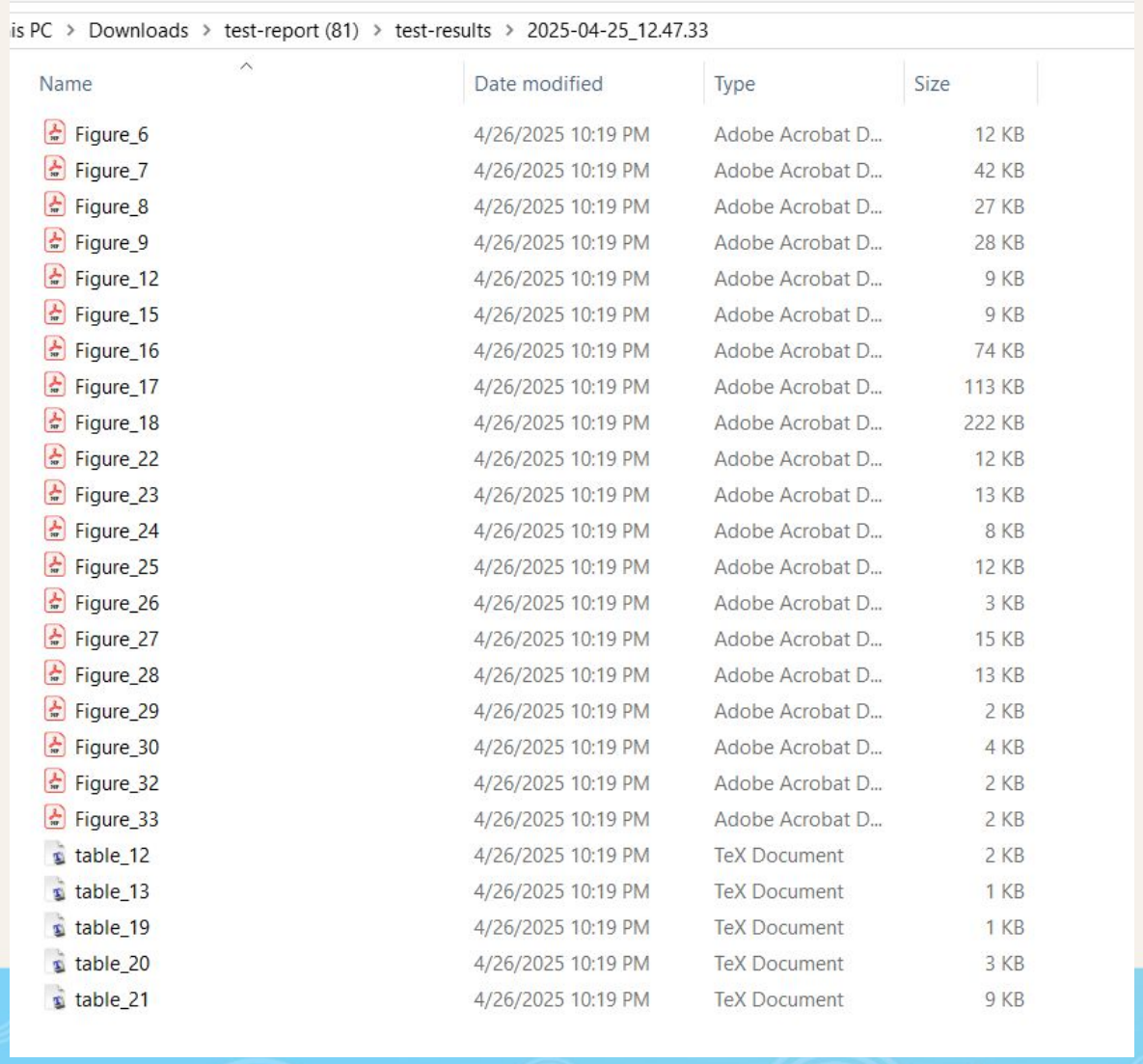
Continuous Integration to Catch Problems Early



Continuous Integration to Catch Problems Early



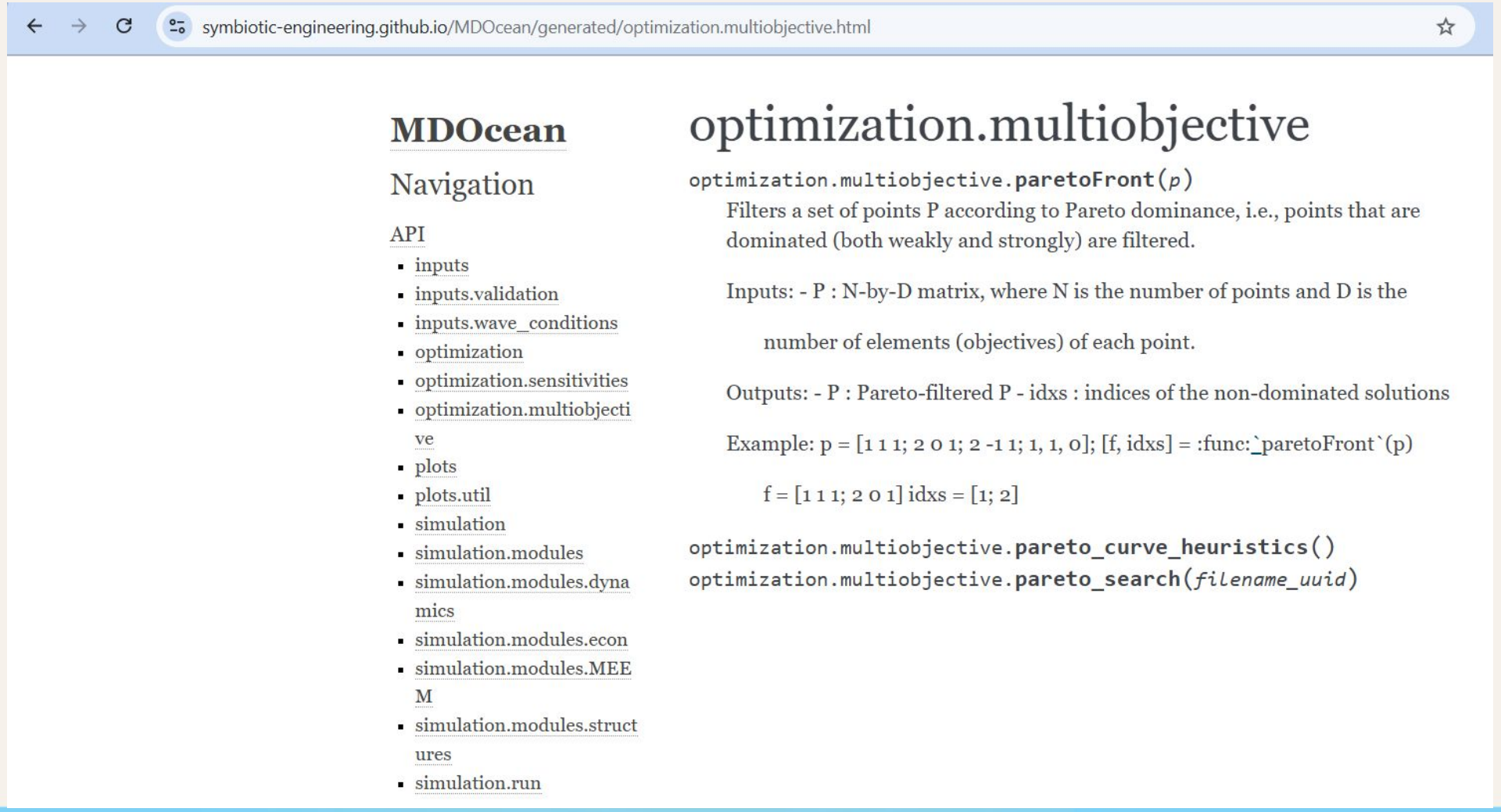
Automatic Figure/Table Generation




```
table2latex(tab5,[save_folder 'table_19.tex'])
```

Calkit: one-click reproducibility with environment replication and caching

Sphinx Documentation



Encourage use by other researchers and WEC developers

Summary: Careful Decisions Everywhere Add Up

1: Semi-analytical models and clever formulation decrease computation time

2: Multi-objective optimization and sensitivity analysis mitigate cost uncertainty

3: Open source software with benchmarks, tests, and CI facilitates consistency

Thank You

SEA Lab
Symbiotic Engineering and Analysis Lab

McCabe, Dietrich, & Haji, 2025. “Semi-Analytical Modeling of Wave Energy Converters.” In prep for submission to Applied Ocean Research.

McCabe, Dietrich, & Haji, 2025. “Leveraging Multidisciplinary Design Optimization to Advance WEC Viability.” In prep for submission to Renewable Energy.

This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE–2139899. Any opinion, findings, and conclusions or recommendations expressed in this material are those of the authors(s) and do not necessarily reflect the views of the National Science Foundation.

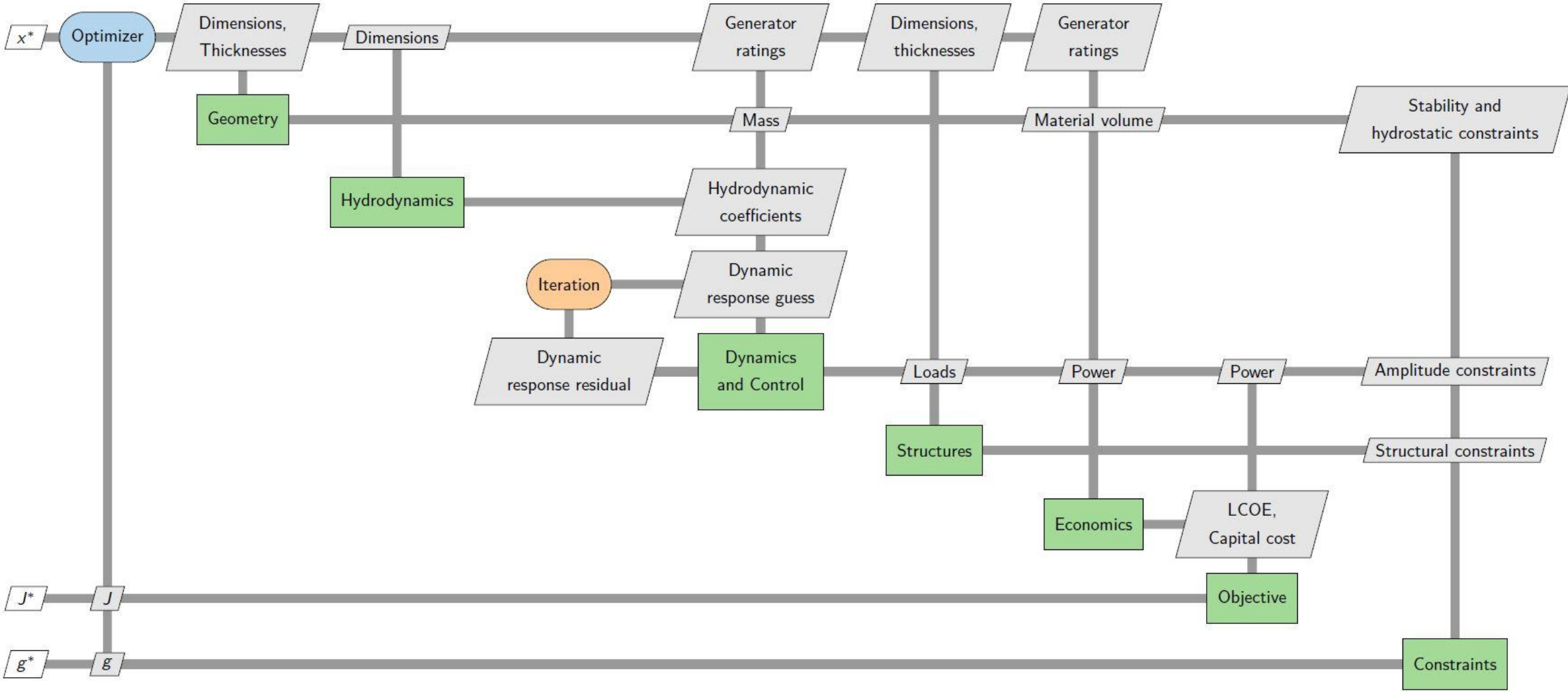
Connect

- github.com/symbiotic-engineering/MDOcean MATLAB version
- github.com/symbiotic-engineering/WEC-DECIDER Python version in progress
- Code is open-source and user-friendly!

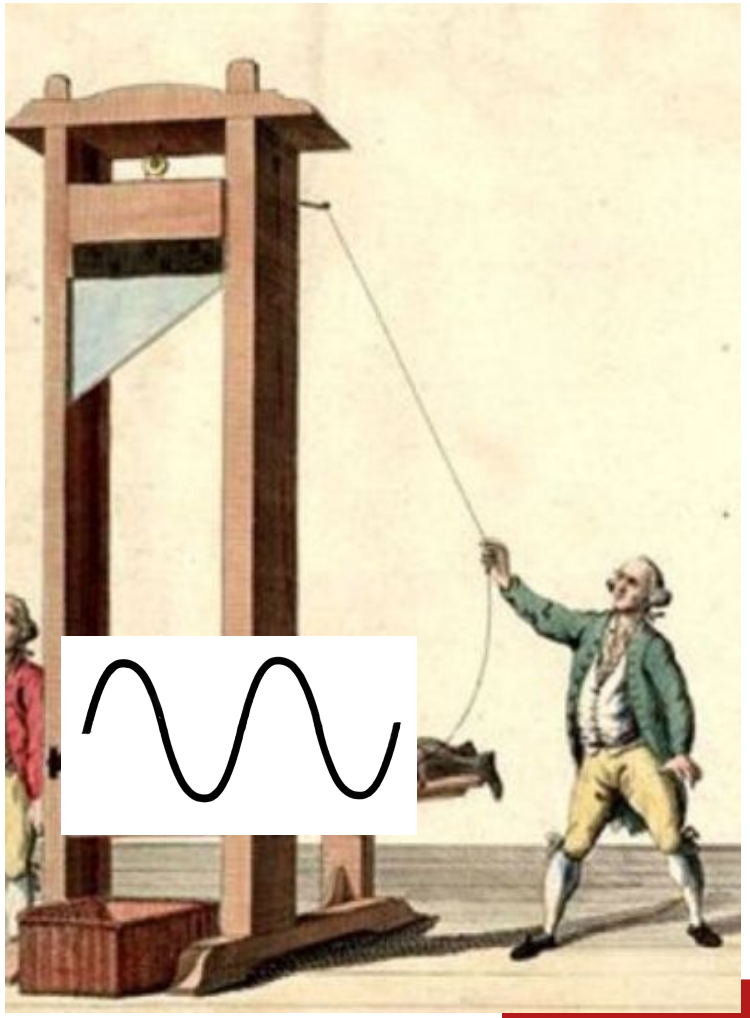
GitHub link

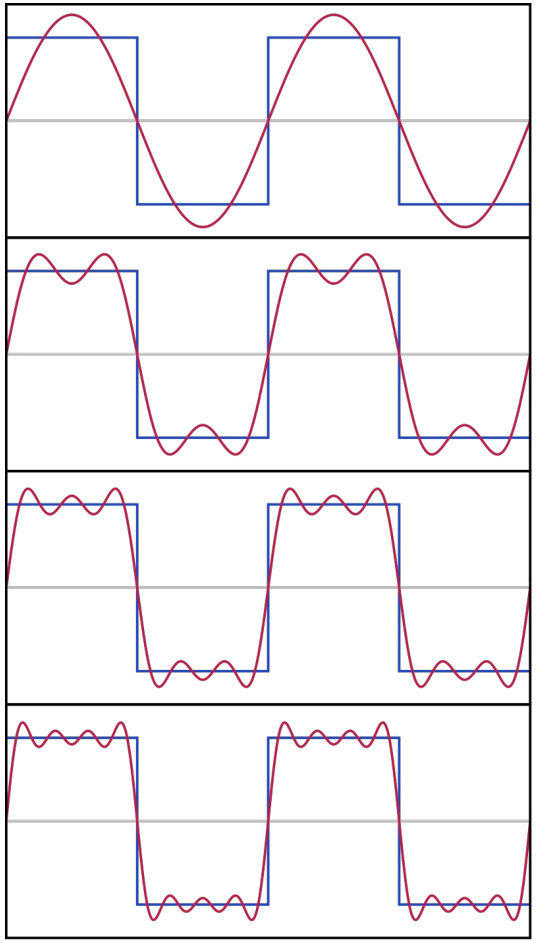
Draft paper link

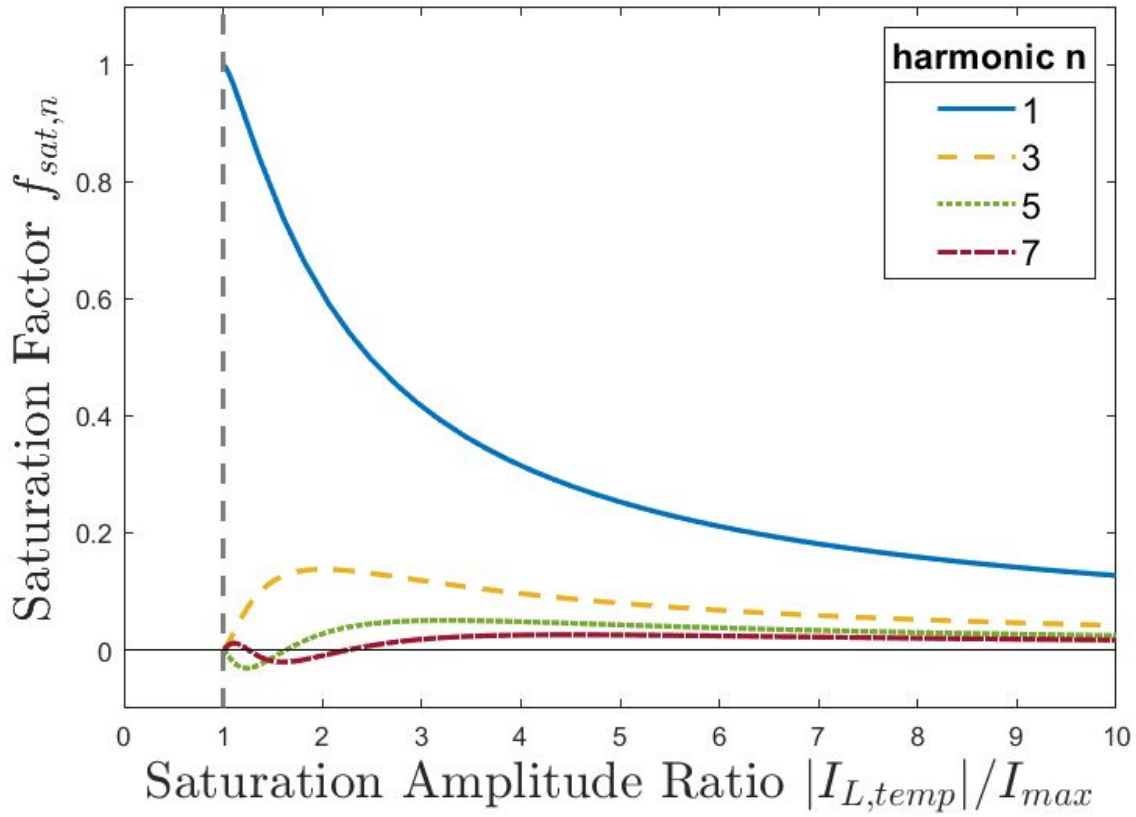
Rebecca McCabe
Final-year PhD student seeking next role
Symbiotic Engineering and Analysis Lab
Cornell University
rgm222@cornell.edu


x^*
Optimizer
Dimensions, Thicknesses
Dimensions
Generator ratings
Dimensions, thicknesses
Generator ratings
Geometry
Mass
Material volume
Stability and hydrostatic constraints
Hydrodynamics
Hydrodynamic coefficients
Iteration
Dynamic response guess
Dynamic response residual
Dynamics and Control
Loads
Power
Power
Amplitude constraints
Structures
Structural constraints
Economics
LCOE, Capital cost
J^*
J
Objective
g^*
g
Constraints

The Saturated Sinusoid

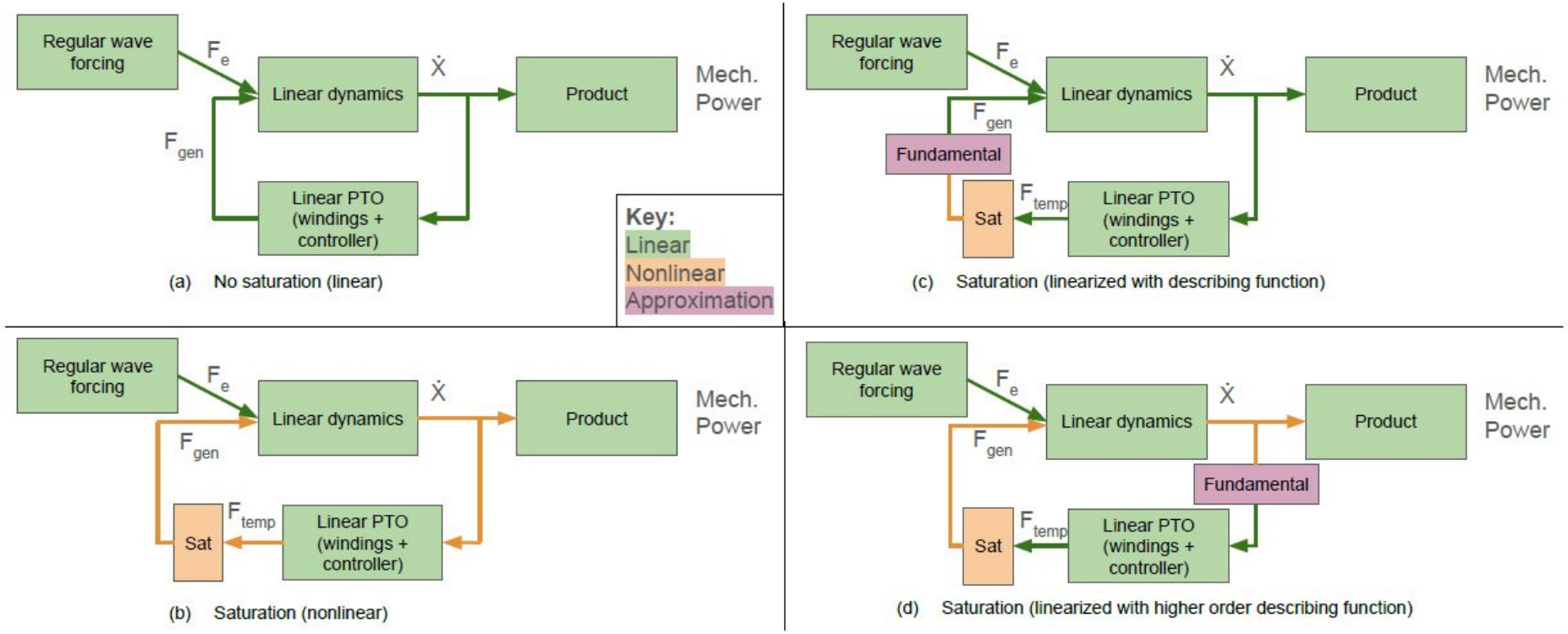
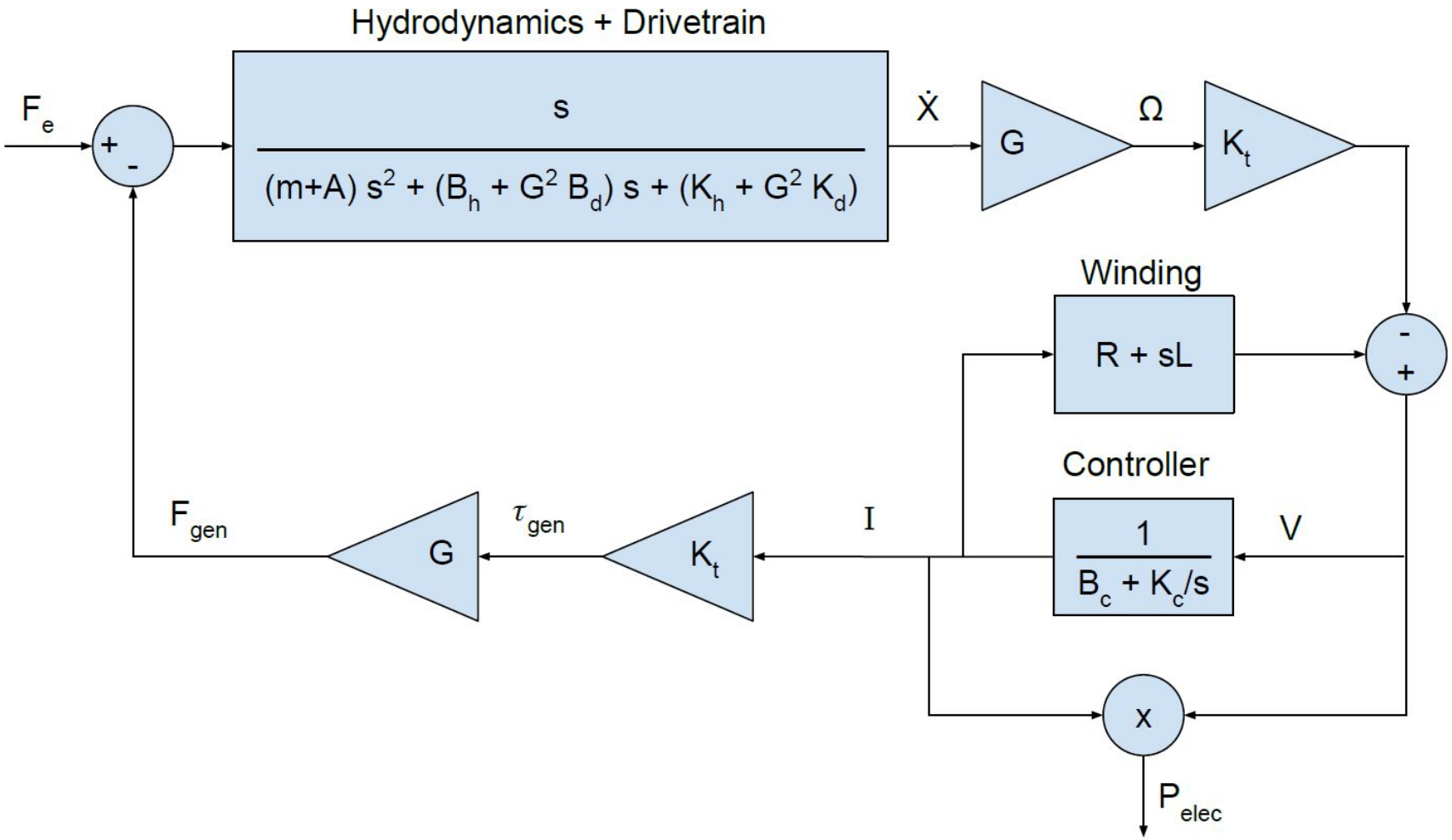






Describing Functions use the Fundamental Harmonic

Assumption: higher force harmonics have a negligible effect on power because they are low-pass-filtered out by the plant



Wave Energy Converter Dynamics