# TECHNO-ECONOMIC OPTIMIZATION OF A DEEP WATER OSCILLATING WATER COLUMN DEVICE

**Mirko Previsic[1] and Anantha Karthikeyan**
Re Vision Consulting
Sacramento, CA, USA

**John McCarthy and Tony Lewis**
Ocean Energy USA
Sacramento, CA, USA

[1]Corresponding author: mirko@re-vision.com

## INTRODUCTION

Most Wave Energy Conversion device-types have undergone some fundamental development and optimization. However, most developments focus on a sub-set of relevant device characteristics such as device performance, without a view on the cost impact of performance-enhancing measures. This approach leads to sub-optimal solutions most of the time and oftentimes fails to identify the optimal design configuration.

A paradigm shift occurs once integrated design methods are applied to the device development process to identify the major cost-drivers and then finding an optimal configuration within a parametric space. These design-spiral approaches tend to be significantly more cost-effective than more linear approaches. However, they do require the appropriate utilization of a wide range of numerical methods and parametric costing tools.

In this paper we present a framework for the techno-economic optimization of a deep-water oscillating water column device. Economic analysis of the baseline device has shown that the levelized cost of electricity from this type of technology is largely driven by structural costs of the hull itself, which was targeted to reduce the cost of electricity from this technology.

To optimize the overall device envelope, all tools had to be setup to allow for rapid parametric variation of dimensions to allow an efficient optimization process to unfold. Models setup included: (1) A parametrically driven performance model, (2) a parametrically driven structural model, (3) an extreme loads model to provide inputs to the structural model, and (4) a parametrically driven cost model. An appropriate economic model was setup to allow for the determination of the Levelized Cost of Electricity (LCoE) for each design iteration studied.

Once these models were setup and validated using appropriate wave tank testing methods, an iterative design-spiral approach was used to systematically identify the lowest-cost design configurations.

This project clearly demonstrated that significant material and cost-reductions are attainable using a carefully designed structural optimization process that is guided by an intelligent techno-economic optimization process. It also demonstrates that for certain structures, FRP may be an economically competitive option at commercial unit scale.

### The WEC Device

The Ocean Energy (OE) Buoy, based on the oscillating water column principle, converts wave energy into useful mechanical energy using the principle that the air contained in the plenum chamber is pumped through an air turbine system by the wave action. This mechanical energy is then converted to electrical power. The device isolates the power conversion system from the seawater and also provides high speed air flow to the turbine.

Initial cost and economic benchmarking studies completed came to the conclusion that the LCoE from this device is primarily driven by its structural efficiency. By structural efficiency we

Preprint submitted to 2018 6th Annual Marine Energy Technology Symposium.
Received January 16, 2018.

refer to a devices ability to generate a certain amount of energy per unit of structural cost of the main absorbing structure. This conclusion was largely due to the following factors: (1) the device is relatively large in scale, so that auxiliary system costs such as riser cables, grid connection, and other items are spread over a significant amount of energy production per year. (2) The system uses an air-turbine system that is known to be efficient, reliable and cost-effective, creating minor cost impacts. (3) It is compliantly moored with mooring loads being low-enough to create insignificant cost impacts and the scale of the device allows those costs to be spread over a sufficiently large annual energy production.

Hydrodynamically, the device is relatively complex, because power capture relies on 4 heavily coupled modes (heave, pitch, surge and the internal free surface). Because of that complexity, it is difficult to fully optimize the system using first principles or design intuition. As a result, the exploration of the design space using numerical sensitivity studies provided a more appropriate optimization approach.

**The Tools Developed**

As a result of these initial findings, the focus of the study was on optimizing the hull dimensions and minimizing the device's structural content. The fundamental aim was to minimize structural costs and maximizing energy production. To do so required a number of different tools to be setup:

1. An Extreme loads model to allow extreme structural loads to be identified. Different numerical methods were investigated including CFD and Boundary Element Methods, however, they proved to be un-reliable and scaled values from tank-testing ended up being used to determine extreme loads.
2. A device performance model was setup that leveraged Re Vision Consulting's in-house numerical time-domain simulation framework RE-WEC. The code-framework leverages WAMIT frequency domain data and augments them in the time-domain with non-linear terms to represent the viscous, mooring and PTO forces. Annual energy yield was benchmarked on a reference site in Northern California near Humboldt Bay, California.
3. A parametrically-driven structural model was used to determine the amount of material needed for any particular configuration. This model was built based on fundamental stress analysis techniques, instead of trying to adapt an arbitrary design rule from the maritime industry.

Performance and extreme load assessment tools were validated using wave-tank testing data to ensure that they were valid. A StarCCM+ model was setup to try to establish extreme loads, however confidence-levels were insufficient to utilize it as a design tool in the integrated design assessment process. The structural model was validated using a commercial Finite Element Analysis (FEA) package, which confirmed that the parametrically driven model was appropriate.

**Cost & Economics**

Having accurate cost data proved to be as important as determining the structural loads and device performance. An extensive cost-study was carried out that started with a comparison of different material choices based on the baseline design. This was done to capture the geometric complexities of the final design while considering all cost impacts including construction, transport and systems integration. Design and cost assessments were carried out for five different embodiments:

*Standard Steel Hull* - Typical steel design techniques were applied resulting in a structure that was built from standard I-beams and plates.

*FRP Hull* – An FRP-version of the steel hull was designed that consisted of bonded I-beams and FRP-plates.

*Honeycomb FRP Hull* – A honeycomb-type structure was developed which allowed the structure to have appropriate stiffness while reducing structural content and simplifying the manufacturing and assembly process.

*Concrete Structure* – A lightweight reinforced concrete structure was designed. To prevent corrosion of the embedded steel, walls had to be designed sufficiently thick, leading to a relatively heavy structure.

*Concrete-Steel Sandwich Structure* – A novel lightweight steel/concrete sandwich design was evaluated that provided interesting cost-advantages due to low labor requirements.

Detailed cost-assessments were made for manufacturing volumes of 100 units or more. This was an important step because single unit cost tend to be dominated by fixed costs and other single unit expenses which are not representative in commercial production volumes. The honeycomb FRP structure was ultimately selected for the detailed design because it provided some interesting competitive advantages including a lower hull handling weight and significant

Preprint submitted to 2018 6th Annual Marine Energy Technology Symposium.
Received January 16, 2018.

advantages in the manufacturing and assembly process.

While the optimization of the hull was at the center of our effort, the optimal configuration of the overall system depended at least to some extent on all the other cost-centers. To account for these costs in an appropriate manner we developed simple cost-functions that allowed these cost-centers to scale with device scale and rated power of the machine. While these scaleable cost-functions are not as accurate as the hull-cost numbers, it was important to incorporate their effect on the LCoE to ensure that we arrived at an optimal hull configuration.

The LCoE model itself utilized standard economic assumptions provided by the US Department of Energy. These rates represent commercial assumptions for mature renewable energy projects at commercial scale and are therefore useful and appropriate for this type of design process.

**Optimization Process & Design Spiral**

An initial scoping study determined over 10 different dimensional variables of interest to the structural optimization process. After some initial sensitivity studies this list was reduced to about 5 critical design variables (such as length, width etc.) that were studied systematically. The initial approach was to leverage full parametric capabilities and evaluate all of the potential design options. However, even if each one of the design variables only has 10 states, this would have led to 10^5 individual configurations to be studied – a design space that was simply too large to handle effectively. Instead, an iterative and adaptive process was used that reduced the number of configurations studied to about 100.

It is important to point out that this optimization was completed for a single reference site and the optimal configuration would look different for other sites.

**Results and Conclusions**

During this project, we were able to demonstrate an integrated techno-economic optimization process that leveraged numerical and experimental capabilities in a design-spiral design approach.

The design optimization process yielded an improvement in the structural efficiency of the device by about 3.5X while the levelized cost of electricity improved by over 60% for the final configuration compared to the baseline. It should also be pointed out that more radical design options were not evaluated during the study that could enable further cost-reduction pathways or design alternatives.

The final FRP design allows for a modular manufacturing approach that can leverage existing FRP manufacturing facilities to pre-fab suitable modular FRP planks that can be assembled close to the final deployment site using a novel jointing process. This allows the manufacturer to leverage economies of scale early in the commercialization process while minimizing labor costs and overheads.

Several areas for additional optimization were identified, including optimal controls, an improved mooring design and an improved launch and recovery process. These were largely outside of the scope of the present project but are being addressed through other strategic projects aimed at accelerating the reduction of the LCoE.

**ACKNOWLEDGEMENTS**

This material is based upon work supported by the Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), under Award Number DE-EE0006403.

Preprint submitted to 2018 6th Annual Marine Energy Technology Symposium.
Received January 16, 2018.