# Preliminary study for the implementation of the "Wave Dragon" in Gran Canaria, Canary Islands, Spain.

A. Miguel Sagaseta de Ilurdoz Cortadellas[1], B. Miguel Ángel Guerra Rodríguez[1], C. Raquel Ramos Pereda[2], D. Pedro D. Cuesta Moreno[3]

[1]Proyect "Gran Canaria, Isla Experimental"
E.I.I.C., Las Palmas de GC University -ULPGC-
Campus of Tafira – Las Palmas de GC, 35017 Las Palmas (Spain)
Phone: +0034 646 455477, e-mail: A. msagaseta@etsii.org, B. maguerraing@gmail.com

[2]RALEY Estudios Costeros S.C.P.
c/ Francisco Gourié, 107, 2ª Planta, ofic. 19, Las Palmas de G.C. (Spain)
Phone: +0034 656 846 900, e-mail: isla@raleyestudioscosteros.net

[3] Department of Mathematics Engineering
E.I.I.C., Las Palmas de GC University -ULPGC-
Campus of Tafira – Las Palmas de GC, 35017 Las Palmas (Spain)
Phone: +0034 653 064180, e-mail: pcuesta@etsii.org

**Abstract.** The island of Gran Canaria offers extraordinary weather conditions for the exploitation of renewable energy. But it has also an isolated power system that is vulnerable and has low inertia. This fact limits the penetration of this energy on the network. Both wind energy and photovoltaics have an important development in the island, but both have clear disadvantages for its exploitation, due to its unstable generation curves, its lack of predictability, the fact that this type of energy can't be generated continuously, and consequently, the problems due to its difficult management. In adition, talking about wind energy, should be noted that Gran Canaria is an ecological paradise, full of natural protected areas, and also it has a high population density. That's why the space for future energetic installations is very limited. However, the Canary Islands are surrounded by an unlimited ocean. The swell is able to supply part of the insular consumption through wave energy. This study analyze the energetic situation of Gran Canaria, the nature of its waves, and the different mechanisms and techniques for the exploitation of this energetic resource, giving an added value to those that allow to obtain quality energy to be poured into the network.

## Key words
Renewable energy, wave energy, energetic generation, ocean, isolated system.

## 1. Introduction

Fighting against climate change and protecting the environment are a priority, not only globally, but also in Gran Canaria, where renewable energies –like photovoltaic or wind energy– are widespread and well developed.

Despite this, the island has a small power system, and it's not connected to any other –as it happens with continental networks. For this reason, there are many disadvantages for the penetration on the network of the renewable energies.

Major problems of this kind of networks are:

A) Lack of predictability of renewable energy sources.

B) Management problems.

C) Lack of continuous generation and disponibility –24 hours a day and 365 days a year.

D) Derived from previous, unstable generation curves.

E) Lack of physical space for full development, due to the high population density and the large number of protected natural areas, because of its biological and landscape richness.

To mitigate the above drawbacks, it's very important, first, to choose those technologies that allow the right management of the generated energy, in order to it can be poured quality energy into the network. Second of all, to prepare a multi-generation system dependent on different renewable energy resources –solar, wind, tidal, wave energy...– that limit the energy dependence of the island of each of these resources separately, reducing the risk of absolute peaks or valleys of generation.

There are experts like Mariusz Malinowski, belonging to the Warsaw University of Technology in Poland, who argue that wave energy could provide the same amount of energy than wind energy. However, its level of development worldwide, and in particular in Gran Canaria, is very limited. Therefore the study focuses on proving technically for Gran Canaria (Canary Islands, Spain), which are the best devices for the use of such an important renewable energy, abundant and poorly developed, exploited and implanted, as the wave energy, the energy from the swell. It's important to emphysize that its application will be in Gran Canaria.

## 2. **Wave energy**

Wave energy is based on the strength of the waves. It is probably the renewable energy source whose exploitation mechanisms have a greater variety. Some are installed on the coast and use the force of waves to drive large masses of air through turbines (Oscillating column systems). Others are installed in shallow water and use systems of levers and pistons that are operated by the force of the waves or pressure changes that accompany the movement of the wave by the marine surface. Finally, floating systems are placed in deep water taking advantage of a few miles from the shore, the waves have their maximum potential energy (because when reaching the coast, there are various factors such as seabed proximity, that causes slowly lost of energy). At the same time, there are differences in their sizes and their generation capacity. Based on the study belonging to Berta Cavia del Olmo, "Explotación del potencial de energía del oleaje en función del rango de trabajo de prototipos captadores" (Reference 3, p. 9-16), there are three very common types of waves on our beaches:

- *Oscillatory waves:* Their movement is circular and have no translation of water, only oscillatory variation in height of sea level. Don't depend on the wind, but the gravitational interaction between Earth, the Sun and the Moon, together with the disturbing action of certain underwater geological elements. This is the easier to predict and the most stable, providing quality energy, but low in energetic level.

- *Olas de Traslación:* These waves are those formed by the arrival of water to the coast. This is the typical wave breaking on beaches and cliffs. These waves have a height and a period on average but can only be exploited by coastal wave energy systems.

- *Olas forzadas:* These are generated by the wind, and therefore, have direction and are less predictable than the rest, but with them, it can be used the same prediction systems for wind energy. They have also the highest energy potential. Management present many problems inherited from the wind, however, since the sea is a system with a much higher inertia than air masses,they are more easily predictable and with less abrupt changes than wind currents that generate them.

Although can only be exploited on the coast, where the waves has a medium-high level, the variety of converters allow its exploitation in multiple locations (which is a great advantage over tidal energy, that needs more defined locations).

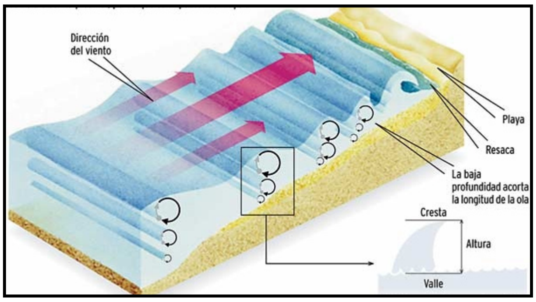


Fig. 1. Diagram of the generation of the forced waves generated by wind.

## 3. Wave energy converters

The variety of waves and the different locations that exist to exploit the swell has resulted in that many experts worldwide have developed various systems for wave energy conversion to electricity, prioritizing different specifications such as: if the system is an active converter (mainly hydraulic pistons or pneumatic) or passive (air or water turbines), directional (mainly uses the waves forced or translation) or non-directional; its location (coastal, shallow or deep water), relative position to sea (submerged, semi-submerged or floating), etc.

Concluding, as established by Julia Fernandez Chozas, "Una aproximación al aprovechamiento de la energía de las olas" (Reference 1, p. 24-114) and in order to have an image of the variety of devices, the following table shows a summary of the basic technical characteristics of non-coastal systems that have been valued in this study:

| | **Power Buoy** | **Pelamis** | **Wave Dragon** | **AWS** |
|---|---|---|---|---|
| Power Device (kW) | 20 | 750 | **7,000** | 1,200 |
| Area occupied (m^2) | 20 | 490 | 51,000 | 90 |
| Storage and energy management | No | No | **Yes (Potencial energy)** | No |
| Displacement capability | Towable | Towable | Towable | Towable |
| Type of waves exploited | Stationary | All | Directional | All |
| Working fluid | Oil pressure | Oil pressure | Seawater | Air |
| Distance from the coast | Deepwater | Deepwater | Deepwater | Shallow |
| Behavior | Active | Active | Passive | Active |
| Visual impact | Low | Low | Low | Low |
| Type of structure | Floating | Floating | Floating | Submerged |
| Main converter mechanism | Hidraulic | Hidraulic | Water Turbine | Hidraulic |
| Generator type | ----- | Asynchronous | Rotating permanent magnets | Lineal permanent magnets |
| Conversion technology | Balsas | Articulated | Depósits | Floats |
| Produced Power Management | No | No | **Yes (individual management of turbines)** | No |

Table I. – Comparison of the most important technical parameters of the most representative systems offshore.

Additionally and based on the study of Julia Fernandez Chozas, "Una aproximación al aprovechamiento de la energía de las olas" (Reference 1, p. 114-144), among others, various models of OWC technology (Oscillating water column) have been considered. In contrast to the other systems that generally have few models,basically differenced in size and generating capacity, OWC systems are a mature technology with multiple designs as shown in the following table:

| | OWC Unión Fenosa | OWC NEL | OWC Pico |
|---|---|---|---|
| Power Device (kW) | 27 | 2,000,000 | 400 |
| Area occupied (m^2) | 48 | 1,552,000 | 96 |
| Storage and energy management | No | No | No |
| Displacement capability | Fixed | Towable | Fixed |
| Type of waves exploited | Directional | Directional | Directional |
| Working fluid | Seawater | Air | Air |
| Distance from the coast | Coast | Deepwater | Coast |
| Behavior | Passive | Passive | Passive |
| Visual impact | Middle | Middle | Middle |
| Type of structure | Fixed | Floating | Fixed |
| Main converter mechanism | Air turbine | Air turbine | Air turbine |
| Generator type | Asynchronous | Asynchronous | Asynchronous |
| Conversion technology | Pneumatic | Pneumatic | Pneumatic |
| Produced Power Management | No | No | No |

Table II. - Comparison of the most important OWC worldwide.

## 4. Gran Canaria's power system

Gran Canaria, as an island, has a small power system and extremely susceptible to changes in consumption and generation that can create problems like frequency variations (about 1 Hz for each 80MW of imbalance in the network), or voltage sags "zeros in generation."

Electricity production is based on 94% in fossil fuel use. 65% of the fuel in the form of fuel oil and 35% as gas-oil. Therefore, the island's power system is very susceptible to changes in the oil market. These fuels are mainly used in gas turbine plants, steam turbines, combined cycles and diesel engines, of which most of the power belongs to the steam turbine, presenting therefore an inflexible structure of generation and little steep generation ramps.

The isolation of the island, also involves high costs of generation because the fuel must be transported to the archipelago from the Iberian Peninsula or any other oil exporter. As a comparison, currently 1MWh of production in the Iberian Peninsula cost around 69.6€ while the average cost in Canary Islands of 1MWh is 146€.

Data from Endesa and Red Electrica de España confirm that in Canary Islands, wind energy has reached 100.4€/MWh while the steam turbines are producing at costs of 114€/MWh (these are the main generators in the archipelago). Therefore, it is clear that renewable energies are not only part of a solution for clean energy, but also economically. However, the lack of flexibility and the proven system instability makes the use of renewable energy something laborious and require the introduction of various energy storage infrastructures as well as a renewal of the production structure to improve response times. This way, currently, the construction of two hydraulic pumping stations in the island is scheduled, between Chira-Soria and Las Niñas-Soria reservoirs, with a total capacity of 320MW and 8.8 GWh of storage capacity, although the works for these installations have not begun yet. At present, the power system of Gran Canaria has a peak demand of approximately 620MW. Photovoltaic installations on the island are close to 100 MW and wind energy installations are close to 136MW. However, in 2015, it's estimated that photovoltaic power will increase to 160 MW, while wind power will do the same to 678MW. This will mean that wind power will represent the 60% of peak demand and the 135% of the valley power of Gran Canaria. In the present circumstances of the system, this would be an unacceptable level of penetration, that the system simply could not bear.

## 5. Comparison and converter selection

The main objective of this study is to ensure, through the potential of the wave energy in Gran Canaria, a new quality renewable energy resource. For this reason, the selection of the device to value shall be based on the suitable skills to manage and control the energy produced. Capabilities like having a wide control of the device in every moment, to limit the power poured into the network, the possible disconnection or connection of the system, speed of response or even if it allows some form of energy storage. All these will be key factors for selecting the device.

Despite the many advantages that have all the systems that have been considered, the outstanding technical features of the Wave Dragon for power management make it the most promising device for electrical generation in isolated systems.

Fig. 2. Picture of Wave Dragon in action in the sea.

Its functioning is based on the ability of directional waves to gain altitude when meet a slope that can be overcome (such as on beaches). This allows the Wave Dragon storing water in a storage tank located above the sea level, then the water is released through a turbine (similar to how the conventional hydraulic power work). Some of its advantages are:

- - *Water turbine as main converter system:* These systems have not only been used for years, so it is a mature technology but also very reliable and capable of providing high quality energy.

- *Modulation of the power supplied to the network*: Using the on / off with the different turbines. This allow to pour a selected power in the network, either to avoid causing a massive penetration or to store water in the reservoir system (see next advantage.)

- *Energy storage:* By basing its operation on the accumulation of water, the device can store energy in the form of potential energy (as do the conventional hydraulic power). This can delay the discharge of energy to the network, providing a very efficient management system but limited to the capacity of its own reservoir tank.

- *Constant production, regardless of sea conditions:* Having a water tank, it can be reached a balance between filling flow and turbine flow, which implies a continuous and stable energy generation. When sea conditions change, increasing or decreasing the filling flow, the turbines can be turned on or off, adapting the functioning of the device and avoiding the intermittent energy generation, wich is typical of the rest of converter systems.

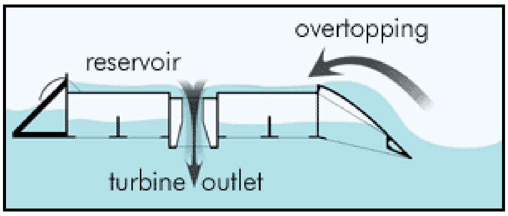


Fig. 3. Functioning of Wave Dragon technology.

Even so, we have to remark that this system has certain disadvantages compared to other technologies. Emphasizing the following:

- Increased sea surface occupied.
- The only use of directional waves, not standing waves (most common in our island but less rich in energy terms).
- A dimensioning thought to optimize performance for extreme situations (waves greater than 5 meters) rather than circumstances more common.

For this reason, the next point of this study will compare the production data of this system with the historic swell data obtained by the team to estimate the production that would have a system of this kind on the coast of Gran Canaria.

## 6. Implementation of the converter into the wave climate of Gran Canaria

The potential wave energy in the world is usually distributed in weather strips: latitude intervals with similar swell potential. Canary Islands are situated on the weather strip equivalent to 24kW/m. With its 236 kilometers of coastline, the island of Gran Canaria may have (in the absence of a more comprehensive study) a potential energy of 5.6 GW of wave energy power.

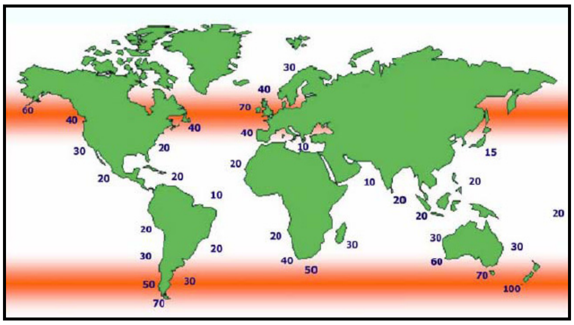

Fig. 4. Global potential wave energy, expressed in kW/m wave.

However, these studies are too general, so it was decided to perform a parallel study carried out by the maritime research firm "Raley Estudios Costeros", based on what are known as "Wana points".

To summarize, we expose the distribution map of the wana points analyzed.


Fig. 5. Mapa de los 10 puntos Wana analizados.

The data set "Wana"consists of time series of wind and swell parameters from numerical modeling. They are, therefore, simulated data and don't come from direct measurements of nature. These data come from the sea state prediction system that "Puertos del Estado" has developed in collaboration with "Instituto Nacional de Meteorología" (INM). However, the "Wana" data isn't predictive data but diagnostic or analysis data. It is important to note that regardless of the coordinate assigned to a "Wana" node, the wave data must be always considered as data obtained in open water and indefinite depths.

These data will be evaluated using data starting as stipulated by Lucía Hidalgo Olea in her study "Análisis del potencial de la energía del oleaje. Caso particular de la Isla de Lanzarote" (Reference 2, p. 73-87). As a result of studying the different historical data of the potential wave energy at each point, we obtain the following graph, which performs a comparison between the potential wave energy in different "Wana" points, expressed in kW/m:

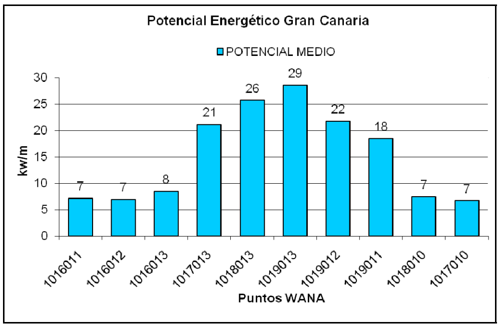


Fig. 6. Potential wave energy (kW/m) of the 10 "Wana" points analyzed.

With the potential wave energy data extracted from the previous study, we select "Wana" points with the highest potential, and these are analyzed by seasons. These are reflected in the following table:

| Seasonal potential kW/m | 1017013 | 1018013 | 1019013 | 1019012 |
|---|---|---|---|---|
| Spring | 18 | 21 | 23 | 19 |
| Summer | 12 | 13 | 14 | 12 |
| Fall | 25 | 31 | 34 | 26 |
| Winter | 29 | 37 | 42 | 32 |
| **Average** | **21** | **26** | **28** | **22** |
| **RMS (root mean square)** | **11** | **14** | **15** | **12** |
| **Máximum** | **29** | **37** | **42** | **32** |

Tabla IV. – Seasonal average wave energy grade of the 4 highest potential "Wana"points.

For the situation and placement of the device should be noted that the northeast coast of the island is protected as "special areas of conservation " of Gran Canaria. So it is discarded the Wana point there (1019013).

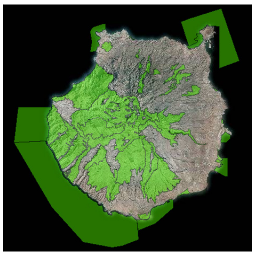

Fig. 7. Special areas of conservation of Gran Canaria.

It can be concluded that the greatest potential is found in the north of the island, namely the occupied between "Wana" points 1017013 and 1018013. Using both as real data, we can define maximum and minimum generation values for the selected model. An estimated, we can say that both historical data present the wave energy climate of the site between 21 and 29 kW/m, close to 24kW/m mentioned above.

To link the the previous review with the Wave Dragon, first we select one of three existing business models for this type of technology. These are represented below in the following table:

| Numbers of Wave Dragon | 24 kW/m | 36 kW/m | 48 kW/m |
|---|---|---|---|
| Weight, a more comprehensive combination of concrete, ballast and steel | 22,000 t | 33,000 t | 54,000 t |
| Width and total length | 260 x 150 m | 300 x 170 m | 390 x 220 m |
| Wave length of the reflector | 126 m | 145 m | 190 m |
| Height | 16 m | 17.5 m | 19 m |
| Reservoir | 5,000 m3 | 8,000 m3 | 14,000 m3 |
| Number of low-head Kaplan turbines | 16 | 16 - 20 | 16 – 24 |
| Permanent magnet generators | 16 x 250 kW | 16 - 20 x 350 - 440 kW | 16 - 24 x 460 - 700 kW |
| Rated power / unit | 4 MW | 7 MW | 11 MW |
| Water depth | > 20 m | > 25 m | > 30 m |

Table V. – Technical specifications for the three models of Wave Dragon.

We choose the model with nominal power of 4MW, for a wave climate of 24 kW/m, being the best in line with the wave climate of Gran Canaria. Extracting on its website and the articles of the Wave Dragon team (references 4 and 5) its data sheet and its potential curve according to the period and height of waves:

**4 MW NOMINAL POWER WAVE DRAGON**

| Specifications | Numbers |
|---|---|
| Weight, a more comprehensive combination of concrete, ballast and steel | ~22,000 Ton (21.400 Ton reinforced concrete + 350 Ton steel) |
| Width and total length | 260 x 150 m |
| Wave length of the reflector | 126 m |
| Height | 16 m |
| Reservoir | 5.000 m3 |
| Energy regulation | Frequency Converters |
| Wave Height Cut-in | > 0.7 m |
| Nominal wave height | 5 m |
| wave height off | ∞ m |
| Kind of turbine | Kaplan. Special designed low head turbines and variable speed booster |
| Working span of the turbine head | 0.5 – 4 m head |
| Turbine blades | Fixed |
| Number of rotor blades Kaplan | 3 |
| Turbine operating range | 125 – 250 rpm |
| Optimum turbine speed | 250 rpm |
| Hydraulic turbine performance (efficiency) | 89 - 92 % |
| Number of turbines | 16 |
| Kind of generator | Generadores permanente de imán -PMG- (se juntaron directamente) Síncrono |
| Nominal power of the generator | 16 x 250 kW |
| Control of the generator | standards investors often control turbine speed generator |
| Water depth | > 20 m |
| Hold level of ties | According to terrain |
| Maximum height above sea level (in the floating position minimum and maximum) | 3 - 6 m |
| Depth (set minimum and maximum float) | 11 – 14 m |
| Rated power / unit | 4 MW |

Table VI. – Technical details of the 4MW Wave Dragon model.

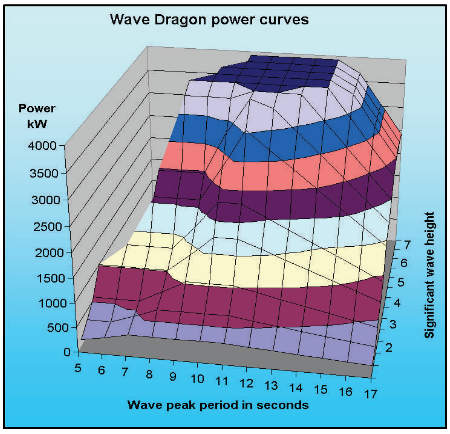


Fig. 8. Potential curve according to the period and wave height of the 4 MW of nominal power Wave Dragon Model.

The historical results obtained from the potential wave energy of northern Gran Canaria -above exposed- related through mathematical calculations with the potential curve of 4 MW Wave Dragon model gives us the following results:

| WANA POINT 1017013 | Generated energy [MWh] |
|---|---|
| Spring | 1,524.23 |
| Summer | 1,350.10 |
| Fall | 1,407.94 |
| Winter | 1,535.68 |
| **Annual total** | **5,817.95** |
| **number of equivalent hours** | **1,454.49 h** |

Table VII. – Generated energy and number of equivalent hours on "Wana" point 1017013.

| WANA POINT 1018013 | Generated energy [MWh] |
|---|---|
| Spring | 1,714.24 |
| Summer | 1,415.08 |
| Fall | 1,628.61 |
| Winter | 1,788.39 |
| **Annual total** | **6,546.33** |
| **number of equivalent hours** | **1,636.58 h** |

Table VIII. - Generated energy and number of equivalent hours on "Wana" point 1018013.

Additionally, based on the above calculations, the following distribution of generated power during a year of production is obtained:

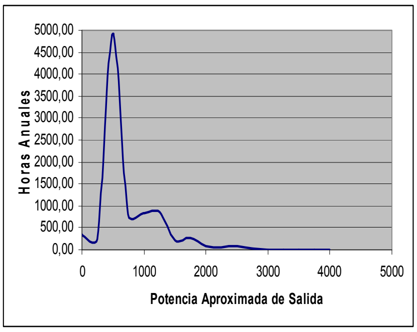


Fig. 9. Power distribution generated during a year of production.

From which we draw two important conclusions:

- Considering the benevolence of the canarian climate, most of the year, this installation will be unused. 85% of operating hours will be under a power of 1.500 kW or less, which is neither 50% of the power rating (4MW).

- The equivalent hours of production of the system relative to its nominal power are among 1.450 and 1.650 equivalent hours, which, from the point of view of amortization, are clearly insufficient.

Speaking on environmental and social terms, considering its contribution to the insular power generation, this device would provide the following benefits, assuming a maximum generation of approximately **6,546.33 kWh** (choosing the largest production data between the two Wana points analyzed):

A) It would satisfy **575 canarian homes**. If we assume that a home has an average of 3 residents, we can conclude that it would cover the energy demand of **1.725 inhabitants**.

B) That would results in the following saving in emissions of polluting gasses:

| reference values | Avoided emisions |
|---|---|
| 0.464 kg of CO2 per kWh | **CO2: 3,037.498 t** |
| 16.52 t SO2 / GWh | **SO2: 108.145 t** |
| 5.83 t NOx / GWh | **NOx: 38.165 t** |

Table IX. – Avoided polluting gasses emissions.

## 7. Conclussion

Considering the isolation conditions of the power system of Gran Canaria and its great weakness against the penetration of renewable energies, is a priority the betting on the integration of renewable energies of different nature (in order to be independent of any specific natural resource) . In particular, those that are manageable, with the goal of being self-sufficient, with clean and quality energy. Wave energy is adjusted and meets greatly in this aspects.

In our effort to study the several existing devices and their viability in the electrical network in Gran Canaria, we reached the following conclusions:

A) The Wave Dragon has the best skills for the generation of quality powe, resembling the operation of a pump turbine.

B) Despite possessing these skills, its design must be optimized to exploit the wave climate of the island, because the smaller Wave Dragon model (4 MW of nominal power) isn't fits too much to the Gran Canaria coast.

Because of this, the future path in the development of the device for its adaptation to Gran Canaria is:

- To reduce its nominal power so that it fits properly to the canarian wave energy level.

- The use of standing waves, much more productive on our shores.

In relation to this, the group "Gran Canaria, Isla Experimental" provides the following analysis concerning about the dimensioning of a single device according to the characteristics of canarian climate. By reducing the number of turbines of the device to 10, it's limited the power rating to 2.5 MW (a representative power for any green generator). Presenting this way a huge cost savings and simplifying the original design. This only stops producing (comparing with the 4 MW of nominal power model) about 42MWh annually, reaching a number of operating equivalent hours exceeding the 2,300 per year (much higher than the original device of barely 1.460 equivalent hours) and uses 93% of the potential wave energy of the island.

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