Design and Optimization of a Point Absorber for the Mediterranean Sea

Proceedings of the ASME 2022 41st International Conference on Ocean, Offshore and Arctic Engineering
OMAE2022
June 5-10, 2022, Hamburg, Germany

OMAE2022-81530

DESIGN AND OPTIMIZATION OF A POINT ABSORBER FOR THE MEDITERRANEAN SEA

Alberto Ghigo*
Marine Offshore Renewable Energy Lab
(MOREnergy Lab)
Department of Mechanical and Aerospace Engineering
Politecnico di Torino, Turin, Italy

Fabio Carapellese
Marine Offshore Renewable Energy Lab
(MOREnergy Lab)
Department of Mechanical and Aerospace Engineering
Politecnico di Torino, Turin, Italy

Sergej Antonello Sirigu
Marine Offshore Renewable Energy Lab
(MOREnergy Lab)
Department of Mechanical and Aerospace Engineering
Politecnico di Torino, Turin, Italy

Giovanni Bracco
Marine Offshore Renewable Energy Lab
(MOREnergy Lab)
Department of Mechanical and Aerospace Engineering
Politecnico di Torino, Turin, Italy

ABSTRACT

In the last few years, a wide range of Wave Energy Converter (WEC) have been designed. Among the most interesting technologies for multiple applications, there is the point absorber: if on one hand, these devices guarantee a limited energy production, on the other hand, they ensure good performances, do not require complex installations and have a limited visual and environmental impact. However, a major obstacle to the development of these technologies is the high investment costs, which prevent their development from an industrial point of view.

The purpose of this paper is to present a frequency domain model for a cylindrical point absorber and to perform a holistic optimization that maximizes the extracted power and minimizes device costs. Optimized parameters comprise shape, dimensions, mass properties, ballast and draft.

The optimization is carried out considering different installation sites in the Mediterranean Sea, chosen from the most productive ones, such as the island of Pantelleria along the Sicily channel and Alghero along the north-western coast of Sardinia, to define an optimal point absorber design for offshore applications in the Mediterranean Sea.

Keywords: Wave Energy, Wave Energy Converter, Point Absorber, Genetic Algorithms, Design Optimization, Mediterranean Sea

NOMENCLATURE

AEP Annual Energy Production
AWS Archimede Wave Swing
BEM Boundary Element Method
DOF Degree Of Freedom
GA Genetic Algorithm
LCOE Levelized Cost Of Energy
PTO Power Take Off
RAO Response Amplitude Operator
WEC Wave Energy Converter

*Address all correspondence to this author.

INTRODUCTION

To reduce greenhouse gas emissions and ensure a more sustainable future in the coming years, it is essential to encourage the development of renewable energy sources. The Paris Agreement, adopted on December 2015 provides to limit global warming to 1.5 degrees Celsius, compared to pre-industrial levels [1]. Currently, fossil fuels are still predominant over renewable sources: according to Renewables 2020 Global Status Report, fossil fuels consumption represents the 79.9% of the total global share of energy consumption, against 11% of renewable sources, like wind, solar and hydropower [2]. But the growth rate of renewables has undergone substantial increase since 2010: in 2020, annual renewable capacity additions increased 45% to almost 280 GW, the highest year-on year increase since 1999 [3]. Among the most promising sources we find solar and wind power. Solar PV development will continue to break records, with annual additions reaching 162 GW by 2022 – almost 50% higher than the pre-pandemic level of 2019 while global wind capacity additions increased more than 90% in 2020 to reach 114 GW [3].

The growth in the renewable sector was due to a number of factors including political support, financial incentives and reduction in the costs of technology making renewable energy cost competitive [2]. Among the leading countries in this rapid growth there are China, Europe and the United States [4].

Growth forecasts are optimistic: despite the Covid-19 pandemic which hindered the development of new projects, the growth rate will remain fairly constant in the next 2 years, reaching respectively with 270 GW becoming operational in 2021 and 280 GW in 2022 [3].

Ocean energy

Among the renewables that have experienced interesting growth in recent years we find ocean energy devices, that exploit waves, currents and tidal to produce energy. In Europe, the highest resource potential for ocean energy exists along the Atlantic coast, with further localized exploitable potential in the Baltic and Mediterranean seas. The theoretical potential of wave energy in Europe is about 2800 TWh annually, and the potential for tidal current was estimated to be about 50 TWh per year [5].

The European Commission supports this development and in 2020 has drawn up a strategy to encourage the development of offshore renewable energy technologies. The main objectives provides 1 GW of installed power for Ocean Energy in 2030, to then reach 40 GW in 2050 [6]. The wave energy, thanks to high predictability, low variability and extremely high energy density, is among the most promising.

In Europe, the highest resource potential is mainly located along the Atlantic coast and in the North Sea. The Mediterranean Sea on the other hand is less energetic but also is characterized by less dangerous extreme conditions. It represents a favourable starting point to develop technologies that later will be scaled up to more powerful sites.

Due to the immense potential of wave energy, a wide range of wave energy converter ideas has been formed to capture energy from waves. There is a great variability of the available designs: among the most diffused there are oscillating water columns, oscillating wave energy converter, rotating mass generators and point absorbers.

Review of point absorber technology

The aim of this paper is to present recent research on point-absorber wave energy converters (WEC) specifically designed for mild climates, such as the one of the Italian seas. These devices oat on the free surface of the ocean or are placed underwater. They can be placed both nearshore or offshore and are held in position by a mooring system connected to the seabed. The wave energy is absorbed by radiating a wave with destructive interference to the incoming waves. A PTO system uses the movement of the buoy in order to extract energy. The production of electrical energy can be achieved via linear generators or via generators driven by mechanical linear-to-rotary converters or hydraulic pumps.

Over the past few years many devices have been studied and developed due to the simplicity of design, the simplicity of the hydrodynamic interaction and similarity with the well-known buoys .

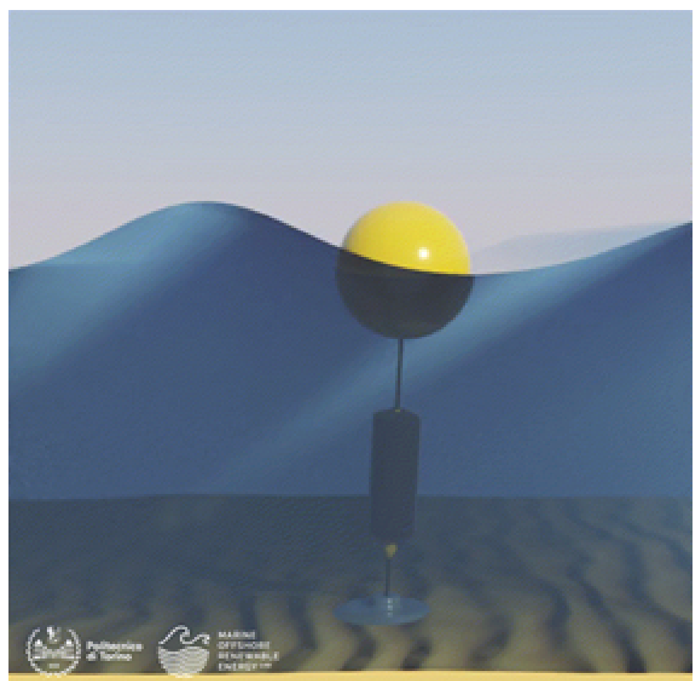

FIGURE 1. POINT ABSORBER.

The **PowerBuoy** is a point absorber, developed by Ocean Power Technologies [7], [8]. The devices is made by two parts: a floating structure with one component relatively immobile, connected throw a mooring system with the seabed, and a second component with movement driven by wave motion. The relative motion is used to drive electromechanical or hydraulic energy converters. A 40 kW PowerBuoy prototype was installed in 2005 for testing offshore from Atlantic City, New Jersey.

The **AquaBuoy**, developed by the AquaEnergy Group, is a point absorber that utilize the wave energy to pressurize a fluid that is then used to drive a turbine generator [9], [10] . The vertical movement of the buoy drives a broad, neutrally buoyant disk acting as a water piston contained in a long tube beneath the buoy. The water piston motion in turn elongates and relaxes a hose containing seawater, and the change in hose volume acts as a pump to pressurize the seawater. The AquaBuoy design has been tested using a full-scale prototype, and a 1 MW pilot offshore demonstration power plant is being developed offshore at Makah Bay, Washington.

Archimedes Wave Swing (AWS) is a wave energy converter is an off-shore, fully-submerged point absorber. Its main two parts are the silo (a bottom-fixed air-filled cylindrical chamber) and the floater (a movable upper cylinder) [11]. Due to changes in wave pressure, the floater heaves and when the AWS is under a wave top, the floater moves down compressing the air inside the AWS. When the AWS is under a wave trough, pressure decreases and consequently the air expands and the floater moves up. In 2004 a 2 MW prototype has already been built and tested at the Portuguese northern coast.

FIGURE 2. POWERBUOY, AQUABUOY AND ARCHIMEDES WAVE SWING, FROM [7], [9] AND [11].

Wavebob is a free floating, self-reacting, axi-symmetric point absorber [12]. It consists of two concentric floating buoys: a torus and a float-neck-tank. The FNT is positioned inside the torus with a small gap called a moonpool separating the two bodies. This is tuned to the incident wave action using a system to change the device's natural resonance frequency without changing the float's draught.

The Uppsala point absorber is composed of a floating body linked to a platform moored to the seabed containing the PTO [13], [14]. The generator is a directly driven neodymium-iron-boron permanent magnet linear generator designed to take advantage of the slow movement of the waves. The buoy action is transferred directly to the generator with a rope activating the translator within the stator, thus converting the kinetic energy of the wave to electric energy. The stroke length of the translator is limited by end stops at the top and bottom. To keep the WEC on the seabed, a concrete foundation with a weight of 35 tonnes is attached at the bottom of the capsule. When the buoy moves with the motion of the waves, the translator inside the linear generator will follow the motion in heave, thus inducing a varying magnetic flux in the stationary stator windings. The power output from the WEC is influenced by a number of different parameters like the buoy size, translator weight, damping.

CETO is a fully submerged point absorber: the hull is made of a submerged buoy that sits a few metres below the surface of the sea and moves with the waves. This orbital motion drives a power take-off (PTO) system that converts this motion into electricity [15]. A prototype scale test of three of these units was installed and tested as part of the Perth Wave Energy Project (PWEP) at Garden Island in Western Australia.

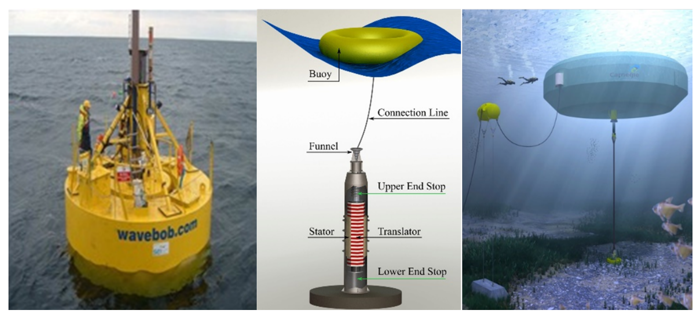

FIGURE 3. WAVEBOB, UPPSALA POINT ABSORBER AND CETO, FROM [12], [13] AND [15].

MATERIAL AND METHODS

The purpose of this paper is to present a frequency domain model for a cylindrical point absorber with one degree of freedom and to perform a holistic optimization that maximizes the extracted power and minimizes device costs. The numerical model is based on the potential flow theory while all the hydrodynamic properties such as the added mass and the radiation damping are calculated using the Boundary Element Method (BEM) software Nemoh [16]. Waves are described by a Jonswap spectrum, with the resource data (wave height and period) extracted from the ECMWF ERA5 database [17] and then post-processed to get the wave scatter and the power matrix for each site.

Optimized parameters comprise shape, dimensions, mass properties, ballast, draft and control parameters. The optimization is carried out considering different installation sites in the Mediterranean Sea, chosen from the most productive ones, such as the island of Pantelleria along the Sicily channel and Alghero along the north-western coast of Sardinia, to define an optimal point absorber design for applications in the Mediterranean Sea. The model, schematized in Figure 4, is made up of several blocks, the geometry, the generation of the mesh and the calculation of the hydrodynamic parameters, the generation of the waves deriving from the specific installation site. The model's outputs include net productivity.

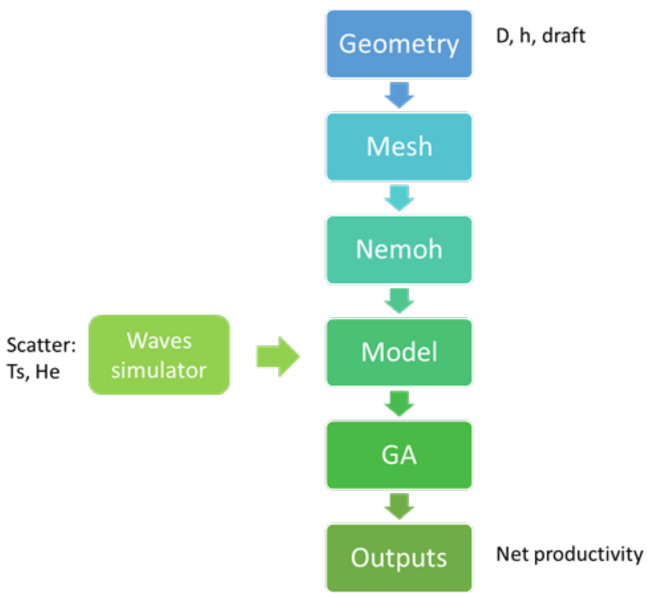

FIGURE 4. OPERATING SCHEME OF THE NUMERICAL MODEL.

Frequency domain model

The oscillating behavior of many dynamic systems can be described with the one degree of freedom (1 DOF) oscillating system presented in Figure 5. According to this model, the whole mass of the system is considered to be concentrated in the solid mass element m. Also, the stiffness of the system is represented by the spring element which applies restoring forces on the body. These forces are linear function of the displacement x of the solid and depend on the stiffness coefficient k. The third element of the system is the damper which represent all the applied damping forces during an oscillation. The damping forces depend on the damping coefficient c.

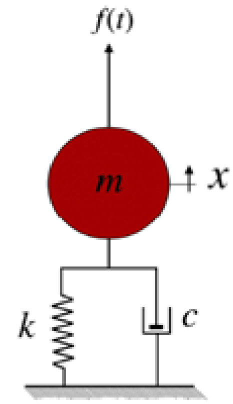

FIGURE 5. GENERAL MASS-SPRINGER-DAMPER SYSTEM.

Frequency-domain analysis is widely used to calculate the dynamic response arising from a monochromatic sinusoidal incident wave. Taking into account that the incoming regular wave has angular frequency ω the oscillating response X a floating solid body is expressed by:

$$(M+A(\omega))\ddot{X}+B(\omega)\dot{X}+KhX=F(\omega) \tag{1}$$

where M is the mass-inertia matrix of the body, $A(\omega)$ is the frequency-dependent added mass matrix and $B(\omega)$ represents the radiation damping matrix of the buoy. The term Kh is the linear hydrostatic stiffness matrix which depends on the buoyancy force for a floating solid body, and $Fe(\omega)$the total wave excitation force composed by Froude–Krylov and diffraction forces. The displacement X, velocity $\dot{X}$ and acceleration $\ddot{X}$ of the body are vectors containing the studied translational motions and rotations (x, y, z, φ, σ, ψ). In this case, the only degree of freedom considered is the displacement of heave, ie along the z-axis.

Equation 1 is the equation of motion of a floating buoy in the frequency domain which can be used to obtain the response amplitude operator (RAO) of the dynamic system. RAO can be defined as transfer functions used to figure out the influence that a specific sea state will have upon the dynamics of a buoy (WECs) through the water waves. Assuming that the incoming amplitude wave is $\zeta = \zeta_0 ei\omega t$, the frequency domain RAO can be written as:

$$RAO(\omega)=\frac{Fe(\omega)}{Kh-(M+A(\omega))\omega^2+iB(\omega)\omega} \tag{2}$$

where $Fe(\omega)$ represents the linear excitation force complex amplitude per wave height amplitude. The RAO is a frequency dependent and complex function.

Geometry

The model allows you to select 3 different types of geometry, visible in Figure 6:

- Cylinder
- Sphere
- Cylinder with ballast

The free parameters are defined according to the chosen geometry. For example, in the case of the cylinder the parameters that act as free variables are:

- Radius, r
- Height, h
- Submerged height of the device, draft

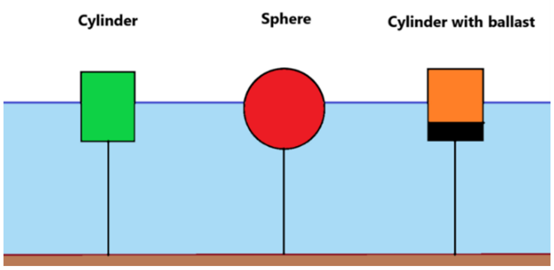

FIGURE 6. DIFFERENT GEOMETRIES INVOLVED IN THE ANALYSIS.

Mesh generation and hydrodynamics

For the calculation of the hydrodynamic parameters, the BEM Nemoh software [16], developed by the Ecole Centrale of Nantes, is used. Nemoh is a Boundary Element Methods (BEM) code dedicated to the computation of first order wave loads on offshore structures (added mass, radiation damping, diffraction forces).

The creation of the mesh of the point absorber, necessary for the BEM software, is carried out using the aximesh function, included in the Nemoh package. This function is easily implemented for axisymmetric solids, such as the cylinder and the sphere. The Nemoh software, called up through the Nemoh function defined as follows:

$$[A, B, Fe] = Nemoh(\omega, dir, depth) \quad (3)$$

Returns the matrix of the added mass $A(\omega)$, that of the radiation damping $B(\omega)$, the external forcings $Fe(\omega)$ after having received as input the frequency vector ω, the direction of the waves and the depth of the installation site. This last parameter, considered constant for all simulations, was set at 30 m.

Irregular waves

Real waves are the result of systems of winds blowing on the water surface. Swells are usually long-crested nearly-unidirectional sinusoidal waves because they were generated by the wind in a previous space or time, but local winds still affect the sea surface, producing short-crested multidirectional highly-irregular waves (sea). For this reason, the sea surface may be expressed as a Fourier series, a superposition of-theoretically infinite regular waves components with different height, frequency, wavelength and random phase (Figure 7).

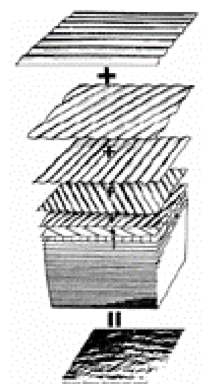

FIGURE 7. SUPERPOSITION OF DIFFERENT REGULAR WAVES, FROM [18].

For a single direction, this takes the following form:

$$h(x,t) = \sum_{n=1}^{N} a_n sin(w_n t - k_n x + \varphi_n) \quad (4)$$

where the subscripts n indicate that the wave parameters are relative to the n-th component of the summation along N. This summation is finite because the contribution of the the n-th wave becomes less significant for increasing frequencies. A wave spectral density function $S_\zeta(\omega_n)$, calculated as the variance function of the waves amplitudes an, carries information about the significance of each wave component-identified by the n-th frequency ω_n in the signal; narrower curves represent waves closer to be regular.

Wave energy spectra

A wave spectrum which describes a uni-direction wave energy sea site is dependent on two parameters: the significant wave height, $H_{1/3}$, and the average wave period T or the peak period T_p. The general form is:

$$s_\zeta(\omega) = H_{1/3} f(\omega, T) \tag{5}$$

In the end of 70s an historical wave measurement program, named the Joint North Sea Wave Project (JONSWAP) took place in the North Sea [15]. The outcome of the specific scientific program is a spectrum considering fetch-limited wind generated seas. The mathematical definition of the JONSWAP spectrum is:

$$s_\zeta(\omega) = \frac{320 H_{1/3}}{T_\mathrm{p}{}^4} \omega^{-5} e^{\frac{1950\omega^{-4}}{T_\mathrm{p}{}^4}} \gamma^A \tag{6}$$

Where:

- $\gamma = 3.3$ (peak enhancement factor)
- $A = exp - \frac{\frac{\omega}{\omega_\mathrm{p}} - 1}{\sigma\sqrt{2}}$
- $\omega = \frac{2\pi}{T_\mathrm{p}}$
- $\sigma = \sigma(a)$. For $\omega < \omega_\mathrm{p}$ results $\sigma = 0.07$, while for $\omega > \omega_\mathrm{p}$ gives $\sigma = 0.09$

GENETIC ALGORITHM OPTIMIZATION

A genetic algorithm (GA) is a model or abstraction of biological evolution based on Charles Darwin's theory of natural selection. The algorithm repeatedly modifies a population of individual solutions: at each step, the genetic algorithm randomly selects individuals from the current population and uses them as parents to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution [19]. Originally developed by John Holland and his collaborators in the 1960s and 1970s, it involves the use of the crossover and recombination, mutation, and selection in the study of adaptive and artificial systems [20]. These genetic operators form the essential part of the genetic algorithm as a problem-solving strategy.

Compared to traditional optimization algorithms, there are many advantages of genetic algorithms. Two most notable are: the ability of dealing with complex problems and parallelism. Genetic algorithms can deal with various types of optimization, whether the objective function is stationary or non-stationary, linear or nonlinear, continuous or discontinuous, or with random noise. This feature makes it ideal to parallelize the algorithms for implementation [20]. As for the disadvantages, it is important to underline that the formulation of fitness function, the size of population, the choice of the important parameters such as the rate of mutation and crossover, and the selection criteria of the new population should be carried out carefully. In fact, any inappropriate choice will prevent the algorithm from converging and produce divergence or it will produce meaningless results.

In the last years, many variants of genetic algorithms have been developed and applied to a wide range of optimization problems, from graph coloring to pattern recognition, from discrete systems (such as the travelling salesman problem) to continuous systems (e.g., the efficient design of airfoil in aerospace engineering), and from financial markets to multi-objective engineering optimization. In the field of ocean engineering, there are many technologies optimized with genetic algorithms, such as wave energy converters [20], floating offshore wind platform [19], etc.

The generic Matlab syntax for genetic algorithm has the following form [21]:

$$x = ga(fun, nvars) \tag{7}$$

where *ga* finds a local unconstrained minimum, x to the fitness function, fun; and *nvars* is the number of design variables of the fitness function.

The considered fitness function fun is a cost function that takes into account the overall cost of the point absorber, in particular the cost of the material, the cost of the mooring system and anchor, the electrical system, as well as and the installation:

$$\begin{aligned} fun = & cost_\mathrm{hull} + cost_\mathrm{mooring} + cost_\mathrm{anchor} \\ & + cost_\mathrm{electrical\ cable} + cost_\mathrm{installation} \end{aligned} \tag{8}$$

The data in Table 1 have been obtained from the literature [22].

RESULTS AND DISCUSSION

To carry out the simulations, some of the most productive sites in the Italian Mediterranean Sea were considered: Alghero, located near the northern coast of Sardinia, the island of Pantelleria, located along the Sicilian Channel and Licata, in the southern part of Sicily.

The Matlab built-in genetic algorithm software ga was used to run an optimization of the device on all the three sites described previously. The main goal was to minimize the LCOE, thus making the device economically comparable to other existing technologies and, at each iteration, the genetic algorithm was

TABLE 1. MAIN COST ITEMS USED IN THE FITNESS FUNCTION TO CALCULATE THE LCOE.

Item	Value
Steel	3.5 €/kg
Ballast	0.1 €/kg
Mooring	500 €/m
Anchor	12000 €/unit
Electrical cable	1000 €/m
Installation	25000 €

able to choose a new value for the main three parameters describing the hull's characteristics: the radius r, the height h and the submerged height of the device, the draft.

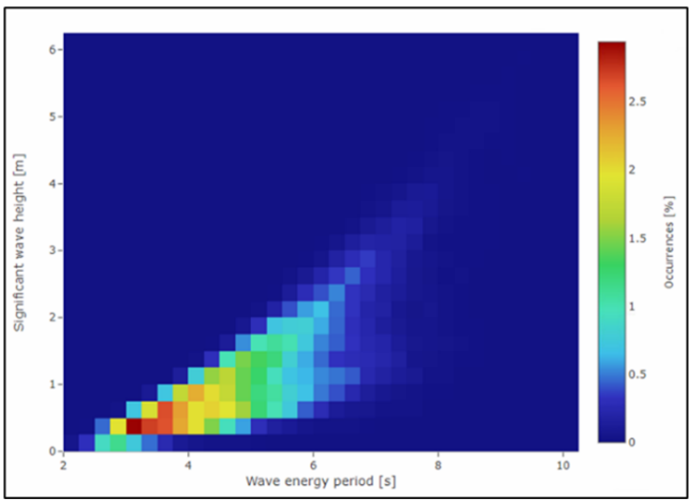

FIGURE 8. PANTELLERIA OCCURENCES SCATTER.

A discrete variation step size was set in order to have a faster convergence. Furthermore, by considering the results, no appreciable change can be seen by varying the parameters of a quantity smaller than these set step size. Boundaries were defined on the base of literature data, from existing technologies and for technical and manufacturing limitations [23]:

- Having the radius smaller than 2 m would reduce the available volume inside the hull so that the PTO and technical instruments could not be installed inside;

TABLE 2. MAIN HULL PARAMETERS CHANGED BY GA, THEIR BOUNDARIES AND VARIATION STEP SIZE.

Parameter [m]	Lower Limit [m]	Upper Limit [m]	Variation Step Size [m]
Radius	1	10	0.5
Height	2	20	0.5
Draft	1	18	0.5

- The same consideration can be made for the point absorber height, so at least 2 m have been considered;
- Concerning the submerged height, the draft, it has been imposed that the point absorber is not completely submerged, but emerges for reasons of visibility.

The goal of the genetic algorithm was to minimize the LCOE of the point absorber. The results of the optimization by genetic algorithm are shown in Figures 9 and 10. In particular, Figure 9 shows the geometric quantities such as the radius, height and draft of the point absorber. Figure 10 shows the trends of the LCOE, the annual energy production and the overall cost of the device. The point absorber obtained from the optimization has a radius of 2 m, a height of 6 m and a draft of 5 m. The AEP obtained, although lower than that obtainable from more productive sites such as in the North Sea or the Atlantic Ocean, is comparable with other WEC technologies [24], [20].

CONCLUSION

The purpose of the paper is to present a frequency domain model for a cylindrical point absorber and to perform a holistic optimization that maximizes the extracted power and minimizes device costs. The numerical model is based on the potential flow theory while all the hydrodynamic properties are calculated using the Boundary Element Method (BEM) software Nemoh. The optimization, made with Genetic Algorithm, aims to maximise the AEP while reducing the LCOE, by varying the shape, dimensions, mass properties, ballast and draft. The optimization of the point absorber made it possible to identify an optimal geometry for the 3 sites of the Mediterranean Sea considered, namely Pantelleria, Alghero and Licata. Future developments to ensure greater reliability of the tool include the implementation and optimization of specific control strategies for the point absorber and the definition of more precise fitness function.

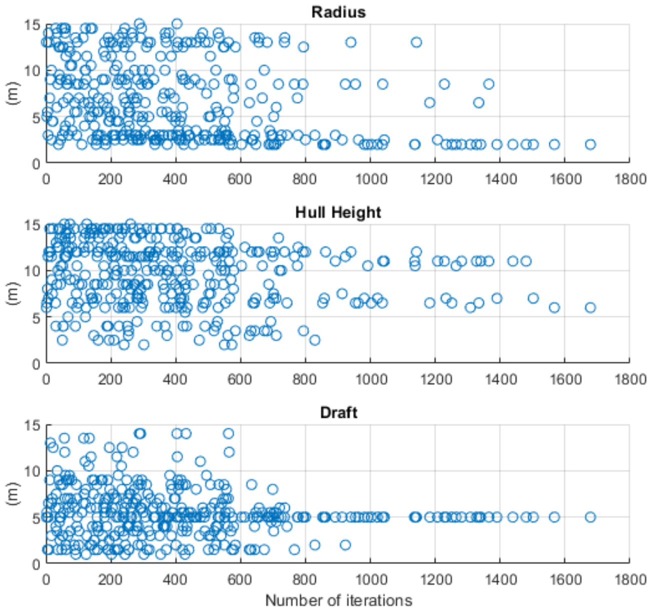

FIGURE 9. HULL RADIUS; HEIGHT AND DRAFT FROM GENETIC ALGORITHM OPTIMIZATION.

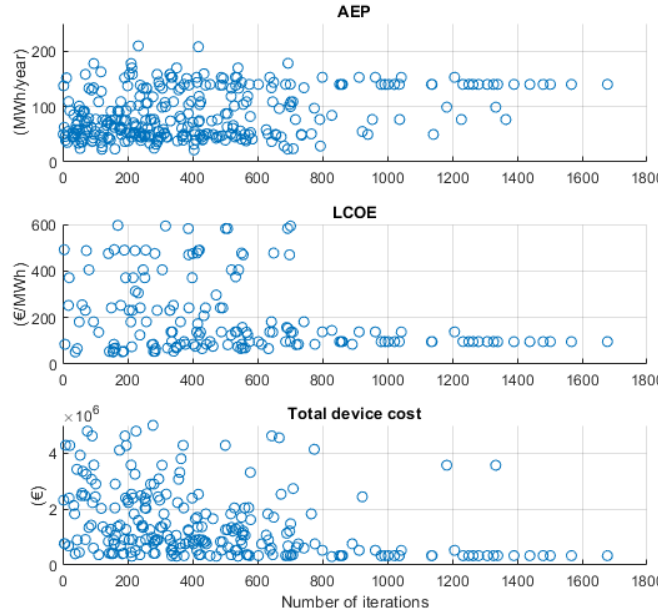

FIGURE 10. AEP, LCOE AND TOTAL DEVICE COST FROM GENETIC ALGORITHM OPTIMIZATION.

REFERENCES

[1] Delbeke, J., Runge-Metzger, A., Slingenberg, Y., and Werksman, J. D., 2019. "The paris agreement". *Towards a Climate-Neutral Europe*.

[2] REN21, 2017. Renewables 2017 Global Status Report. Tech. rep., REN21 Secretariat. See also URL `https://www.ren21.net/gsr-2017/`.

[3] IEA, 2021. Renewable Energy Market Update - Outlook for 2021 and 2022. Tech. rep., International Energy Agency, May.

[4] IEA, 2020. Renewables 2020: Analysis and forecast to 2025. Tech. rep., International Energy Agency. See also URL `http://www.overleaf.com`.

[5] , 2018. Ocean Energy: Key trends and statistics 2018. Tech. rep., Ocean Energy Europe. See also URL `https://www.oceanenergy-europe.eu/`.

[6] D, M., 2019. "Ocean energy: Technology development report".

[7] Edwards, K., Mekhiche, M., et al., 2014. "Ocean power technologies powerbuoy®: system-level design, development and validation methodology".

[8] Qiao, D., Haider, R., Yan, J., Ning, D., and Li, B., 2020. "Review of wave energy converter and design of mooring system". *Sustainability,* ***12***(19).

[9] Poullikkas, A., 2014. "Technology prospects of wave power systems". *Electronic Journal of Energy & Environment,* ***2***(1), pp. 47–69.

[10] Weinstein, A., Fredrikson, G., Parks, M., and Nielsen, K., 2004. "Aquabuoy - the offshore wave energy converter numerical modeling and optimization". In Oceans '04 MTS/IEEE Techno-Ocean '04 (IEEE Cat. No.04CH37600), Vol. 4, pp. 1854–1859 Vol.4.

[11] Beirdol, P., Valerio, D., and da Costa, J. S. Linear model identification of the archimedes wave swing.

[12] Weber, J., Mouwen, F., Parish, A., and Robertson, D., 2009. "Wavebob—research & development network and tools in the context of systems engineering". In Proc. Eighth European Wave and Tidal Energy Conference, Uppsala, Sweden, Vol. 8, pp. 416–420.

[13] Li, S., 2017. "Low-frequency oscillations of wind power systems caused by doubly-fed induction generators". *Renewable Energy,* ***104***, pp. 129–138.

[14] Faizal, M., Ahmed, M. R., and Lee, Y.-H., 2014. "A design outline for floating point absorber wave energy converters". *Advances in Mechanical Engineering,* ***6***, p. 846097.

[15] Rafiee, A., and Fiévez, J., 2015. "Numerical prediction of extreme loads on the ceto wave energy converter". In Proceedings of the 11th European Wave and Tidal Energy Conference, Nantes, France, no. 09A1-2.

[16] Babarit, A., and Delhommeau, G., 2015. "Theoretical and numerical aspects of the open source bem solver nemoh". In 11th European wave and tidal energy confer-

ence (EWTEC2015).

[17] Hersbach, H., B. B. B. P. B. G. H. A. M. S. J. N. J. P. C. R. R. R. I. S. D. S. A. S. C. D. D. T. (2018): Era5 hourly data on single levels from 1979 to present. copernicus climate change service (c3s) climate data store (cds). URL:https://cds.climate.copernicus.eu.

[18] Journée, J., and Massie, W., 2001. "Offshore hydromechanics".

[19] Ghigo, A., Cottura, L., Caradonna, R., Bracco, G., and Mattiazzo, G., 2020. "Platform optimization and cost analysis in a floating offshore wind farm". *Journal of Marine Science and Engineering,* ***8***(11).

[20] Sirigu, S. A., Foglietta, L., Giorgi, G., Bonfanti, M., Cervelli, G., Bracco, G., and Mattiazzo, G., 2020. "Techno-economic optimisation for a wave energy converter via genetic algorithm". *Journal of Marine Science and Engineering,* ***8***(7).

[21] MATLAB, 2021. *version R2021a*. The MathWorks Inc., Natick, Massachusetts.

[22] Frank Sandner, Yu Wie, D. M. E. G. J. A. X. M., 2014. Deliverable D4.3.3 – Innovative Concepts for Floating Structures. Tech. rep., InnWind.Eu. See also URL https://www.oceanenergy-europe.eu/.

[23] Rava, M., Dafnakis, P., Martini, V., Giorgi, G., Orlando, V., Mattiazzo, G., Bracco, G., and Gulisano, A., 2022. "Low-cost heaving single-buoy wave-energy point absorber optimization for sardinia west coast". *Journal of Marine Science and Engineering,* ***10***(3).

[24] Tan, J., Polinder, H., Laguna, A. J., Wellens, P., and Miedema, S. A., 2021. "The influence of sizing of wave energy converters on the techno-economic performance". *Journal of Marine Science and Engineering,* ***9***(1).