Numerical Modeling and Optimization of the iProTech Pitching Inertial Pump (PIP) Wave Energy Converter (WEC)

Cooperative Research and Development Final Report

CRADA Number: CRD-22-22968

NREL Technical Contact: Stein Housner

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5000-92188
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Cooperative Research and Development Final Report

Report Date: November 13, 2024

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: iProTech

CRADA Number: CRD-22-22968

CRADA Title: Numerical Modeling and Optimization of the iProTech Pitching Inertial Pump (PIP) Wave Energy Converter (WEC)

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Sponsoring DOE Program Office(s):

Office of Energy Efficiency and Renewable Energy (EERE), Water Power Technologies Office

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$120,000.00
Year 2, Modification #1	$00.00
Year 3, Modification #2	$00.00
Year 4, Modification #3	$00.00
TOTALS	$120,000.00

Executive Summary of CRADA Work:

This work generated a first-of-its-kind automated workflow to couple time-domain simulations of wave energy converters written in one software language with a set of design generation and evaluation scripts written in another software language. This automated workflow used an existing optimization package to analyze the sensitivity of different design parameters on the power output of a specific WEC, iProTech's Pitching Inertial Pump (PIP). Geometric, inertial, and power take-off variables were all varied and optimized to find values that produced the highest amount of power generated over varying wave conditions. The findings on these parameter sensitivity studies are used to inform future design iterations of the PIP WEC. Including more design variables in the optimizations will only increase computational run time and further software development is needed to analyze a larger optimization.

CRADA benefit to DOE, Participant, and US Taxpayer:

- Assists laboratory in achieving programmatic scope, and/or
- Uses the laboratory's core competencies, and/or

Summary of Research Results:

Many design optimizations were performed of the iProTech Pitching Inertial Pump (PIP) to maximize the power output of the wave energy converter (WEC). The time-domain numerical simulation tool, WEC-Sim, written in MATLAB, was able to be integrated with design scripts written in Python to completely automate the design process using information from time-domain simulations. This workflow was used to optimize various parameters of the PIP WEC individually, which provided insights on which geometric or inertial design variables had the largest affect on power output. The larger goal of combining all these different design variables into one optimization was not able to be completed, as the increase in number of design variables greatly increases the computational run time of the optimization. Valuable insights were gained on the sensitivity of different design parameters of the PIP WEC.

Task 1: Develop an automated workflow

NREL has successfully developed an automated process to calculate time-domain performance metrics from incremental geometry changes automatically. The starting pitching inertial pump (PIP) WEC description was carefully parameterized to allow for ease in numerical mesh creation using the python package, Meshmagick [1], followed by hydrodynamic coefficient calculation using the python package, Capytaine [2], followed by time-domain numerical simulation using WEC-Sim [3], written in MATLAB. The challenge was combining the WEC-Sim tool, written in MATLAB, with the other tools, written in Python. This was achieved using a MATLAB engine python package, written for direct coupling between MATLAB and Python. This automated workflow can be seen in the light green shape in Figure 1.

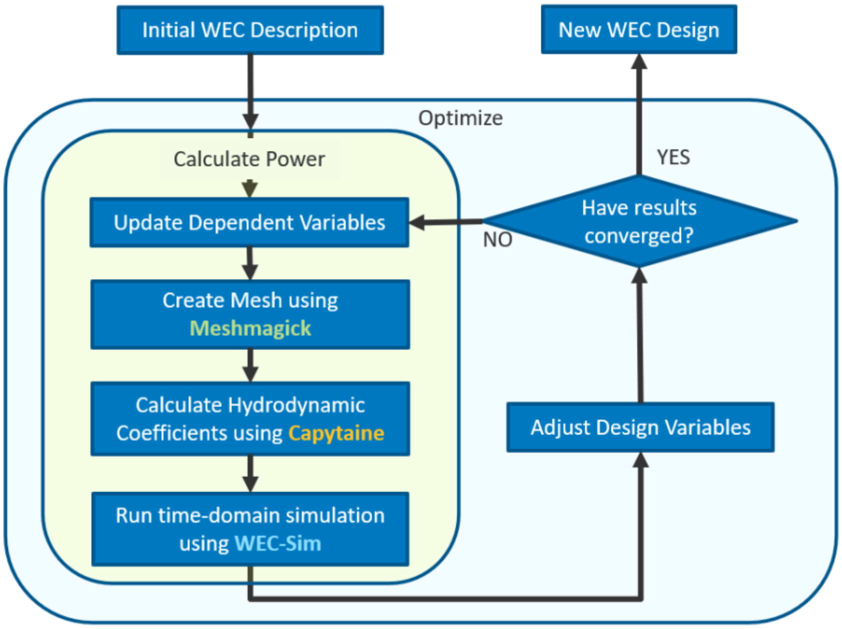

Figure 1. Graphical explanation of how the automated numerical tool works

With this new workflow, small changes in WEC geometry could be quickly re-analyzed in the time-domain without manually setting up new meshing and hydrodynamic calculation scripts.

Task 2: Integrate optimization frameworks with the automated workflow

With the automated workflow set up, we then used different optimizers that could algorithmically determine which design variables of the WEC design should be adjusted to minimize an optimization objective. This can be seen in the light-blue shape of Figure 1. Many optimization frameworks are available for integration. We started with various optimization algorithms included in the SciPy python package [4] given the relatively simple integration with the existing modeling workflow. We evaluated the various algorithms provided in SciPy and used the ones that produced the most accurate results in the least amount of iterations (to minimize computational expense of the time-domain simulations). We ran various single-variable design optimizations of the PIP WEC using the COBYLA optimization algorithm to maximize the power output of the WEC or the total power output of the WEC across many wave conditions. An example result of an optimization of the “noseX” parameter of the PIP WEC (a proxy for the length of the WEC) is provided in Figure 2.

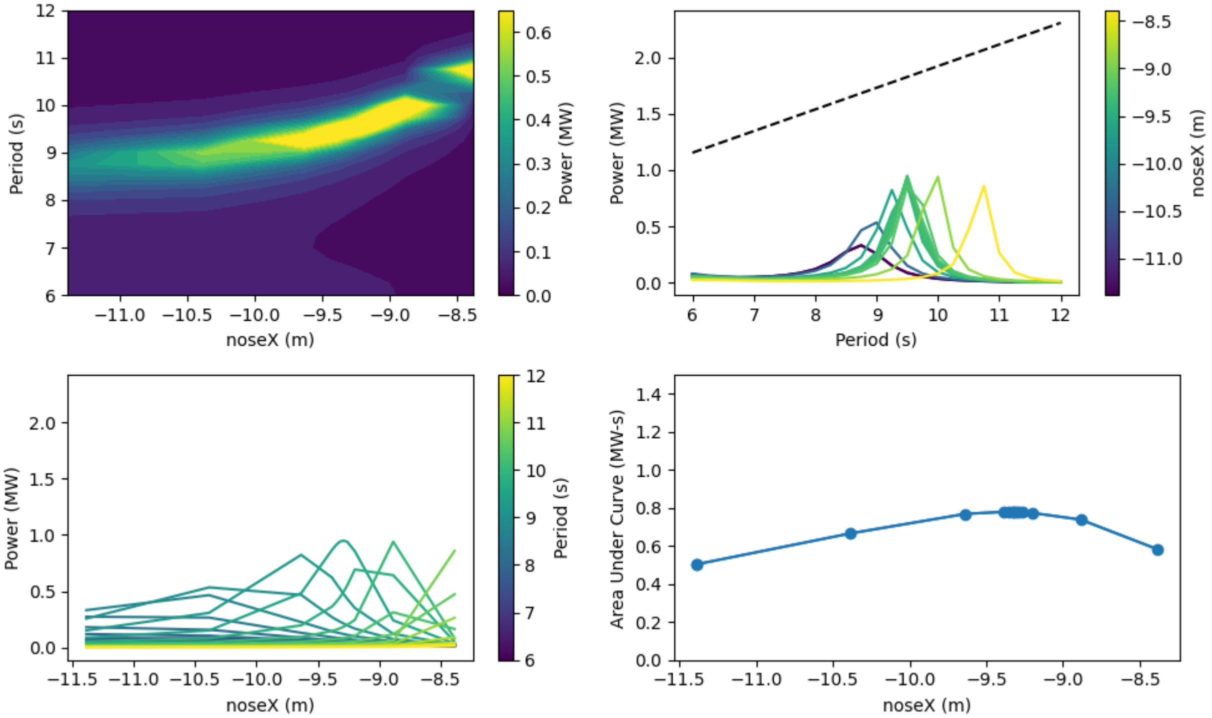

Figure 2. Power outputs for a noseX optimization

The top left subplot of Figure 2 shows different noseX values (lengths) of the WEC that were tested in the automated workflow in different wave conditions of varying regular wave periods. The z-axis of the contour plot shows the power output of those different design shapes at the different wave periods. The top right and bottom left subplots of Figure 2 show different horizontal and vertical “slices” of the top left contour plot. The bottom right subplot shows the optimization objective value at each design iteration, and how the optimizer converges on the noseX design with the highest cumulative power (area under the curve). With these results, we were successfully able to integrate the SciPy optimization framework into the automated numerical modeling workflow.

Task 3: Produce final optimal design results for the PIP

This task was unsuccessful as we were not able to integrate optimization algorithms that could effectively handle many design variables in an efficient amount of time. We produced many single-variable optimizations with results similar to Figure 2, but did not have the capacity to integrate other optimization frameworks that could better look at varying multiple variables, or multiple objectives. A final, optimal design of the PIP was not achieved, but valuable insights into the most influential design variables of the device were found, which can help inform further studies.

Task 4: Map optimal system parameters to hydraulic components (subject to the availability of funding)

This task was also not able to be completed due to the availability of funding. The stiffness and damping parameters of the hydraulic components were able to be optimized within the automated workflow but were not used to provide a better PTO model in WEC-Sim.

Task 5: CRADA Final Report: Preparation and submission in accordance with Article X.

This report serves to meet the requirement for the CRADA Final Report with preparation and submission in accordance with the agreement's Article X.

References:

[1] Ecole Centrale de Nantes, Meshmagick, https://github.com/LHEEA/meshmagick

[2] Ancellin et al., (2019). Capytaine: a Python-based linear potential flow solver. Journal of Open Source Software, 4(36), 1341, https://doi.org/10.21105/joss.01341

[3] Kelley Ruehl, Adam Keester, Nathan Tom, Dominic Forbush, Jeff Grasberger, Salman Husain, David Ogden, and Jorge Leon, "WEC-Sim v6.0". Zenodo, October 20, 2023. https://doi.org/10.5281/zenodo.10023797.

[4] Pauli Virtanen, Ralf Gommers, Travis E. Oliphant, Matt Haberland, Tyler Reddy, David Cournapeau, Evgeni Burovski, Pearu Peterson, Warren Weckesser, Jonathan Bright, Stéfan J. van der Walt, Matthew Brett, Joshua Wilson, K. Jarrod Millman, Nikolay Mayorov, Andrew R. J. Nelson, Eric Jones, Robert Kern, Eric Larson, CJ Carey, İlhan Polat, Yu Feng, Eric W. Moore, Jake VanderPlas, Denis Laxalde, Josef Perktold, Robert Cimrman, Ian Henriksen, E.A. Quintero, Charles R Harris, Anne M. Archibald, Antônio H. Ribeiro, Fabian Pedregosa, Paul van Mulbregt, and SciPy 1.0 Contributors. (2020) **SciPy 1.0: Fundamental Algorithms for Scientific Computing in Python**. *Nature Methods*, 17(3), 261-272.

Subject Inventions Listing:

None.

ROI#:

None.