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Performance evaluation and analysis of a micro-scale wave energy system

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Abstract—**This paper explores the realm and concept of micro-scale wave energy converters (WEC's) as power sources for instrumentation and other low-power (≤50W average) ocean applications. We further discuss the possibilities & limitations for such a system. Wave energy devices have been used to provide low levels of remote power; most notably, Y. Masuda developed a very successful oscillating water column WEC system to power navigation buoys [1]. The vast majority of the work in wave energy to date, however, has been focused on the development of larger systems. This paper attempts to reconcile aspects of research and development of larger-scale WEC systems with what might be possible at a smaller scale. Importantly, we set a series of physical limitations on the converter that ensures it is deployable by at most one or two people. This work examines the most significant WEC archetypes that have been developed to date and addresses their performance within the above context of micro-scale power generation. We ultimately present two WEC archetypes that have the most potential for performance at a small scale. Further, we show that a well-designed micro-scale Wave Energy system can produce a constant annual power of around 25-50W that is somewhat independent of climate. Loss paths are examined and broken down and it becomes straightforward to see that geometric hull optimization has the largest potential to improve performance.**

Index Terms—**MicroWEC, CWR, Wave Energy Converter, Power Performance, Experimental**

I. Introduction

WAVE Energy Converters currently appear to be far from any kind of convergence, and this is evident both in terms of the range of technological solutions and the variety of scales present. However, one thing all development has in common to date is the drive towards developing grid scale power that can compete with other renewables and even potentially conventional generation. This goal is laudable and should be supported, but it neglects the fact that the technology has not yet been commercially proven at a smaller scale. The common argument here is that the poor cost-effectiveness of the technology at a small scale precludes development of smaller systems, and while this is a fair statement, it is perhaps only true if one is only developing smaller systems with a view to scaling them into larger systems. This paper suggests that if one focusses on the development of a smaller WEC as the end goal, the development pathway can become quite different. While the technical challenge is somewhat greater, the design drivers and the allowable design space, can be seen to be quite different for smaller WEC.

Its well understood that all WEC are oscillating systems and thus as their physical size reduces, the disparity between the incident wave periods and the system natural periods become much greater. Most device developers rely on increasing physical size in order to increase the WEC natural period in order to develop a resonant response and improve performance, pushing down the cost of energy. Alternatively, advanced controls are another way to help mitigate this effect, but practical implementation still requires development and relies on the capability of the power take-out (PTO) for implementation. Furthermore, with regards to the PTO, as physical size becomes smaller, the PTO performance becomes more important with friction, dynamic and particularly static, can become challenging. Lastly, the archetypes currently developed for WEC have all been developed with a focus on larger scales for grid power. Opening up the design space by removing the requirement for large structures may allow the use of novel architectures and materials that are simply not practical at larger scales. The removal of these constraints requires a reassessment of generic WEC types with an eye to implementation at small scale and opens the door to new and previously impractical architectures through exploration of this search space using advanced machine learning and optimization [2], [3].

II. Definition of System Scale

The general definition of WEC scale can be vague at best and arbitrary at worst, however, for the purposes of this article, we will refer to the ultimate end implementation of the system (rather than in the term of scale model as a route to proving performance of a larger system) Thus we consider the following definitions of scale:

- **Utility Scale** Devices designed for large scale grid tie applications with individual power output in the 100's of kW to MW of rated power. Intended to be arrayed (ultimately) into large farms with power in the 100's of MW.
- **Community or Facility Scale** Devices also designed for shore connected grid tie, albeit into microgrids or remote weak grid applications. Individual device rated power in the order of ≤ 100kW device size and expected to be either installed individually or in small arrays.
- **Small Scale** Smaller systems that are designed to be deployed individually. Rated power expected

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from them may be in the region of a few hundred W to a few kW. Typical application may tethered to a remote platform.
- **Micro Scale** Devices of this scale will be physically small systems with a mean power output in the sub 100W range. These systems are intended for isolated deployments to power instrumentation or similar oceanographic equipment. In this paper we shall define the term 'MicroWEC' to refer to devices of this size.

A. MicroWEC Design Framework

In order to develop the concept of the MicroWEC, and place limits for optimization, we need to develop a design framework within which to operate. While this is clearly somewhat arbitrary, it is intended to serve as a starting point for further work in this area.

Mass & Size
: Realistically, if we look to the potential use cases for this scale of WEC, it seems reasonable to assume that the system should be deployable by one or two people from a small boat with minimal equipment. Given that the recommended maximum weight for a single person to lift is 25kg [4], two people would set the upper weight (for a single item) at 50kg.

Structure
: We shall assume that the system must be self contained and cannot rely on another structure to provide a reaction force or a platform for system components. Systems should thus include their own reaction mass or structure. For a seafloor referenced device, this would include the anchor which would need to be deployed using the same resources as the WEC.

Survival
: The system should not be climate limited and must contain some level of inherent detuning or a survival mechanism. It would be unreasonable for devices of this size to be designed individually for a given climate in the same way that larger systems are currently.

Power Quality
: The MicroWEC device must be a self-contained system that provides smoothed power out to an external load. Furthermore, it must be capable of providing a minimum level of power at all times. It is understood that this may not be a strict requirement in all applications, but this criterion is helpful for the purposes of comparison, as discussed further below.

Operational
: Ultimately such a system should be capable of operation for multiple years, although it may not be practical for the first iteration of such a system to comply with this.

Mooring
: See notes on structure above. It is envisioned that both free-floating and fixed position systems are potential applications. However, if a position mooring is required, it should be installable in the same way and with the same constraints as the device, without requiring special operations.

B. Subsystems

As with all WEC, a MicroWEC comprises three key subsystems as listed below. We will consider this logical breakdown into (somewhat) independently optimizable systems and use this as a framework for enhancement.

- **Wave to Mechanical Energy Capture**
- **Mechanical to Electrical Energy Conversion**
- **Energy Storage & Power Conditioning**

C. Power Metrics

While a power matrix provides the standard measure of WEC performance, this may be less relevant for a MicroWEC. Given that the MicroWEC is a standalone power system, supplying power to a (likely) somewhat constant load, the performance of the Energy Storage and Power Conditioning should also be considered as part of the overall performance. Thus it may be more practical to define a different, more relevant metric of power. Given that a typical use case might be powering an oceanographic sensor package, it is suggested that a suitable metric be the maximum power than can be provided without interruption 24/7/365 into an attached load. This would be a calculated trade-off between on-board storage and energy generation, but this simple and practical metric provides information on the capability of the WEC to power a load in a given climate.

III. Existing Approaches & WEC Archetypes

Referring to the EMEC categorization of different wave energy device types, let us consider the limitations and advantages of each with respect to operation within the constraints of a MicroWEC. A detailed description of the operating principles for each of the device archetypes presented here can be found in [5]. For each concept a subjective ranking of suitability for implementation at a micro scale is proposed.

Attenuator
: A key advantage is that the attenuator is a self referencing system and can provide inherent displacement limitation in steep waves. However, these devices tends to require that their length be a significant fraction of the wavelength. Flexible attenuator concepts, such as the bulge wave and flexible electro-polymer systems, may mitigate their size by the potential for simple deployment and light weight, but it is not clear if the PTO's required for these types of devices would scale well and be able to provide tangible amounts of power at this scale. ★★☆☆☆

Point Absorber
: The point absorber concept should be broken

into two categories: two-body and one-body (seafloor referenced). Both of these concepts have the potential for high capture width ratios, which is a significant benefit at small scale.

Two-Body: The two body point absorber is self referenced, and has the potential for high displacement with a correctly designed PTO which can result in good performance and deployability at small physical sizes. However, it does not have a natural survivability without some active adaptation, although this may be implemented through the use of flexible or variable volume designs. ★★★★☆

One-Body: Certainly the simplest concept at small scale, the bottom referenced point absorber has the ability for good power capture at small physical sizes. However, their requirement to reference against the seafloor means that the PTO stroke is directly related to the H_S of the sea state, which may be challenging for a small device. Furthermore, as the device must react in tension against the seafloor, this may require a different, heavier anchor than used exclusively for station keeping, thus the device size may become limited by the capability of the anchor. ★★★★☆

Oscillating Wave Surge Converter (OSWC)

Floating OSWC systems tend to have a lower capture width ratio (CWR) than other concepts [6], although they may have the potential for good operation in high waves due to the compliance of the flap. ★★☆☆☆

Oscillating Water Column (OWC)

The simplicity of the oscillating water column is such that it has previously seen use at small scale. This power generation concept has been built into lighting buoys [1], [7] and the reliability has been shown to be quite high. However, the power to weight ratio of these systems tends to be lower than other concepts, thus when considered within the limitations of a standalone easily deployable system, may result in quite low relative power. ★★★☆☆

Overtopping or Terminator

The physical size constraints for either of these approaches tends to disqualify them at the scale in question. Overtopping devices need to create a storage reservoir at minimal height above the waterline and it is expected that this minimum height would make a minimum working system too large or too low power to meet the specification. A terminator device may be more practical from a power and size standpoint, however, the requirement for a small system to operate in fully exposed waves would seem to be impractical for these concepts. ★☆☆☆☆

Submerged Pressure Differential

This type of device has a number of potential advantages with regards to operation as a MicroWEC. By operating sub surface it has natural power limiting in large waves and there may be specific instrumentation (or defense) applications that would require a sub-surface system. However, as with the one-body point absorber, the seafloor anchor would likely comprise a large proportion of the mass budget, although the device itself has the potential to be quite light. ★★★★☆

Rotating Mass

The rotating mass concept is highly scalable as demonstrated by the self winding wristwatch. Although the efficiency at a small scale may be reduced due to its sensitivity to the wave steepness, it is likely to have a good inherent survivability due to the enclosed nature of the system. ★★★☆☆

Other

While MicroWEC development should logically start as a development of one or more of the concepts noted above, the significantly different design space may well mean that an optimum MicroWEC architecture is a completely different concept not yet explored. It is suggested that it is important that the future direction of this work is not overly constrained by existing WEC archetypes and new concepts are explored. Such new development could perhaps be assisted by multi-objective optimization techniques as discussed in Section VI .

IV. Case Study

In order to investigate the potential of MicroWEC's, we will use performance data from a 1:10 prototype of a community scale grid-tie WEC (Oscilla Power Triton-C) as an indicative MicroWEC system. The general Triton architecture is shown in figure 3 and is further discussed in [8].We shall refer to this system as the hypothetical *MicroTriton* MicroWEC system. At its target scale, the Triton-C WEC is optimized for maximum performance with a characteristic dimension of 10m providing a power output of around 80kW in fully energetic ocean conditions. As such, the representative 1:10 model is not optimized for operation as a MicroWEC, but as we demonstrate, it is useful to establish a conservative estimate for performance at a small scale. The MicroTriton is shown in Figure 1.

The MicroTriton is a two-body WEC that fits within the physical specification of the MicroWEC definition. It comprises a floating surface expression, connected via three lines to a submerged, ring shaped reaction structure. As the float is excited by waves, relative velocity and force is developed with respect to the ring, which is then captured in a power take out system (PTO). The upper floating body is 0.8m x 1m with a mass of 30kg while the reaction body has a diameter of 1m and a mass of around 50kg. The ring and float can be placed into the water separately, (float first, ring second) ensuring compliance with the MicroWEC specification.

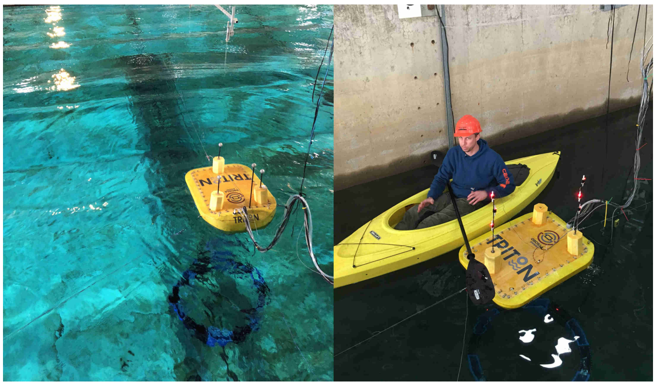

Fig. 1. Images of the TritonC 1-10 scale model 'MicroTriton'.

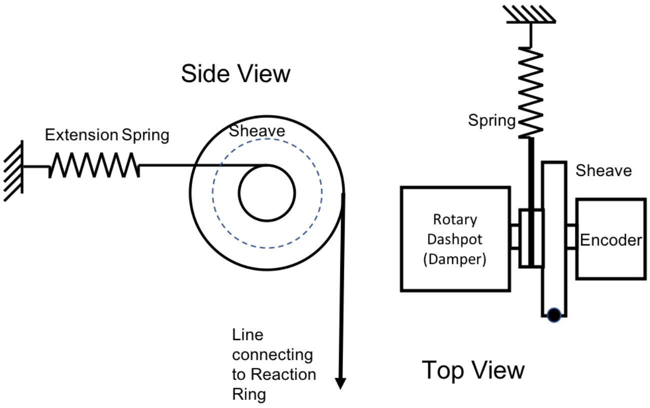

Fig. 2. Sketch of the model PTO implemented in the MicroTriton.

Performance data was collected in a series of physical model tests at the EC Nantes ocean tank in 2018 as part of a MARINET award and was used to derive the capture width curves shown in Figure 4. As can be seen, there is strong frequency dependence with a natural period of around 1.5s. The operating characteristic of the device also shows a reduction in in capture width with increasing wave height. Only passive PTO control (fixed, linear damping) was employed.

For the model tests, a mechanical PTO as shown in Figure 2 was used to provide a representative, linear, damping characteristic. Each line (tendon) between the surface float and submerged reaction ring is wrapped onto a separate sheave which provides an independent PTO. Linear damping was provided through a rotary

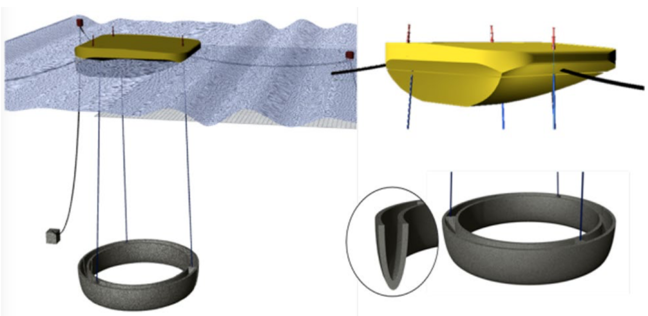

Fig. 3. Oscilla Power's Triton architecture.

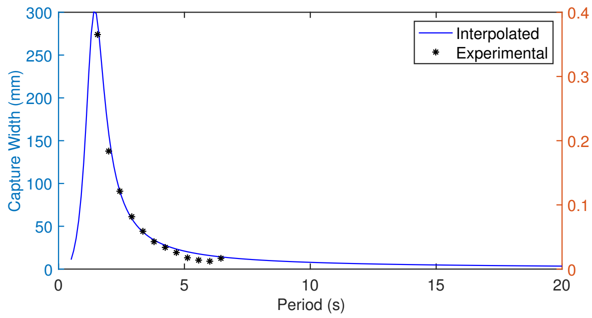

Fig. 4. Capture width curve for the MicroTriton. Dots indicate experimentally derived points. Capture Width Ratio (CWR) is shown on right hand Y scale.

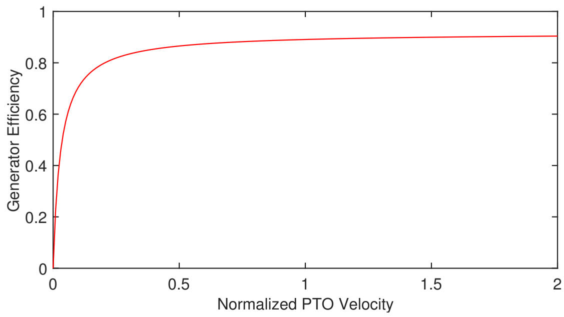

Fig. 5. Normalized Generator Efficiency curve.

dashpot, while the mean force required to balance the reaction ring mass was provided by a mechanical spring. The spring & damping parameters were identical for each of the three representative PTO's. Velocities, torques and forces were measured directly and used for subsequent analysis of performance. PTO output was calculated using the product of velocity and dashpot torque and then multiplied by an efficiency representing a suitably sized permanent magnet generator. The efficiency is derived from data provided directly from Siemens and shown in Figures 5 and 6.

D. Evaluation of the MicroTriton in a Range of Climates

Capture width and PTO efficiency data was applied to a series of climates around the US that would represent a range of typical deployment locations. The selected climates were Great Lakes, Gulf Of Mexico,

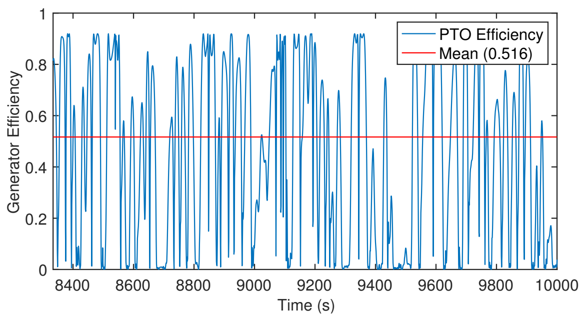

Fig. 6. Normalized time series of generator efficiency in typical sea state. Mean generator efficiency in the normalized case shown by red line.

North East US Coast (Isle of Shoals, NH) and Mid Pacific (Kanehoe, Hawaii).

The typical statistical approach to determining performance as the product of the climate joint probability distribution and the system power matrix may not be the most useful approach in the context of the MicroWEC. Given that a key characteristic that we previously defined was that the MicroWEC should provide a constant level of power, a time-series analysis was needed. This therefore requires the inclusion of power storage and a consideration of the time dependent variation of the climate. Furthermore, the mass of the energy storage system is a non trivial constraint for small systems, and must be considered as part of the overall mass. For the MicroTriton system considered here, it is felt that it is reasonable to assume the mass of the float could ultimately be reduced by up to 20%, thus we would be able to dedicate this mass to batteries without impacting performance. Using Li-Ion batteries with a specific energy density of 160Wh/kg [9] this gives us a maximum storage capacity of 800Wh. To address short term variability and provide a buffer between the PTO and batteries, a small supercapacitor (80F 30V) was included. Such an element allowed us to impose a charging limit of 60W to the Li-Ion batteries.

Physical model data in realistic irregular waves was used to understand how the mean (mechanical) power output of the MicroTriton varies with period and height. A 'typical' 30 minute power time series from an irregular wave test was then selected from the physical model data and normalized about the mean power. In this case a 'typical' power time series is one whose distribution provided the closest fit to the mean observed distribution across different tests. The normalized power series could then be scaled based on the expected mean power output for each H_S T_P pair, allowing the generation of a power time series for any incident wave condition. Although it is understood that this is an approximation, the power time series is expected to fit roughly the same distribution regardless of wave height or period. This approach allows the construction of a full year of time series power data from 30m averaged climate data. A similar approach was taken for the PTO velocity and it was assumed that all of the three PTO's would have a similar profile.

By understanding the variation in power and velocity over a wave by wave timeframe, we can assess the PTO efficiency in more detail and understand the power flows within the WEC and thus the limitations of the storage and impacts on the ultimate supplied electrical load.

The analysis used a minimum of three years of 30 minute averaged time series data collected for each of the climates indicated above from the NOAA NDBC website [10]. As discussed above, this data was used to generate estimated annual mechanical power and velocity time series for the MicroTriton in each of the climates. The velocity time-series data was used to generate a PTO efficiency time series which was multiplied by the power time series to give the instantaneous electrical power output. The instantaneous power was accrued into stored energy in both short and long terms storage at each timestep (0.1s) using the parameters above, across the full three year dataset.

To understand how different levels of storage impacted the mean delivered power, this analysis was repeated with different values for ultimate load and long term storage capacity. This allowed identification of the maximum constant load that could be achieved for a given storage level, within the constraints applied. The results of this analysis can be seen in Table I.

As storage increases, the mean power delivered starts to asymptote to the mean captured power, as expected. However, the seasonal variability of the climate will clearly have a significant effect on the amount of storage required to achieve this this. What we can see from this data is that with the exception of the Mid pacific climate (Hawaii) the lower energy climates tend to require less storage in order to provide a constant power close to the average maximum.

Also of note, the power available in the climate appears not to closely correlate with the captured or delivered power. This appears due to the fact that higher energy climates tend to have a larger proportion of longer periods within which the efficiency of the MicroWEC would be correspondingly smaller.

V. Analysis

While the MicroTriton described above is a scale model of a system optimized for performance in a grid-tie application and not specifically for this application, it is expected that it will serve to identify the order of magnitude of power that might be expected for a system constrained to the size of a MicroWEC. We can thus use this as a starting point from which to measure the performance gains that might be expected from a system that is more tailored to these operating conditions. Thus from here we can infer the capability and potential of MicroWEC systems in general.

E. Mechanical energy capture

While clearly different device architectures will have different performance bounds (maximizing passive performance through mass/buoyancy distribution is assumed for any architecture) further improvement in hydrodynamic performance for a given architecture can be achieved through geometry optimization and advanced (or active) controls.

In order to understand the quantitative value of improving these parameters, and thus help direct further optimization work, we can examine the impact of alterations to the CWR curve. While this will not identify specific improvements for the MicroTriton system, the purpose of this analysis is to explore the performance potential for MicroWECS in general.

Assessing the hydrodynamic performance improvement that can be expected is challenging to predict. However, for the purposes of this analysis, with appropriate consideration given to earlier optimization work [11], we consider geometric optimization and advanced controls as the primary approaches to performance improvement. For this analysis, it is assumed that through geometric modification (through changing the

TABLE I
MICROTRITON POWER OUTPUT ACROSS DIFFERENT CLIMATES FOR VARYING STORAGE LEVELS.

Climate	Climate Power *(kW/m)*	Mean T_P *(s)*	Captured mean *(W)*	Storage *(Wh)*	Delivered constant *(W)*	PTO Efficiency
Great Lakes	1.75	3.45	12.1	100	12.0	28%
Gulf of Mexico	6.63	5.88	26.37	200	22.58	42%
US East Coast	8.51	7.14	29.98	700	23.93	42%
Mid Pacific	13	8.33	29.11	200	27.1	40.2%

hull geometry) we may be able to shift the natural periods of the system, while through advanced controls, we can primarily increase the CWR at periods longer than the system natural period. This preliminary investigation considers these approaches as providing independent improvements, although in reality they will be dependent and any further work should explore an approach that would co-optimize these parameters.

If we look at the CWR for the system in Figure 4 the MicroTriton achieves a peak ratio of 0.4, which is in the typical range for point absorber devices [6], however, the short natural period and sharp frequency dependence contribute strongly to the performance. If we are able to improve the CWR at longer periods, we should be able to generate substantial improvements. In order to examine this, we generated three improved CW curves that represent three improvement scenarios. 1) Moving the natural period 0.5s, to the right through geometric optimization or architecture changes, 2) Improving the hydrodynamic efficiency at periods longer than the natural period through either advanced controls, using an assumed improvement in capture width of ~ $1.5 - 2\times$ at periods roughly twice the natural period, and 3) A combination of strategies 1 & 2. These improved capture width curves are shown in Figure 7 and the impact of these is detailed in Table II. As expected, increasing the hydrodynamic efficiency provides significant performance increases, with geometric optimization appearing to provide about 25% performance increase independent of climate. The application of advanced controls show even higher potential improvements in annual power of up to 50% with larger gains found in climates with longer periods. Further, these improvements compound well and together suggest that at least a 50% mechanical power output can be achieved with a successful co-optimization approach.

It is suggested that hydrodynamic performance improvements, such as those suggested, could be obtained through a machine learning or genetic algorithm approach, as previously identified in [3] [2] using the objectives identified here as goals for the search.

F. *Mechanical to Electrical Energy Capture*

In the MicroTriton case study, a simple rotary PTO was assumed whose efficiency varied as a function of the velocity. The physical size of the MicroWEC envelope along with the increased displacement requirements (as discussed in Section V-D) may provide quite tight constraints on the PTO design. However, if we consider that the efficiency curve as shown in

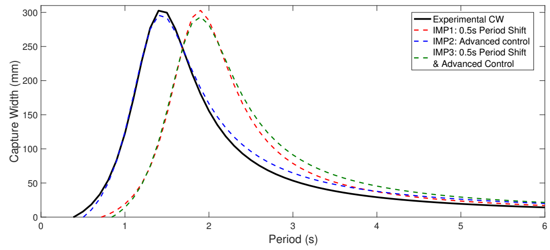

Fig. 7. Capture width curves that represent hydrodynamic performance improvements.

Figure 5 is fairly typical for any rotary generator, we can see that the effective efficiency due to typical wave driven velocity variation will be limited to roughly ~ 60%. When this is averaged across the year for different climates the mean efficiency becomes ~ 40% except for smaller climates where the lower velocities impact this more significantly. These values are low, but perhaps fairly typical of WEC PTO's and as such there is limited opportunity for significant performance gains. It should further be noted that static and dynamic frictional effects were included implicitly in the MicroTriton PTO, and as this was a representative scale model, significant effort was taken to reduce these effects. However, while experience has taught that friction is a significant obstacle in a representative physical model, MicroWEC's are intended for fully energetic seas with wave heights and excitation forces that are many times what would be expected in a physical model, so the contribution of friction may be less concerning.

G. *Storage Losses*

Losses in the power electronics and storage can effectively be simplified into energy losses where either short or long term storage is full and developed power has to be dissipated as heat. While there will be proportional losses in the power electronics that are in the order of 2-5% percent, these are relatively insignificant. Short term storage is required to provide a high capacity buffer between the generator and the longer term storage. The use of supercapacitors in this function has been explored [12] in MHK devices and allows the highly variable generator output to not exceed the capacity of the subsequent downstream electronics. In the case of the MicroWEC it would provide a smooth power limited charge rate to a Li-Ion or similar long term storage battery. For the climates and powers examined with the MicroTriton case study,

TABLE II
MICROTRITON DELIVERED POWER WITH DIFFERENT CAPTURE WIDTH IMPROVEMENT STRATEGIES ACROSS DIFFERENT CLIMATES.

Improvement Strategy	Great Lakes 1.75kW/m Power (W)	Gain	GoM 6.63kW/m Power (W)	Gain	US East Coast 8.51kW/m Power (W)	Gain	US Pacific 13kW/m Power (W)	Gain	Mean Improvement
Baseline	12.04W		23.04W		29.98W		26.77W		
Period Shift (PS)	14.96W	24%	27.90W	21%	37.22W	24%	33.13W	24%	23%
Active Control (AC)	16.63W	38%	33.26W	44%	45.13W	51%	41.95W	57%	47%
PS + AC	18.57W	54%	35.36W	53%	47.34W	58%	42.58W	59%	56%

the energy lost due to limitations in either the long or short term storage sizes appears to be relatively small and typically around 10% or less of the provided power, as shown by the difference between the mean captured power and delivered power in Table I.

H. Additional Challenges

The use of scaled-down larger WEC concepts is not expected to be a practical solution for micro and small WEC systems. When devices are scaled for model testing, the focus is always on ensuring representative performance, in a scaled environment. As such, the inherent survivability of these systems in a fully exposed sea, where the environment may be an orders of magnitude more energetic, is unlikely to be adequate. Although the frequency dependence of micro-scale systems will help to limit loads, as discussed in this paper, the operation of MicroWEC's in larger waves will need to be carefully considered and will likely require quite different approaches from existing utility scale WEC concepts.

One of the most important considerations with regards to survivability (and performance) for a MicroWEC is the required PTO displacement. The MicroTriton model and the larger Triton C system system both employ a high displacement rotary drivetrain that permits a PTO stroke that is greater than the device characteristic dimension. It can be seen that long PTO stroke is a common requirement for smaller WEC's across different archetypes as this will correlate strongly to the max H_S for a given deployment environment. While the specifics of certain WEC archetypes will constrain displacements differently (as noted above in section III), this trend is expected to remain.

VI. FURTHER WORK

An additional concern is that the data used in this work is limited to that which is available publicly and as such the minimum reported period of the data is 3 or 4s. The majority of NDBC wave measurement buoys are designed to filter out shorter periods than this, however, small wind waves with periods in the 1.5-3s range are likely to be important for power generation. MicroWEC systems are especially sensitive to the higher frequency tail of the spectrum which in this analysis must be assumed for < 3s, As an example, the discussed MicroTriton system will produce roughly 30W in 1.5s / 30cm waves. The short wave content should be directly investigated in spectra of interest for future analysis.

The unoptimized MicroTriton WEC appears to be able to produce around 25W constant, that is somewhat independent of climate. The largest gains are likely to be achieved through the improvement in the device capture width as indicated in Table II. These improvements imply that a power of around 40-50W may be possible for a MicroWEC. Further gains may be possible with different device archetypes and through geometric optimization. A key advantage of MicroWEC's is that the small size means there will be engineering approaches available that are simply not practical at large scale, such as 3d printing, flexible structures, & specialist materials. Furthermore, the small size allows for design iteration at 'full scale', resulting in a faster and lower cost design evolution.

Only one archetype, the two-body point absorber was considered here and in future we intend to examine how the capture width varies for different archetypes. Furthermore, we anticipate that machine learning and system optimization approaches can be bought to bear on the hydrodynamic design of the most promising archetypes. In particular, the development of drivetrains that can accommodate proportionally greater stroke is an important requirement and a significant engineering challenge for MicroWEC systems.

It should be understood that the storage size needed to maintain a constant output will increase as the MicroWEC power performance increases, however, storage will be limited by the physical constraints of the MicroWEC, and will thereby provide an upper constraint on the maximum constant load that can be achieved. As an example, if we improve the MicroTriton hydrodynamic performance by 50%, we can only increase the constant output power by ~ 20% before exceeding the mass limits imposed by the maximum storage criteria (1000Wh).

VII. CONCLUSIONS

In this paper we have presented the general concept of the MicroWEC. We have shown through an experimental case study that mean annual power outputs in the order of 50W may be expected with some optimization, and that the power output is far less dependent on the climate that would be expected. We have also elucidated on some of the main design challenges and although it is clear that hydrodynamic optimization and controls are key to increasing the power output, the physical mass constraints of on-board storage may prove to be a key limiting factor to the maximum deliverable power.

Most importantly, however, by demonstrating the feasibility of a micro scale WEC that can provide a constant power output even in lower energy climates such as the great lakes, we hope to pave the way for the development of technology that can enable new persistent marine applications.

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