Numerical Modelling of the Maiden Wave Energy WEC Device

Cooperative Research and Development Final Report

CRADA Number: CRD-22-22640

NREL Technical Contact: Salman Husain

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5700-89320
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Suggested Citation
Husain, Salman. 2024. *Numerical Modelling of the Maiden Wave Energy WEC Device: Cooperative Research and Development Final Report, CRADA Number CRD-22-22640.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5700-89320. https://www.nrel.gov/docs/fy24osti/89320.pdf.

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NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Water Power Technologies Office. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

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Cooperative Research and Development Final Report

Report Date: March 10, 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: Maiden Wave Energy LLC ("MWE")

CRADA Number: CRD-22-22640

CRADA Title: Numerical Modelling of the Maiden Wave Energy WEC Device

Responsible Technical Contact at Alliance/National Renewable Energy Laboratory (NREL):

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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	$100,000.00
Modification #1	$0.00
Modification #2	$0.00
TOTALS	$100,000.00

Executive Summary of CRADA Work:

NREL will develop meshing and modelling scripts to automate exploration of the design space for Maiden Wave Energy's Wave Energy Converter ("WEC") device. This will aid Maiden Wave Energy to assess a range of different device configurations and explore how different variables in the system affect the concept's performance.

CRADA benefit to DOE, Participant, and US Taxpayer:

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

Summary of Research Results:

This report contains Protected CRADA Information, which was produced on 03/10/2024 under CRADA No. CRD-22-22640 and is not to be further disclosed for a period of six (6) months from the date it was produced except as expressly provided for in the CRADA (for technical paper currently in process to be published prior to this CFR).

The project developed a modeling framework that can be used for domain search and design optimization. Modeling framework helped design an algorithm to select suitable device configurations and scale for specific deployment sites. The modeling framework is agnostic to device configuration, scale, and layout complexity. The modeling framework was generalized and can be easily used within a numerical optimization routine, for control design, or with Machine-Learning-based methods; all while using the open-source packages in Python.

The TSR will be able to use the developed tools for any other device configurations which may have different number of pods, scale, and configuration layout. The TSR will be able to interact with the developed tools by defining some basic operational parameters, while the hydrodynamics coefficients are generated accordingly, and the corresponding WEC-Sim model is generated and simulated.

The presented sets of results also showcase a roadmap for future development. Future development could follow the same analytical approach – assess the individual pods, the overall performance, and the effect of PTO mechanism – to identify a suitable device for a prospective site.

Purpose:

NREL will provide numerical modeling support to MWE for a DOE Testing & Expertise for Marine Energy ("TEAMER") program project.

Statement of Work:

Task Descriptions: NREL and MWE shall complete the following tasks:

Task 1: *NREL will provide training on the publicly available Capytaine and Wave Energy Converter SIMulator ("WEC-Sim") software that was developed by NREL and is listed on Appendix B, to MWE.*

Task 1 Results:

NREL provided MWE training slides and presentations. The training and project updates were provided regularly through the course of the project. A running presentation explaining the project updates and methodology being used was provided to the TSR from week-to-week, or on a bi-weekly basis.

Task 2: *MWE will deliver to NREL its initial device drawings (in CAD) for MWE's WEC device, with shape and size representations of the WEC device to be simulated.*

- NREL will develop python mesh generation scripts that can generate Boundary Element Method ("BEM") compatible meshes and easily vary device configuration (e.g. dimensions, number of floats).
- MWE will review python mesh generation scripts and be able to execute them.

Task 2 Results:

The entire simulation process was automated such that a user would only need to define some general parameters such as configuration scale, pod size, pod spacing in a Python script; following which, the hydrodynamics coefficients will be generated in Capytaine, a corresponding WEC-Sim model would be automatically generated and simulated. The general workflow to simulate the Maiden WEC arrays can be summarized as follows,

- Generate the hydrodynamics coefficients for MWE arrays,
- Initialize MATLAB from Python,
- Write the necessary input files,
- Programmatically generate the corresponding WEC-Sim models in Simulink,
- Simulate MWE array in WEC-Sim and log data.

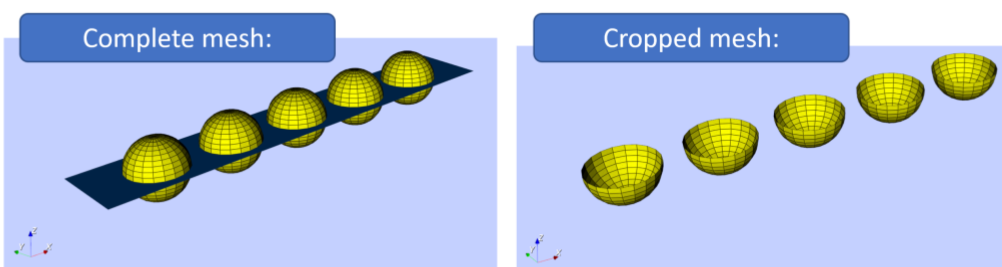


Figure 1 Visualization of the meshing process. In this example 5 floats are meshed (i.e. we're modelling a 5 pod system).

Task 3: *NREL will generate capytaine python scripts to compute hydrodynamic coefficients. NREL will compare results against WAMIT and plot.*

Deliverable: NREL will provide capytaine python scripts and plot compare results to MWE.

Task 3 Results:

Python scripts were developed to create these meshes automatically from a few variables provided as inputs. The meshes could be cropped automatically at the waterline for usage with the BEM code (Capytaine). Before running the systems of meshes through the Capytaine, a convergence study was performed for a baseline configuration to determine a good number of panels to use in our BEM runs. After determining an ideal mesh resolution, Python scripts were developed to generate meshes of a full system, based on a few input parameters. For example, if the spine length and number of pods are defined then the float size will be automatically computed. A mesh convergence study was a more rigorous verification and found to be more useful that cross-code comparison with WAMIT.

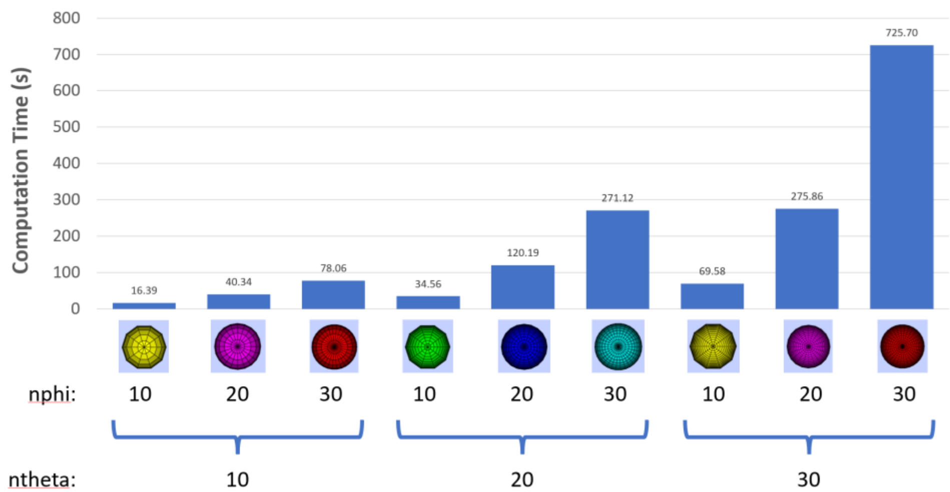


Figure 2 Computation time comparison for various mesh resolutions.

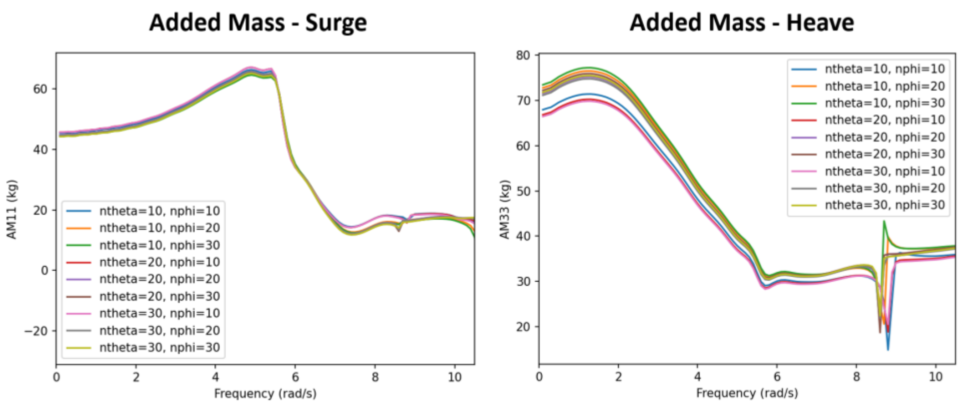


Figure 3 Comparison of hydrodynamic coefficients for mesh convergence study.

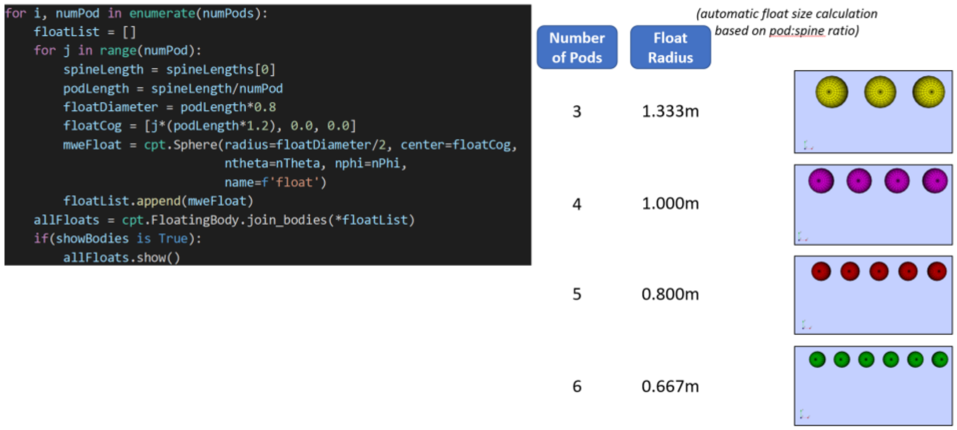


Figure 4 Various meshes produced automatically from a Python script by varying a few different system configuration parameters.

Task 4: *NREL will develop time-domain models of the device in WEC-Sim to simulate device dynamics.*

Deliverable: WEC-Sim .slx model files and .m input files to MWE.

Task 4 Results:

The test-plan stipulated the investigation of device configurations with different number of pods arranged in varying configurations – requiring a wide range of WEC-Sim models. A programmatic approach was developed to generate WEC-Sim models to address the wide range of device topologies. The code read the hydrodynamic coefficients generated in Capytaine and determined the blocks necessary to generate the WEC-Sim model, added the necessary Power Take-Off (PTO) blocks, and the pertinent connections between each block. Figure **Error! Reference source not found.** shows an example of a programmatically generated WEC-Sim model that can be used to simulate a 10 pod device.

The entire process was automated – from the generation of WEC-Sim models to post-processing. The user only needs to define some key parameters such as the device to simulate, and the sea-states – either in Python or MATLAB. The code will then grab the necessary hydrodynamic coefficients, generate the corresponding WEC-Sim model, and simulate the system for all the sea-states defined by the user. Following which, the simulation results are compiled and post-processed to generate the necessary plots. Given the long time-histories for which all the systems were simulated, an effective way to summarize the results was to take Fast Fourier Transforms (FFTs) and report the peak of these FFTs – representing the amplitude of the periodic motion resulting from the regular waves (sinusoidal waves with a single frequency). This allowed generating heat-maps of power generation for all permutations of wave heights and wave periods expected to be observed in the North Atlantic and Pacific Oceans.

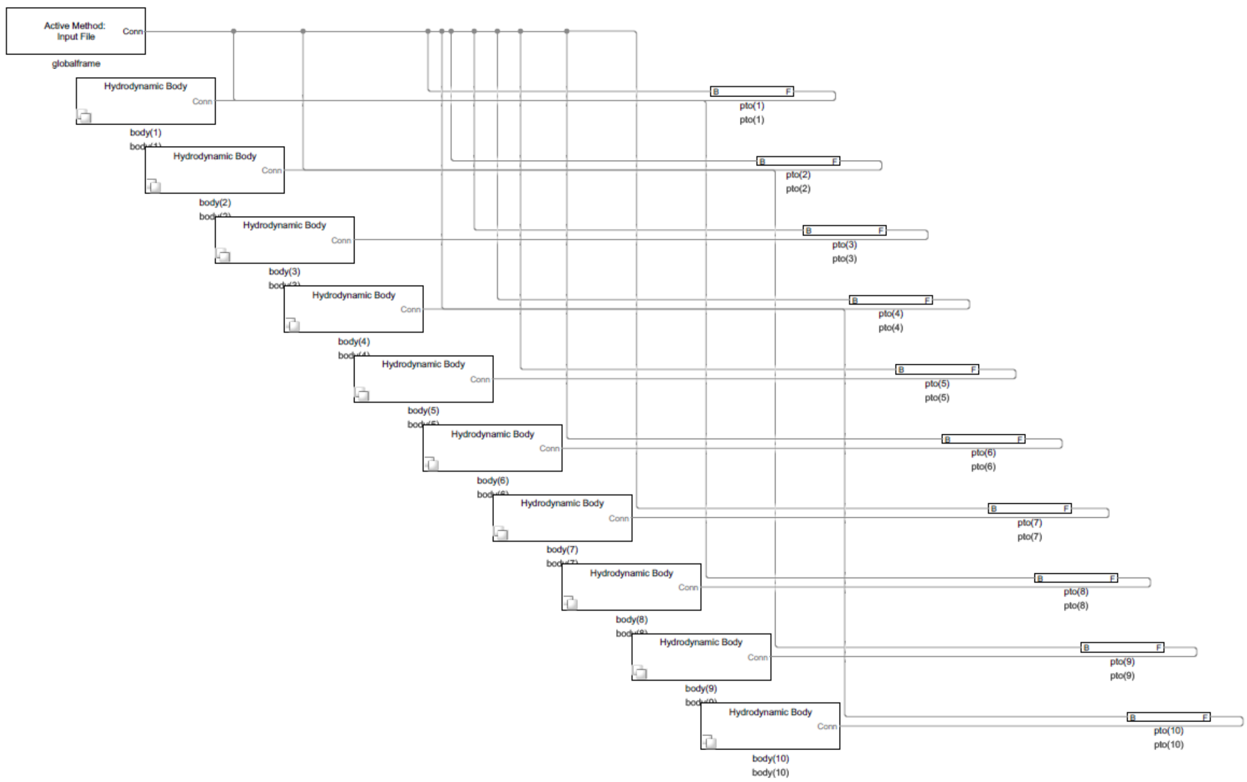


Figure 5 A sample WEC-Sim model that was programmatically generated.

Task 5: *NREL will run the WEC-Sim models based on the results from Tasks 1-4 for a range of configurations. NREL and MWE will collaboratively compare/review configurations and assess device performance. NREL and MWE will ensure MWE has all the required files/information to reproduce the results.*

Deliverable: NREL will provide MWE necessary model input files to reproduce results, along with post-processing scripts to plot results.

Task 5 Results:

The results presented in the following subsection show the device characterization for different configurations of the Maiden WEC array design archetype. This subsection shows four sets of results,

1. Power produced by each pod for every configuration,
2. Power matrices for each configuration,
3. Comparison of performance of each configuration for a sweep of PTO damping,
4. Annual Energy Production for some selected sites.

The first three sets of results show the intra-array power characteristics across the different pods of a certain configuration scale, the overall power produced by each configuration, and the effect of different PTO damping. These results are then used to make device recommendations for seven chosen sites that are representative of sites across the United States along the eastern coast, the western coast, and the states of Alaska and Hawaii. Refer Post-Access report for detailed results.

Power produced by each pod.

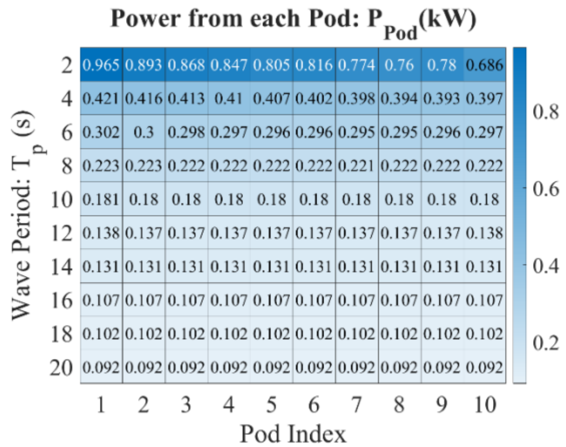


Figure 6 Power from each pod for a device with length 10 m.

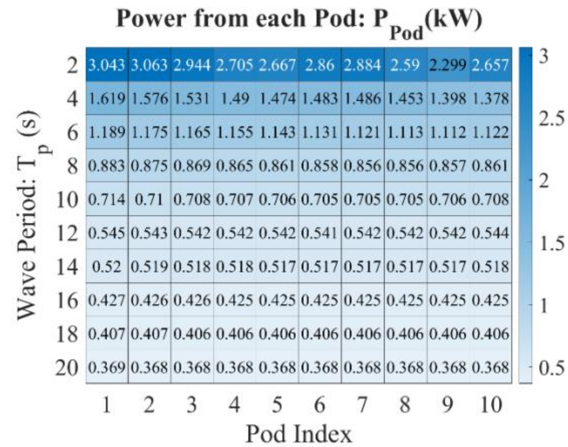


Figure 7 Power from each pod for a device with length 20 m.

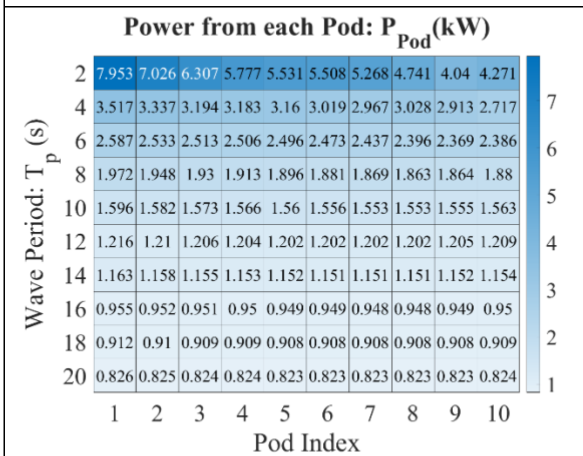


Figure 8 Power from each pod for a device with length 30 m.

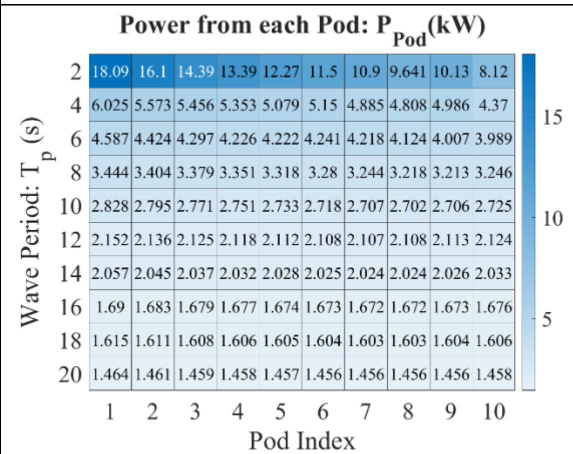


Figure 9 Power from each pod for a device with length 40 m.

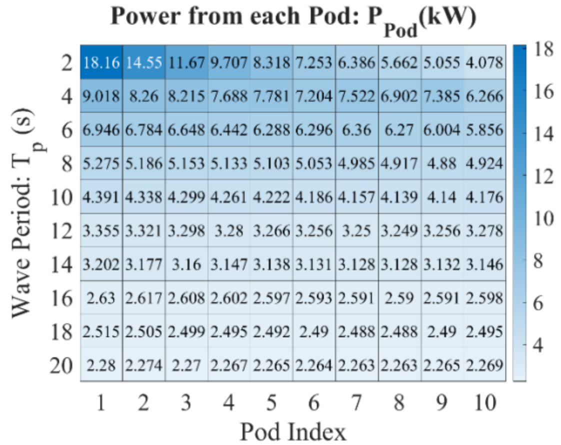


Figure 10 Power from each pod for a device with length 50 m.

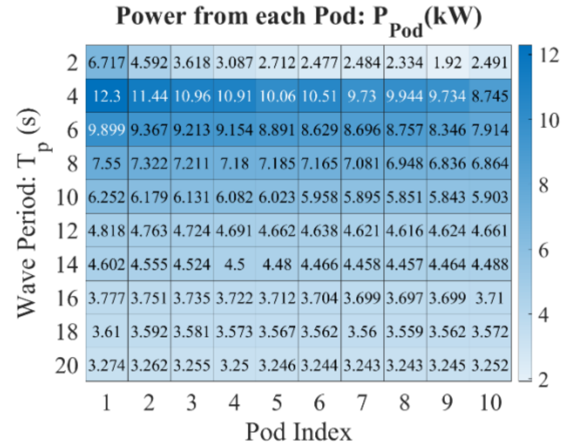


Figure 11 Power from each pod for a device with length 60 m.

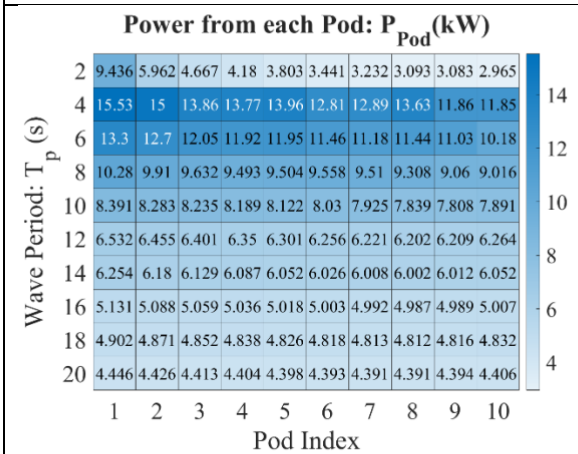


Figure 12 Power from each pod for a device with length 70 m.

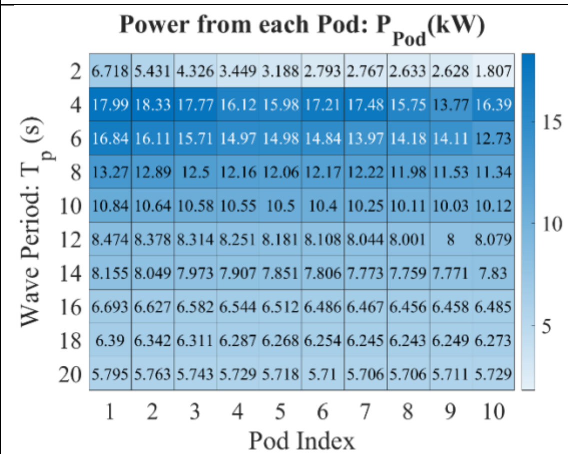


Figure 13 Power from each pod for a device with length 80 m.

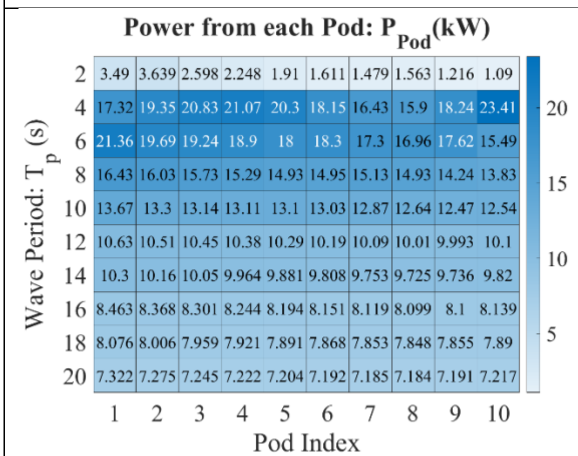


Figure 14 Power from each pod for a device with length 90 m.

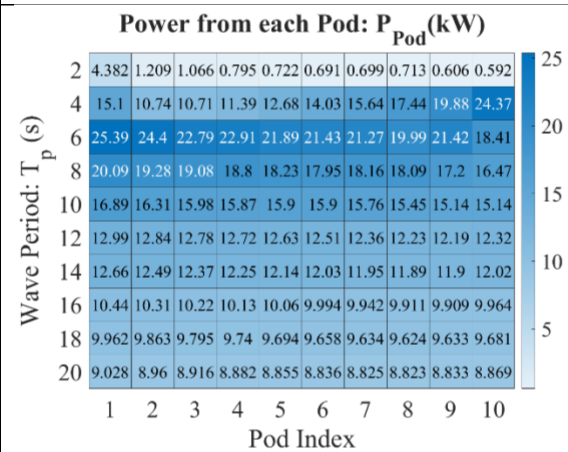


Figure 15 Power from each pod for a device with length 100 m.

Power matrices for each configuration

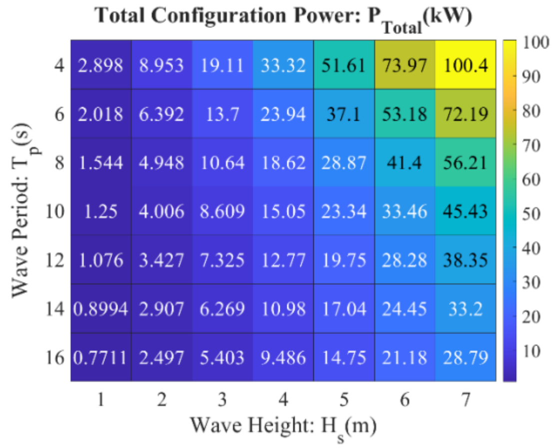


Figure 16 Power matrix for a device with length 10 m.

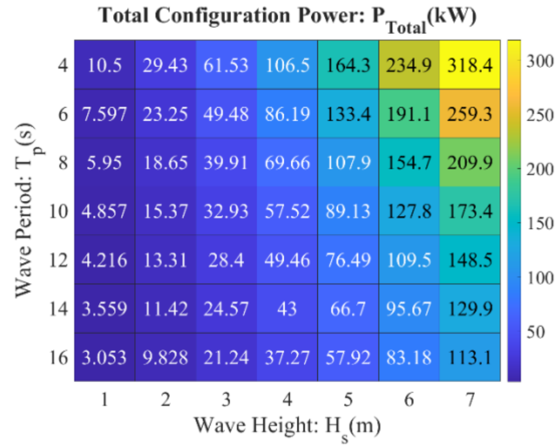


Figure 17 Power matrix for a device with length 20 m.

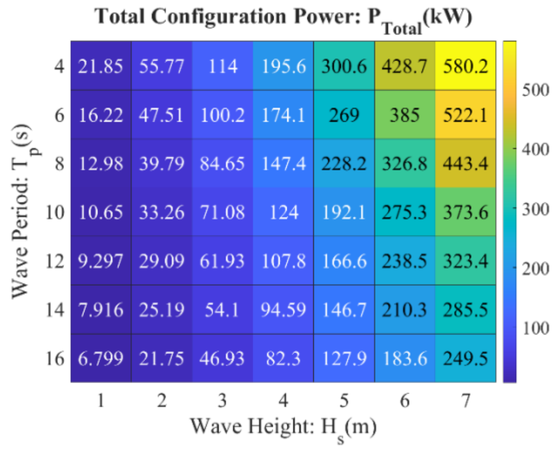


Figure 18 Power matrix for a device with length 30 m.

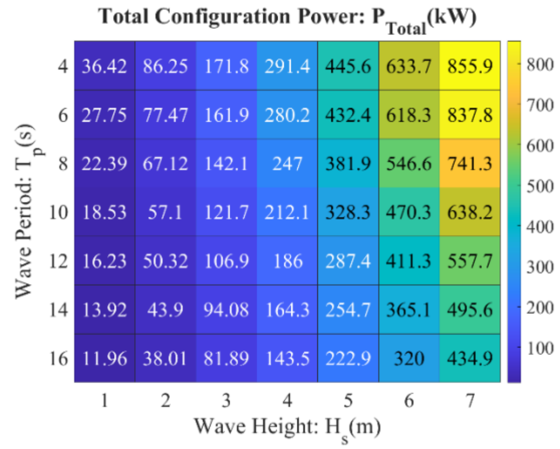


Figure 19 Power matrix for a device with length 40 m.

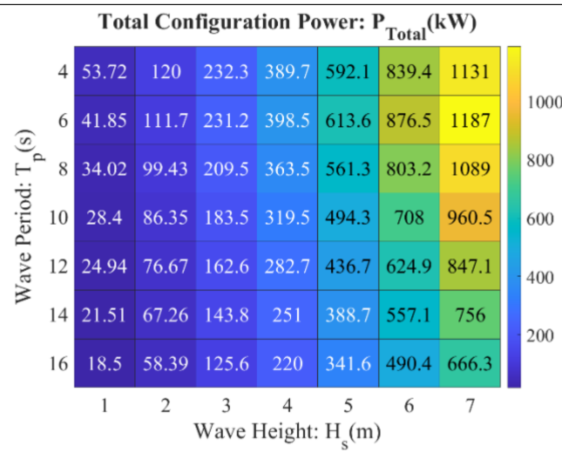


Figure 20 Power matrix for a device with length 50 m.

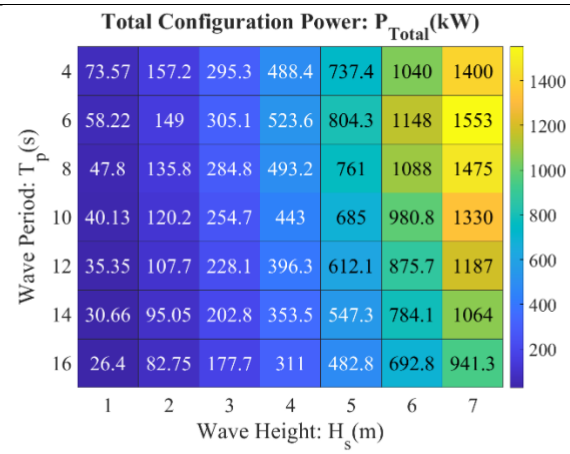


Figure 21 Power matrix for a device with length 60 m.

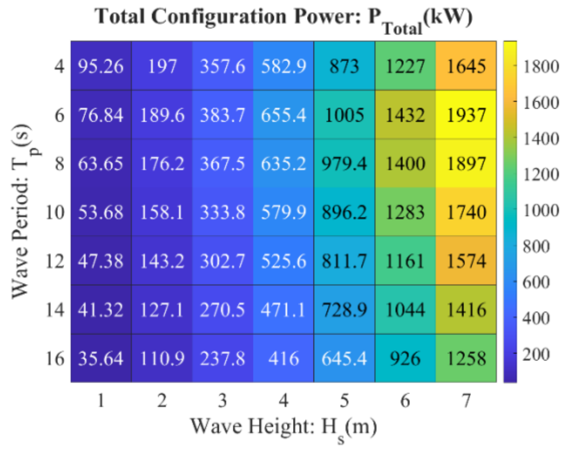


Figure 22 Power matrix for a device with length 70 m.

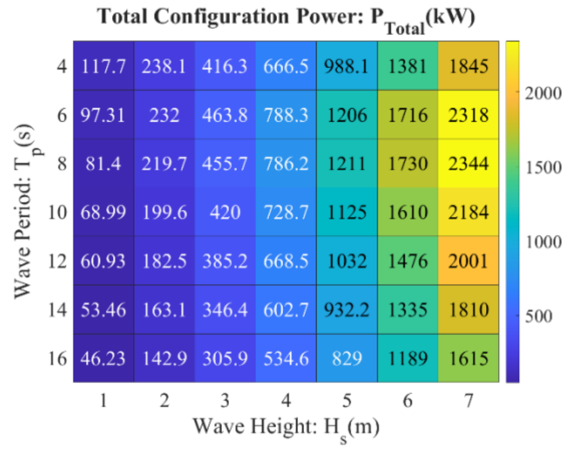


Figure 23 Power matrix for a device with length 80 m.

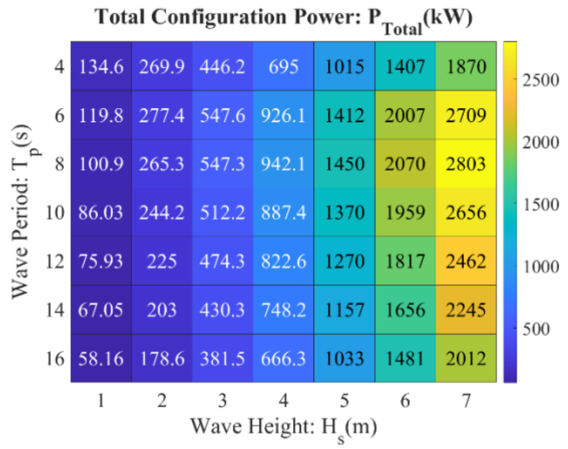


Figure 24 Power matrix for a device with length 90 m.

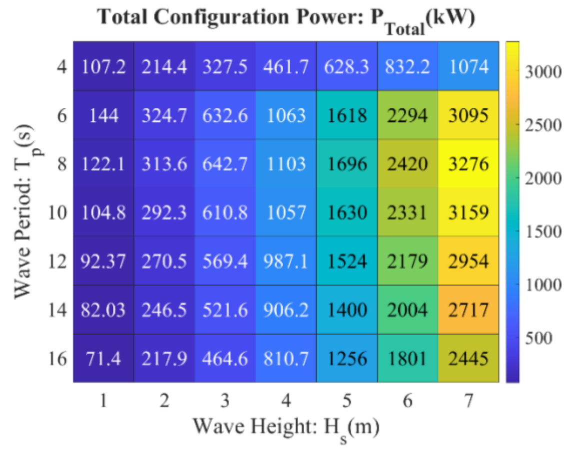
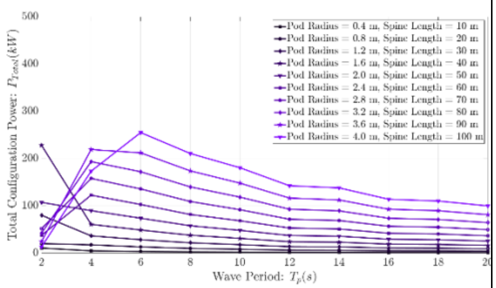
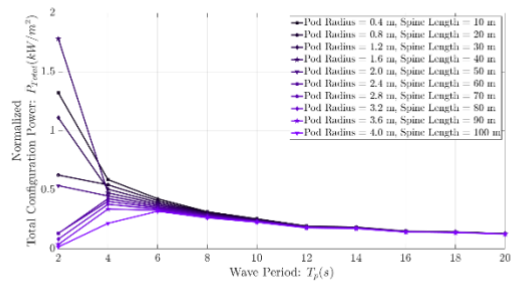


Figure 25 Power matrix for a device with length 100 m.

Comparison of performance of each configuration for a sweep of PTO damping

Table 1 Comparison of performance of each configuration for a sweep of PTO damping

<table>
<tr><th>Percent of Optimal PTO Damping</th><th>Total Configuration Power: $P_{Total}(kW)$</th><th>Total Configuration Power per unit area: $\overline{P}(\frac{kW}{m^2})$</th></tr>
<tr><td>50%</td><td>
</td><td>
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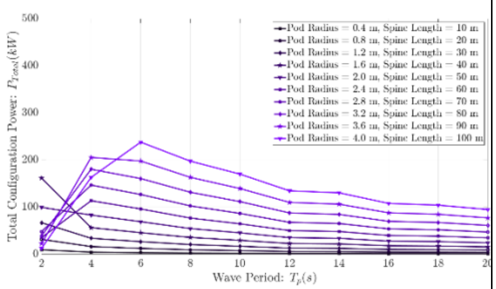
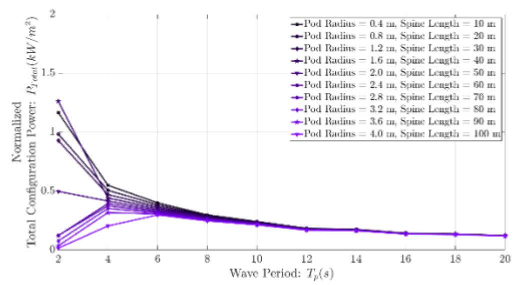
<tr><td>75%</td><td>
</td><td>
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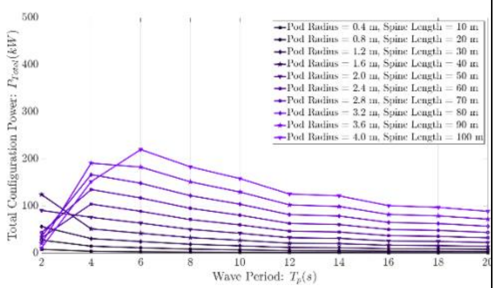
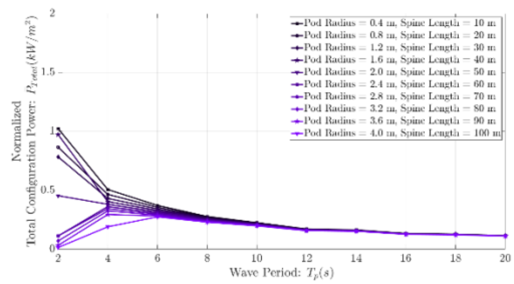
<tr><td>100%</td><td>
</td><td>
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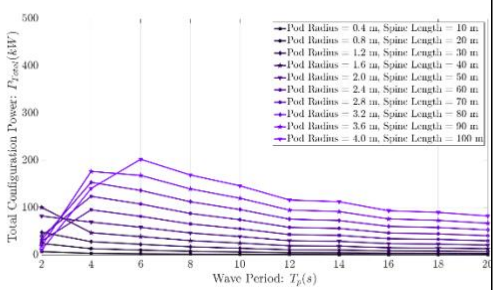
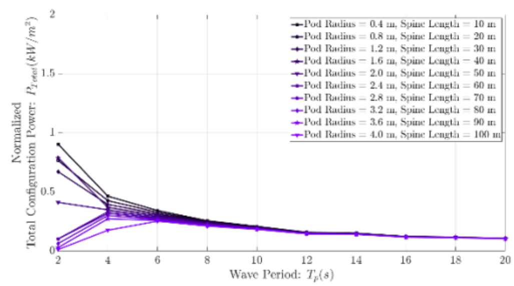
<tr><td>125%</td><td>
</td><td>
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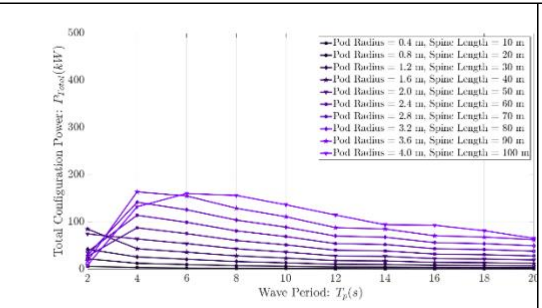
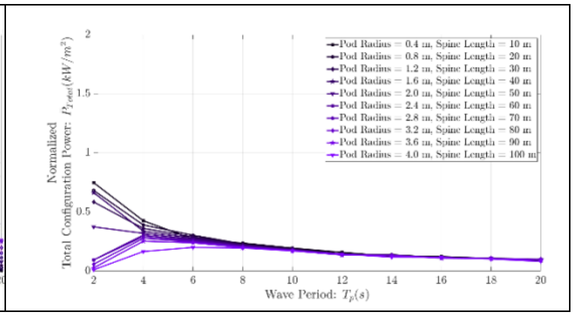
150%		

Annual Energy Production for some selected sites (detailed results for all sites considered are mentioned in the post-access report).

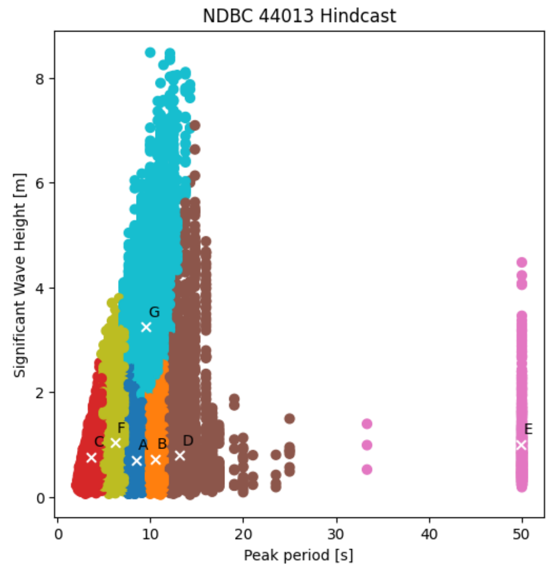


Figure 26 A summary of recorded sea-states at site 44013. The colored clusters represent the binned sea-states used for the estimation of energy production.

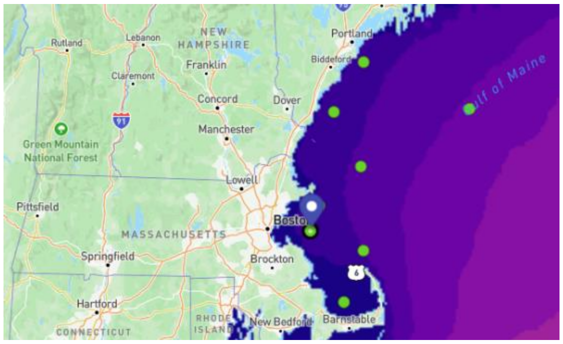


Figure 27 Location of the NDBC buoy ID 44013 near the East-Coast of MA.

Table 2 Summary of Annual Energy Production (AEP) at NDBC 44013.

NDBC 44013	No. of Pods: 10		Spine length: 90 m	Radius of Pod: 3.6 m
Significant Wave Height: Hs (m)	**Peak Period: Tp (s)**	**Weight**	**Power: (kW)**	**Annual Energy Production: (MWh)**
0.70	8.48	0.22	47.63	93.01
0.72	10.52	0.19	47.07	78.37
0.77	3.64	0.29	60.39	15.40
0.79	13.18	0.062	42.26	22.96
1.00	49.94	0.0036	15.04	0.47
1.03	6.17	0.19	72.70	118.71
3.24	9.54	0.043	431.17	165.43
			AEP (GWh)	**0.63**

Task 6: *Reporting*

- TEAMER Report: NREL and MWE will prepare post access report for TEAMER (with all results and analysis).
- CRADA Final Report: NREL and MWE will prepare CRADA final report in accordance with Article X.

Task 6 Results:

- TEAMER Report:

  The report was successfully completed and delivered.

  For greater detail on the process and analysis, the researchers (Husain, Salman; Ogden, David; Spector Solomon) are currently working towards publishing a forthcoming journal article titled *Exploring the Design Space of the Maiden Wave Energy Converter Concept: A Numerical Investigation of Floating Body Configurations.* In the event the article is not accepted by any currently seeking publication in academic or industry journal, it may be published by NREL.

- CRADA Final Report:

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

Subject Inventions Listing: None.

ROI #: None.