MICRO-SCALE WAVE ENERGY CONVERTER DESIGN AND OPTIMIZATION

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1. INTRODUCTION

While research in wave energy converter (WEC) design and technology has continued to advance toward grid-scale implementation, there is a new interest in simultaneously exploring smaller-scale wave energy development. This interest is borne of multiple potential benefits. Primarily, while the cost of power from very small-scale (herein called micro-) WECs is likely to be substantially higher than grid scale WECs, the development of such devices is likely to require a significantly less cost, such as reduced design time, greatly reduced capital costs, and integration with smaller systems—and not the power grid—reduces overall system costs. Additionally, many emerging markets could use micro-WEC power where grid-scale WEC power is intractable; in particular remote sensing applications, but also offshore charging for autonomous robots, and many others. These applications currently rely upon battery storage, transported fuels, or small-scale photovoltaics, but do not currently capitalize on the local wave resource for power development.

For the purpose of this paper we define the MicroWEC category to be loosely <200W with a physical footprint and mass that allow them to be handled by an individual. This definition is such that they are likely to be comparably inexpensive, can rapidly be designed and deployed, and have a wide range of potential implementation scenarios, making them attractive to researchers and offshore industries. However, the assumption that existing grid-scale WEC design and optimization efforts can simply be scaled down to meet the reduced power need of these potential applications is invalid. As the scale of power demand and the physical envelope of the WEC reduces, the design drivers and the technical challenges change significantly. For example, a MicroWEC is expected to operate in wave environments where the ratio of wave height to device characteristic dimension is likely to much higher, thus the flow regime around a smaller WEC is different and more non-linear than a larger one in a similar environment, likely necessitating different hull shapes as compared to current grid-scale WECs. Furthermore, the drivetrain is also likely to require a different approach. As loads are reduced, alternative materials and manufacturing methods such as 3D printing now start to become economically feasible. Additionally, given the fact that there are limited alternative power sources in these remote applications, the cost tolerance (per watt) is likely to be much higher.

By examining and embracing these differences, we can start to explore alternative designs for small scale micro-WECs that are able to provide power for remote applications, enabling extended persistence and potentially rapid deployability [1]. ref Ben Maurer APL + others).

We propose a new design and optimization paradigm for small-scale WECs for application in these emerging markets. This adaptable design framework will combine lessons from existing grid-scale WEC design with heuristic and meta-heuristic optimization techniques tailored for micro-scale applications. The goal of this research is to establish an optimization methodology for the design of micro-scale WECs, and to design physical models that will validate our approach through testing.

1.1 Learning from Previous WEC Research

While it is likely intractable to scale down existing WEC designs for micro-scale generation, there remain design decisions for grid-scale WECs that may be applied to the domain of micro-WECs. Various groups have tried to develop systems for this segment with varying success (OPT, other reference); however, the majority of these approaches have tended towards well-known architectures adapted from existing designs (such as simple point absorbers) and thus tend to have poor hydrodynamic efficiency. Recent work at APL on the DARPA WEBS device [1] is an excellent example of how a WEC can be tailored to this segment.

There has been extensive work completed on the development and application of advanced active controls for wave energy [2] and a number of existing grid-scale WECs have been designed for active control. This research is likely readily adaptable, and extremely important for micro-WECs as the mismatch between natural periods is likely to be severe. As such, incorporating active control as an inherent part of the optimization paradigm is critical, however, the requirement for cou-

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pled device/PTO dynamics and a time-domain numerical approach can be computationally expensive and alternative suitably representative approaches will need to be investigated, such as developing reduced order numerical representations, or limiting the control complexity.

While the design space is different and the resulting devices are expected to fit different trends, the general body of knowledge on WEC development will be extremely important in the development of suitable solutions. In particular, WEC specific challenges of managing the extreme load variability, mechanical PTO efficiencies, reliability and redundancy, amongst others, will need to be addressed.

There has been previous research in grid-scale WEC optimization that provides a foundation for this research. Namely, WEC hull geometry optimization work was undertaken by McCabe [3] and subsequent researchers at the University of Edinburgh. This genetic algorithm approach explored the optimization of a symmetric WEC hull to maximize the power development of the device. This research intends to build on this previous work.

1.2 New Knowledge Generation for Micro-WECs

It is likely that the numerical evaluation of the hydrodynamic interactions of waves and microWECs would need to be redeveloped to address operation in a relatively (to the characteristic dimension) much more extreme and non-linear environment. For the proposed optimization approach, hydrodynamic evaluation would be primarily numerical and it will be important to develop a suitably generic, limited-order numerical representation that can allow adequate representation of each device iteration in faster-than-real time. Existing open source codes such as NEMOH and WECsim can be adapted for this purpose. Frequency domain analyses have also been used for rapid evaluation of solutions to date (ref mOcean and Seabased) although these tend to rely on small displacements and linear wave assumptions and may not be adequate for smaller devices.

The design and development of WECs for commodity electricity production, such as grid-scale power, has a specific set of driving design parameters; however, smaller applications, such as remote ocean power, have different bounding design drivers, and so using the same architecture as developed for grid scale power may not result in the optimum performance at small scale.

Further, to be most useful these micro WEC devices must also maintain reasonable capture widths (efficiency) so as to ensure the size does not increase such that they can remain easily deployable.

For applications such as remote power for AUV/UUV persistence, there are limited alternative power sources and so the costs of vessel support become a limiting factor in operations and thus there are increasing advantages for fully autonomous operations

2. METHODOLOGY

The first step in the development of a micro WEC design and optimization approach is to assess the potential applications of these systems. The goal of this research is to create a framework for optimizing small-scale WECs, and as such, the research is inherently application-agnostic. However, it is important to understand the fundamental differences between small-scale and grid-scale application, so creating a test suite of micro-WEC applications is ideal. We will concurrently define a set of potential locations and accordant wave resources for testing purposes, to enable the proposed optimization framework to be applicable in diverse scenarios.

Given that the micro-WEC optimization problem is inherently complex and multiobjective, we will start with a seed set of micro-WEC designs. We will parametrize the shape of the various expressions of a wave energy extraction system. Through iteration, device architectures can then be evolved, and their performance evaluated against a suitable fitness metric. These designs will serve as a control/seed set in the subsequent optimization system.

Next, we will develop the multiobjective micro-WEC design strategy. While the strategy itself will require preliminary research to confirm our approach, we theorize the following framework parameters.

We will employ NSGA-II, a multiobjective genetic algorithm approach, as the overarching optimization algorithm. NSGA-II has been successfully applied to multiobjective complex systems optimization, as it is capable of accommodating non-convexities in objective and constraint modeling, as well as discrete and continuous design decisions. This approach accommodates multiple, competing objectives, and develops a Pareto frontier of optimal solutions during every evaluation. These Pareto-optimal solutions are propagated following a traditional genetic algorithm strategy, will possible solutions being mated, mutated, and evaluated iteratively until a converged, optimal solution is found. Additional information about traditional genetic algorithms can be found here [reference to Senecal].

The design variables?the values that will be optimized throughout the optimization approach?will be the hull shape and PTO parameters, to include active control strategies. The hull shape can be defined by a series of coordinates in 3D space, subject to realistic design constraints (such as symmetry and convexity).

A typical approach for the design of WEC controls is to optimize the device performance using a passive PTO, then look at gains that can be achieved by applying active controls. However, by optimizing hull geometry along with, or while assuming an active control strategy, this may allow for new geometries that can further take advantage of advanced controls. Other design variables, such as the mass of the device, may be optimized if other objectives are deemed of interest.

The objective functions we propose to use to find optimal micro-WEC designs are (1) the maximization of power development of the device, abiding by an equality constraint to ensure solutions do not exceed a maximum device power; and (2) minimize capital and O&M costs of the micro-WEC. These objectives will be weighted and are designed to be competing, such that the beneficial performance of one objective will directly contribute to a negative performance of the other objective.

While initial theory for both of these objectives have been defined for grid-scale WECs, the modeling approaches necessary for evaluating these objective functions will need to be evaluated to understand limitations and may need to be further developed. We intend to adapt NEMOH and WECsim [references], understanding that frequency domain analyses that rely on linear theory may not be adequate for small devices. We will need to adapt existing codes that translate hydrodynamic interaction to power development, depending on the underlying functionality of the design micro-WECs. Additionally, we will need to create new models to measure the cost of these devices, but we will leverage our previous work in cost model development to do this [4][5].

3. ASSESSMENT

The intent is that a number of MicroWEC systems will be developed starting from differently initially conditions and constraints. These can then be evaluated against the initial applications identified. It is expected that there will be different foundational, optimized designs to meet the different wave climates and power production scenarios.

An important aspect of MicroWEC development is that the scale of these devices encourages practical experimentation with full-scale units at reasonable costs and within short timescales. The output of which is able to feed back into confirming validity of numerical modelling approaches much quicker and with more certainty than through the use of scale models. This is a critical step to show that these designs work and establish a baseline of work on microWEC performance.

4. DISSEMINATION

Our intent is to disseminate this work widely in order to help WEC designers to understand the design needs of small-scale WECs. To facilitate this, we will make this work publicly available. All code, data, and publications will be released via open engineering channels, such as GitHub and FigShare. We will create a central website that will act as a repository and front end for the knowledge generated through completing this research.

Furthermore, the optimized microWEC designs will be made publicly available, including detailed drawings, CAD models, and Bills of Material. This is to encourage widespread understanding and adoption of microWEC technology.

Lastly, all assessment methods and testing data will be accessible via the project's website, which will enable reproduceability of our research and encourage sound validation practices in the design of microWECs.

5. REFERENCES

[1] Maurer, B. D. Supporting DoD maritime systems. Ocean Renewable Energy Conference XII.

[2] Ringwood, J. V., Bacelli, G., and Fusco, F. "Energy-maximizing control of wave-energy converters: The development of control system technology to optimize their operation". pp. 30–55.

[3] McCabe, A. P., 2013. "Constrained optimization of the shape of a wave energy collector by genetic algorithm". *Renewable Energy,* ***51***, pp. 274–284.

[4] Forinash, C., and DuPont, B., 2016. "Optimization of Floating Offshore Wind Energy Systems Using an Extended Pattern Search Method". In Proceedings of the 35th International Conference on Ocean, Offshore, & Arctic Engineering, pp. 1–11.

[5] Forinash, C., and DuPont, B., 2016. "Optimization of Floating Offshore Wind Energy Systems Using an Extended Pattern Search Method". *35th International Conference on Ocean Offshore & Arctic Engineering, In Press*, pp. 1–11.