Sandia National Laboratories

Re-Imagining the RM3 through control co-design

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UMERC/METS

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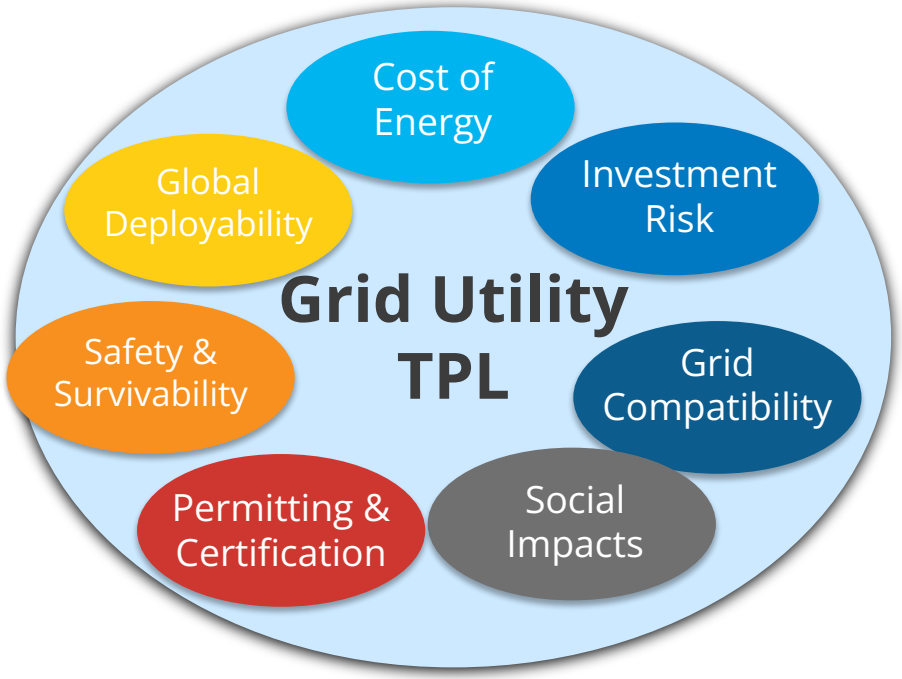
SAND No. SAND2024-10057C

Project Overview

TPL Assessment

Evaluate anticipated holistic performance of technologies and identify problem areas



Innovation

Horizon-scanning efforts identifying novel and high-impact innovation for wave energy

RM3 Redesign

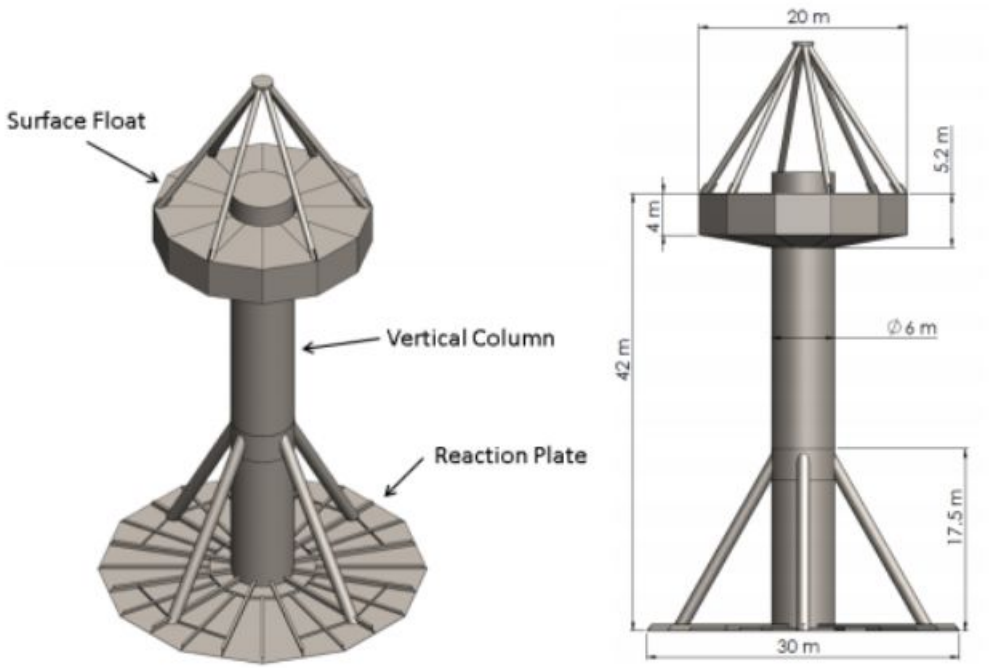
Employ novel control co-design paradigms in a familiar context to provide worked example of best practices

Why the RM3?

The reference model project, and perhaps especially the RM3, is one of the most cited, referenced, and utilized WEC geometries.

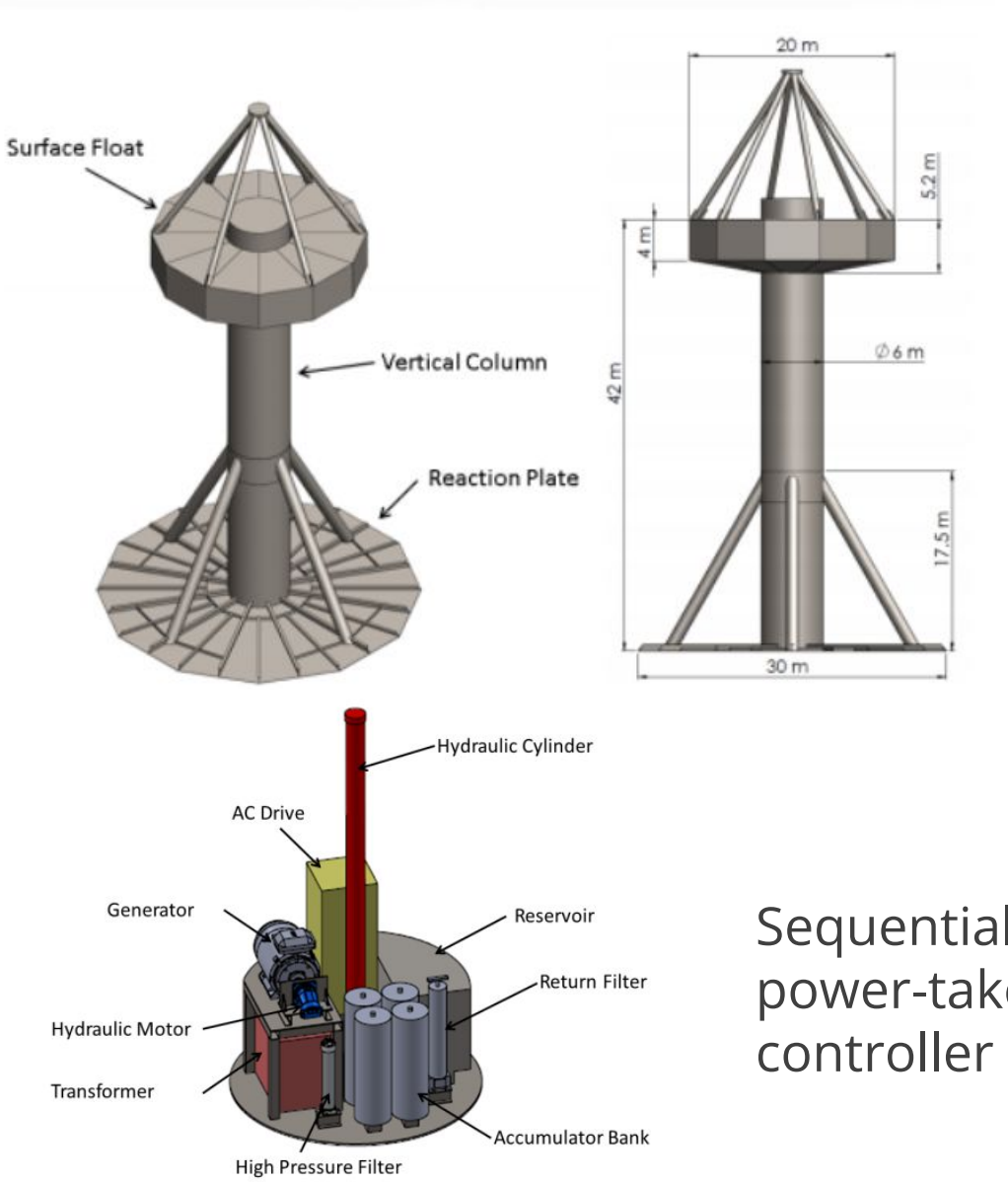
Forecast-based stochastic optimization for a load powered by wave energy	Dillon, T., Maurer, B., Lawson, M.	May 2024
Beta-version Testing and Demonstration of the Design Load Case Generator	Neary, V., Ahn, S., Michelen, C.	September 2023
Hybrid Model Predictive Control of a Two-Body Wave Energy Converter with Mechanically Driven Power Take-Off	Zhang, Z., Qin, J., Wang, D.	August 2023
PacWave Anchoring and Mooring Study	Housner, S., Sirnivas, S.	August 2023
Analysis of wave resource model spatial uncertainty and its effect on wave energy converter power performance	Lokuliyana, R., Folley, M., Gunawardane, S.	August 2023
Marine Spatial Planning of a Wave-Powered Offshore Aquaculture Farm in the Northeast U.S	Hasankhani, A., Ewig, G., McCabe, R.	June 2023
Research on wave excitation estimators for arrays of wave energy converters	Zhang, Z., Qin, J., Wang, D.	February 2023
A designed two-body hinged raft wave energy converter: From experimental study to annual power prediction for the EMEC site using WEC-Sim	Jin, S., Wang, D., Hann, M.	January 2023
Integration and Demonstration of Marine Energy Models with Microgrid Software	Barajas-Ritchie, A., Jackson, D., Cotilla-Sanchez, E.	September 2022
Multidisciplinary Optimization to Reduce Cost and Power Variation	McCabe, R., Murphy, O., Haji	August

Preliminary Verification and Validation of WEC-Sim, an Open-Source Wave Energy Converter Design Tool	Ruehl, K., Michelen, C., Kanner, S.	June 2014
Methodology for design and economic analysis of marine energy conversion (MEC) technologies	Neary, V., Lawson, M., Previsic, M.	April 2014
Validation of Theoretical Performance Results using Wave Tank Testing of Heaving Point Absorber Wave Energy Conversion Device working against a Subsea Reaction Plate	Previsic, M., Shoele, K., Epler, J.	April 2014
Review of Methods for Modeling Wave Energy Converter Survival in Extreme Sea States	Coe, R., Neary, V.	April 2014
Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies	Neary, V., Previsic, M., Jepsen, R.	March 2014
Reynolds-Averaged Navier–Stokes simulation of the heave performance of a two-body floating-point absorber wave energy system	Yu, Y., Li, Y.	March 2013
The Contribution of Environmental Siting and Permitting Requirements to the Cost of Energy for Marine and Hydrokinetic Devices Reference Models #1, #2 and #3	Copping, A., Geerlofs, S.	November 2011

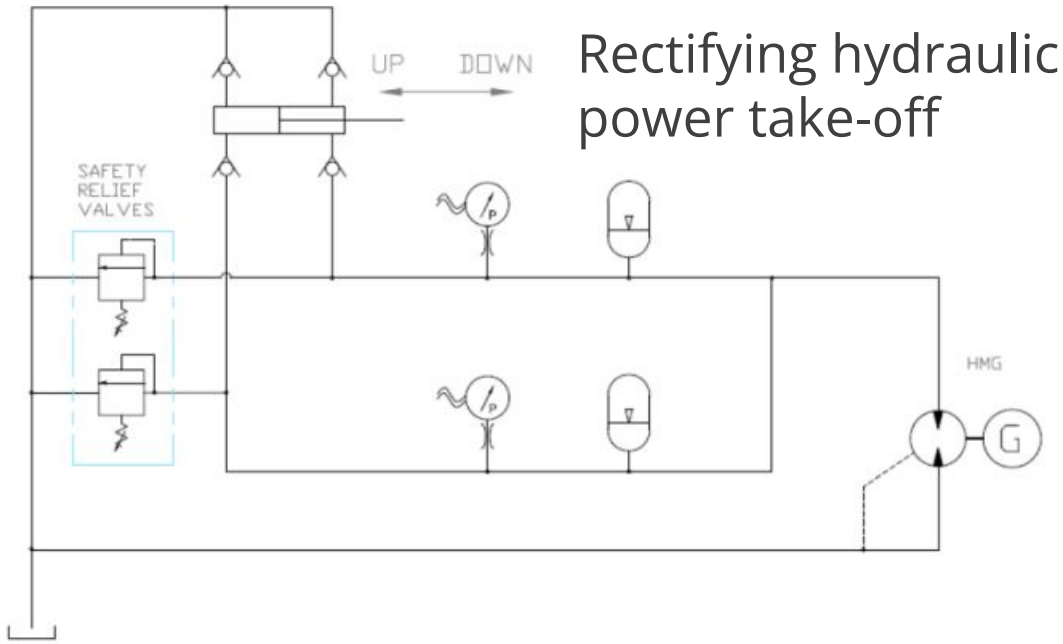


Images from V. Neary, M. Previsic, R. Jepsen, M. Lawson, Y. Yu, A. Copping, A. Fontaine, K. Hallett, D. Murray (2014). Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies.

RM3 as it was



The reference model project was never intended to develop competitive, optimal WECs, but provide open-source models.



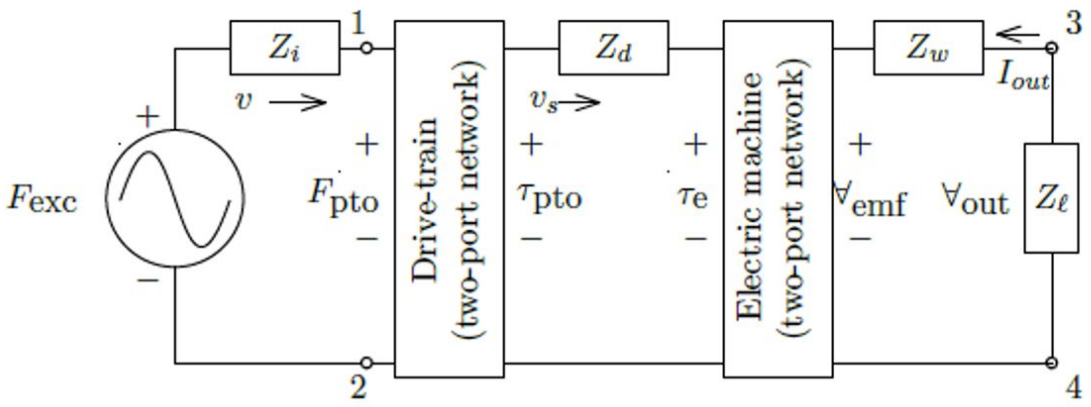
Rectifying hydraulic power take-off

Sequential design of hull, power-take-off, and controller

Images from V. Neary, M. Previsic, R. Jepsen, M. Lawson, Y. Yu, A. Copping, A. Fontaine, K. Hallett, D. Murray (2014). Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies.

Co-designing the RM3

The efficient delivery of waves-to-wire energy requires that each subsystem in the power conversion chain is design simultaneously and in coordination.

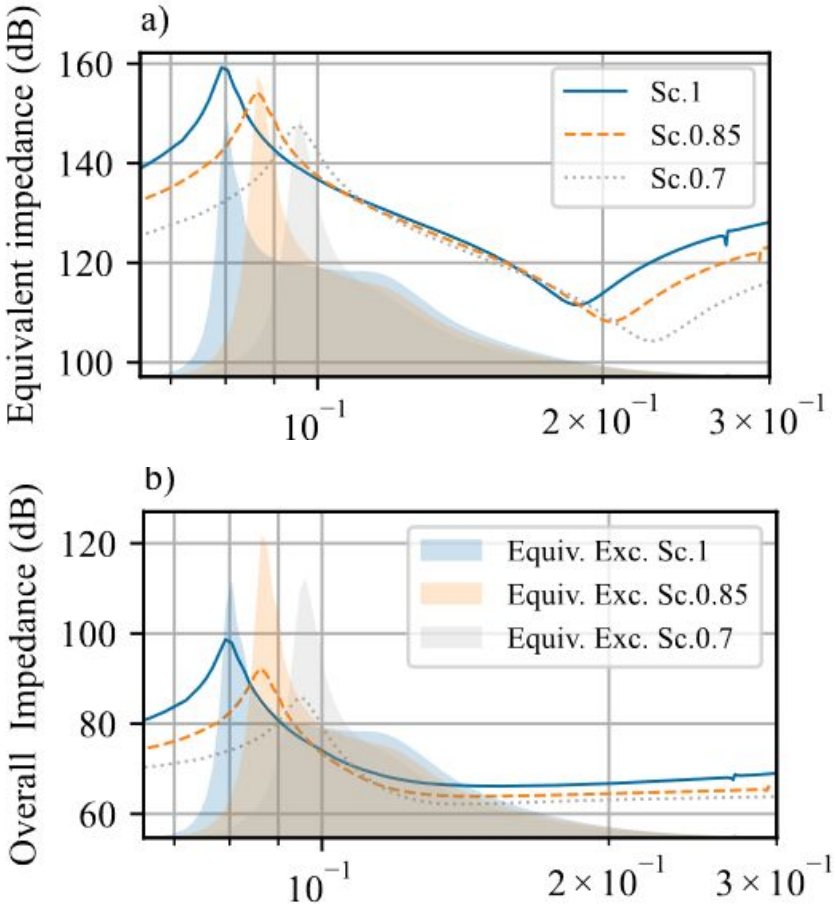


https://github.com/sandialabs/WecOptTool

$$Z_{i,BEM}(\omega) = j\omega\big(M + m(\omega)\big) + B_v + R(\omega) + S/(j\omega)$$

$$Z_d(\omega) = I_d j\omega + B_d + \frac{K_d}{j\omega}$$

$$Z_w(\omega) = R + j\omega L$$



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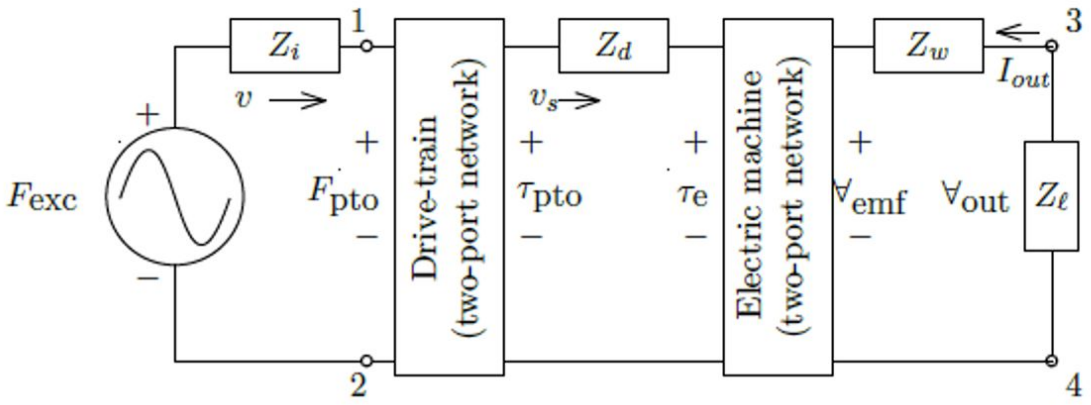

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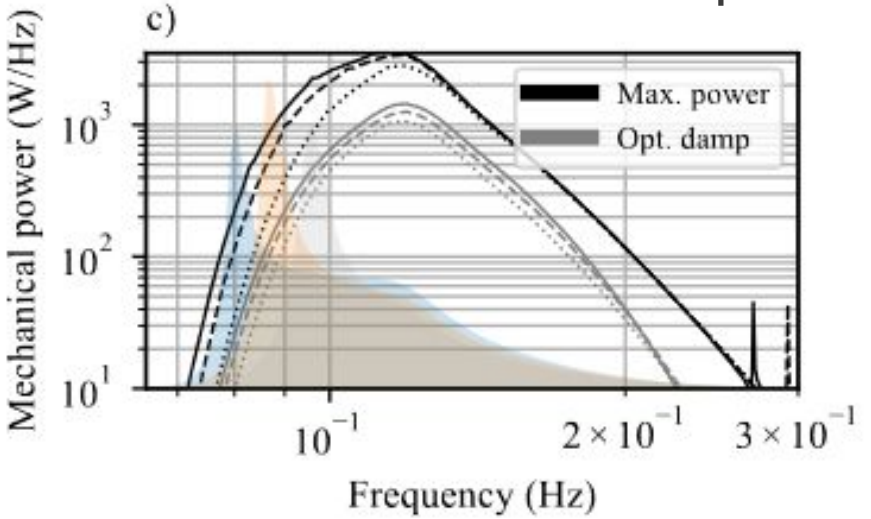

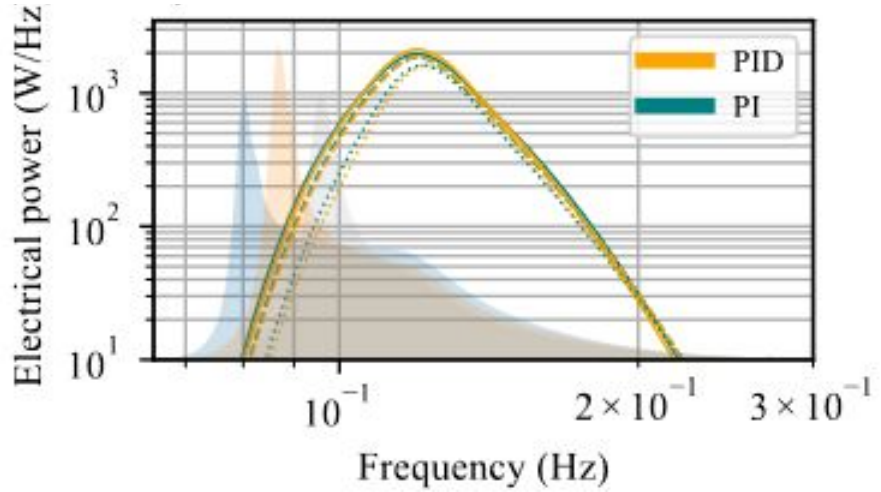

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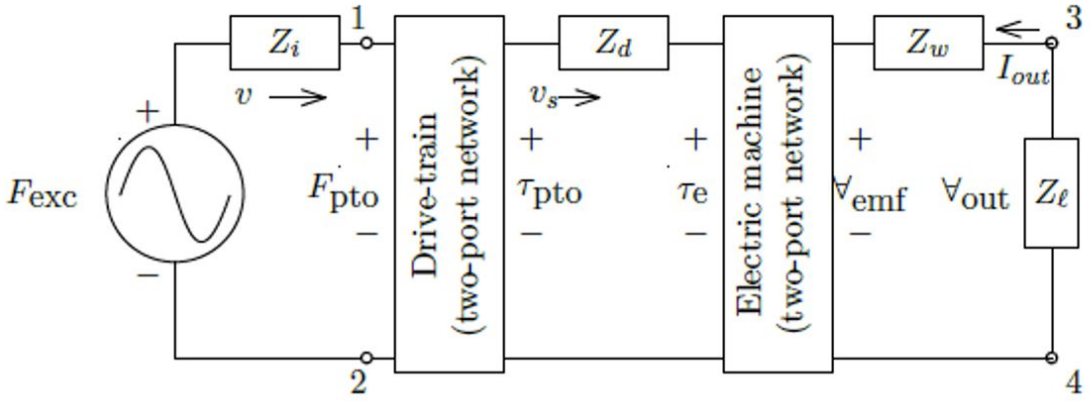

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WecOptTool relies on an informed selection of these parameter ranges and constraints. It can be challenging to develop this knowledge for a "TBD" design morphology and/or to translate tool outputs to a realizable, component-level design.

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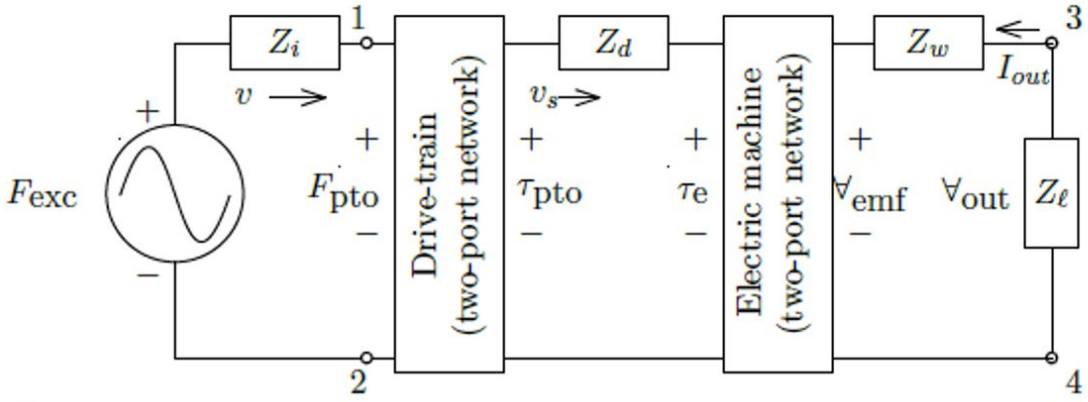
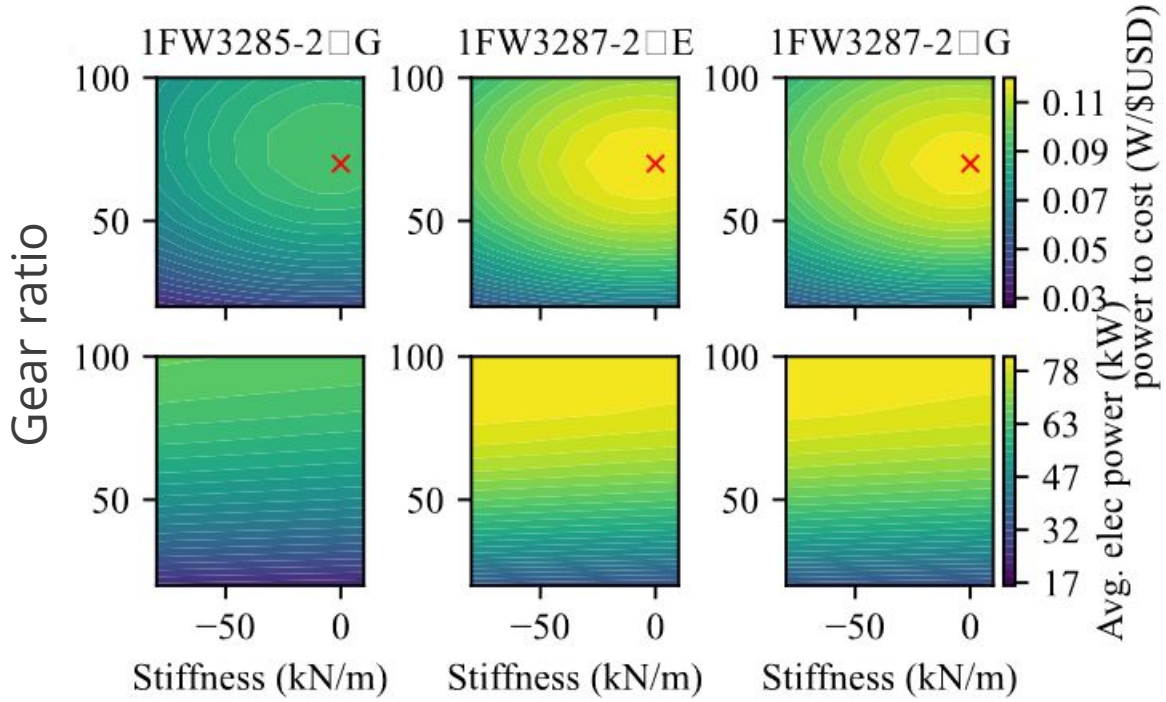


D. Gaebele et. al, “Re-imagining the RM3 with Wave Energy Converter Control Co-Design.” *Renewable Energy*. (UMERC2023 special issue!)

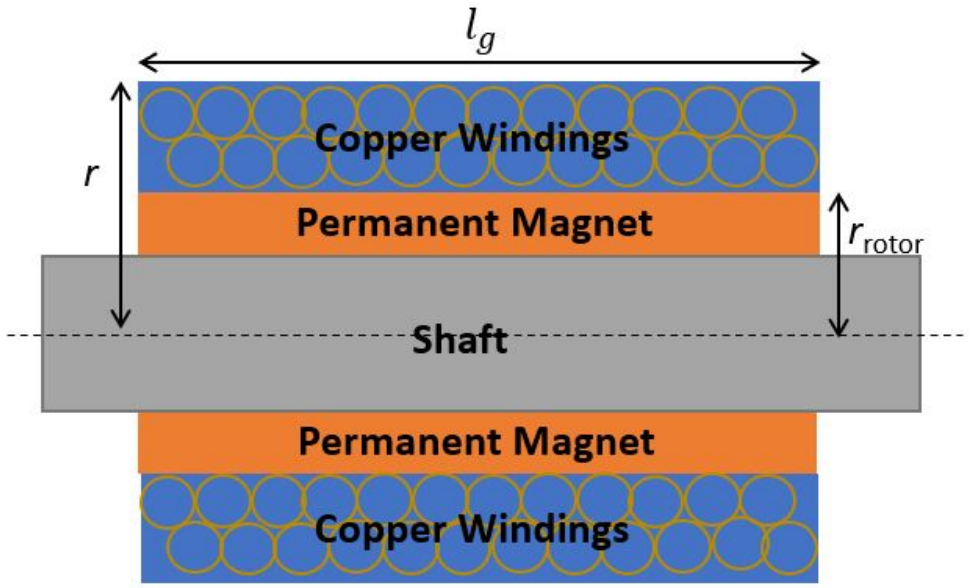
Informed by cost models (in $), WecOptTool and co-design techniques can be leveraged to suggest LCOE optimal designs

This can advise selection of real components!



Implications for components

Novel components may be especially useful for the unique demands of WECs that are physically realizable, but not COTS. We have begun by considering rotary generators.



$$K_t = 2NB_{max}l_g r_{rotor}$$

$$T_{max} = K_t I_{wire,max}$$

$$l_{wire} = N2\pi r_{rotor}$$

$$R_{wire} = R_m l_{wire}$$

$$L_{winding} = \frac{\mu_{Cu} N^2 A_{coil}}{l_g}$$

$$m_{Cu} = l_{wire} A_{wire} \rho_{Cu}$$

Physics + empirical observations

Implications for components

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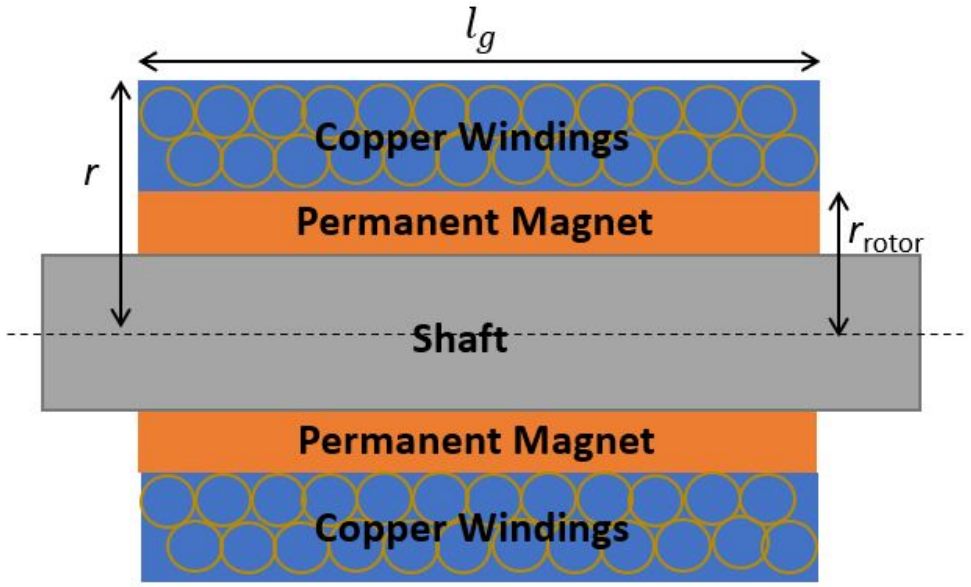

$$\underbrace{\frac{l_{wire} d_{wire}^2}{4} \geq l_g((r_{rotor} + 0.0254)^2 - r_{rotor}^2)}$$

Physics + empirical observations

Implications for components

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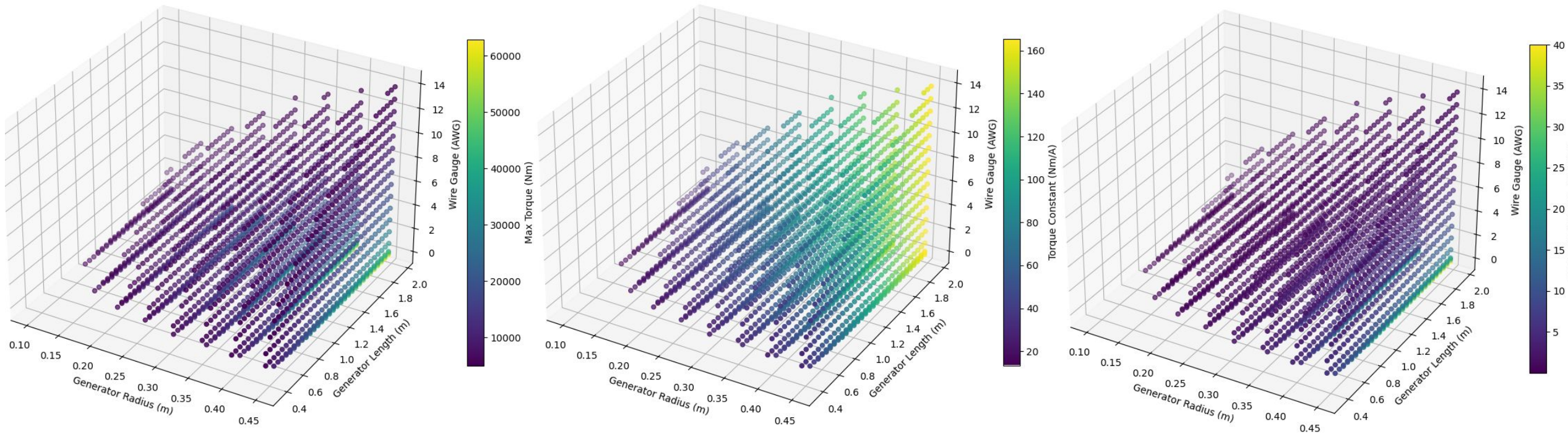
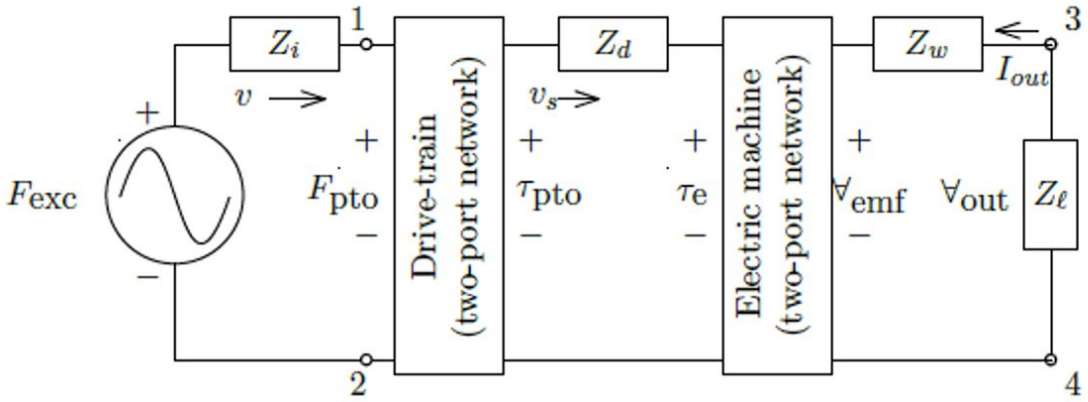
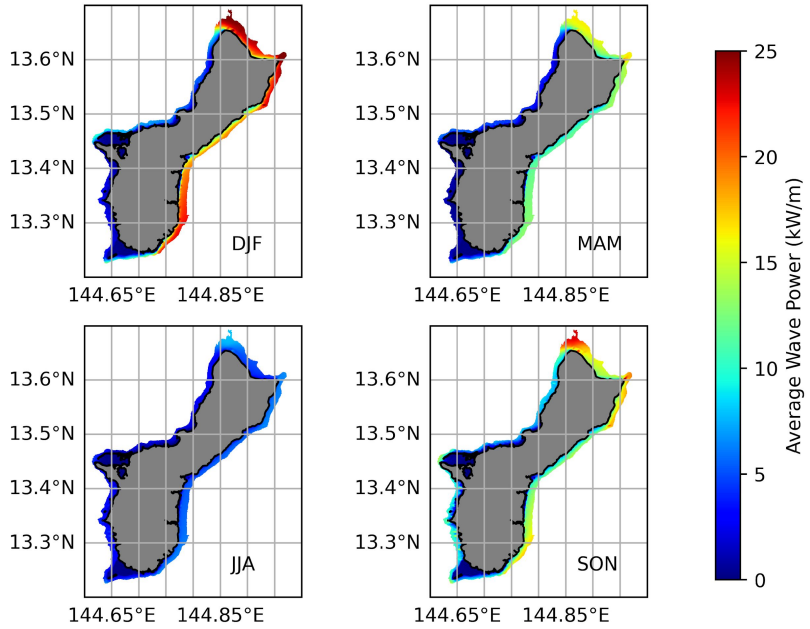


Promising areas





- Large inertia generators
- High phase-number generators
- Materials (cheaper!) selection

$$Z_d(\omega) = I_d j\omega + B_d + \frac{K_d}{j\omega}$$

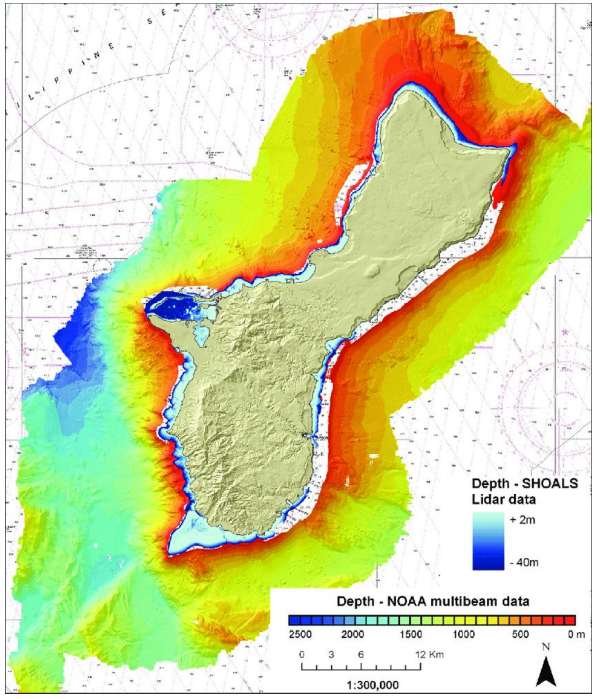
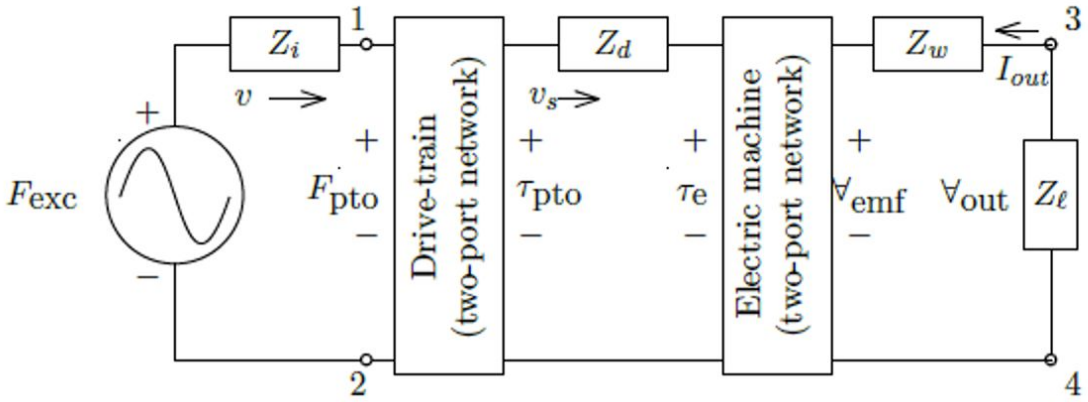


Image at left from: Island of guam territory of guam (marine chart : US81048_P2828), Nautical Charts App.

Ongoing challenges

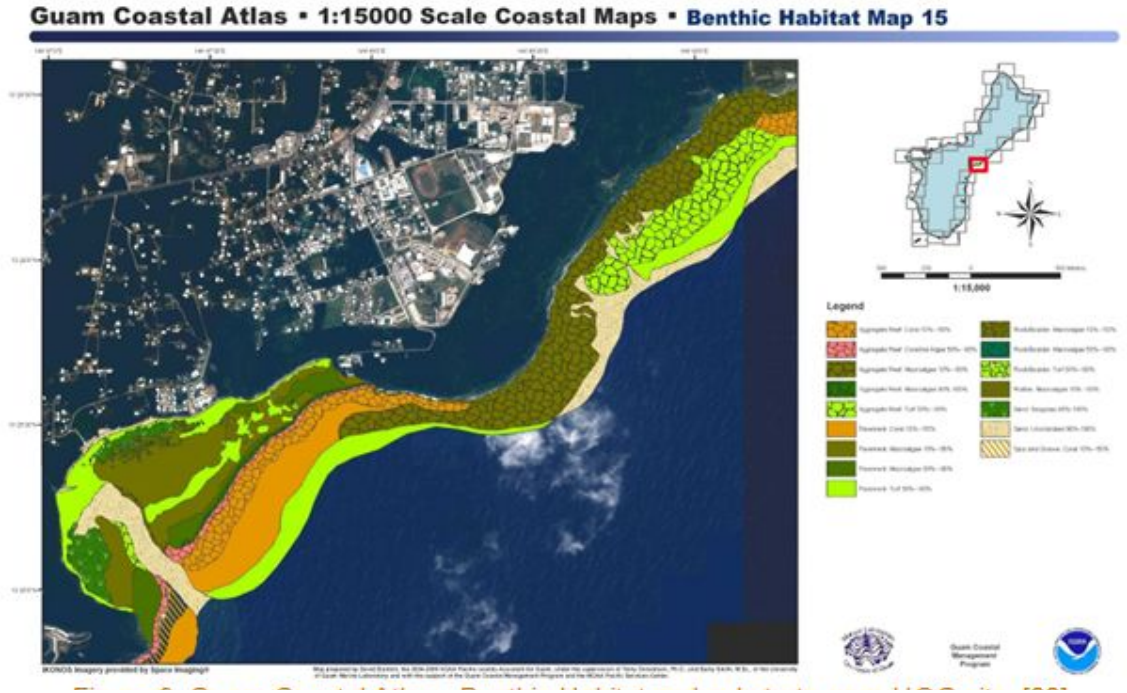


- Contemporary cost (in $) information
- Robustly quantifying “externalities”

$$Z_d(\omega) = I_d j\omega + B_d + \frac{K_d}{j\omega}$$

Image at right from Guam Power Authority forwarded from a Resident.

Image at bottom from: Burdick D. Guam coastal atlas. Benthic Habitat Data Coast. Provid. 2006



Thank you!

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