SEA ENERGY PROJECT: THE REVOLUTION OF THE WAVES

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Abstract

The hydraulic, wind or photovoltaic energies, among other renewable energies, are in continuous expansion and development, but a new way to obtain it begins to emerge, related to the strength of the waves. Currently there are some buoy-type devices that allow a certain amount of energy to be obtained, but with only one support that monitors the vertical movement of the waves. This only support I think reduces its efficiency. That is why a system has been designed with three anchoring points equidistant at an angle of 120º that, independently, can generate electricity, thanks to the vertical movement of each of them. Under controlled conditions, it has been possible to obtain a total of 18 V of potential that has allowed to light an LED screen, thanks to the conversion of the alternating electrical energy originated in the three engines, in a continuous thanks to a system of diode bridges. The next step is to test it in a wave simulator and observe its viability. To do this, you have already contacted the UPC. Although it is a first prototype; therefore, improvable, it is a first modification of existing systems.

Keywords: wave energy, waves, environment, technology, innovation.

Introduction

To what extent does traditional energies have a limit of existence? Are renewable energies maximized? Is the energy produced by the waves really known? And the existing systems, are they efficient? These are some of the questions that have allowed me to carry out this work.

All renewable energy, that is to say, that energy whose source appears in nature in a continuous and practically inexhaustible way, presents an increasing boom in order to replace the so-called non-renewable energies (eg fossil fuels, nuclear energy, among other).This is due to a progressive increase in the demand for electric power worldwide, as well as the great number of difficulties of the current systems to generate it and the associated environmental problems. For this reason, more and more alternatives are being sought in order to respect the environment.

The hydraulic, wind, thermal and photovoltaic energies are in continuous expansion and development, but a new way of obtaining energy through the force of waves and tides begins to emerge. This is known as wave energy or wave power and has a great energy potential, estimating that only Europe would be able to generate between 120 and 190 TWh / year (data for 2011); if compared to a nuclear power plant, it is capable of generating 8 to 10 GWh / year, enough for 2 million homes (data for 2017).

Currently there are buoy-type devices that allow a certain amount of energy to be obtained (Ría de Bilbao, Spain; Sotenäs, Sweden; Fortaleza, Brazil; **Figure 1**), but these have a unique support that monitors the vertical movement of the waves (**Figure 2**) . All of them are characterized by presenting only one support in the buoy, although there are other systems, not analyzed in this work, with different design.

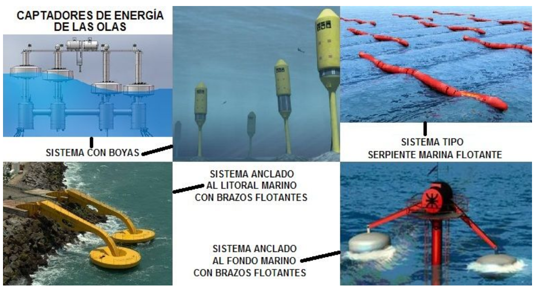


Figure 1. Some of the existent systems.
Source: https://energias-renovables-y-limpias.blogspot.com/2012/08/definicion-de-energia-undimotriz-y-sistemas-de-captacion.html

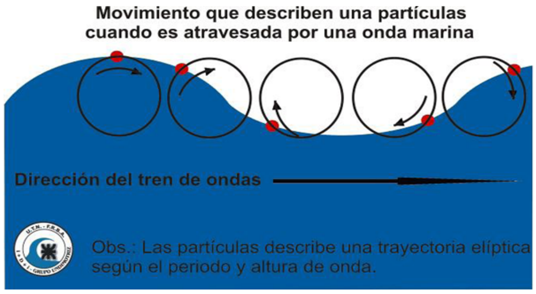


Figure 2. Physics of wave movement.
Source: https://www.mecanica.frba.utn.edu.ar/energiaundimotriz/

With all these data, the motivation to carry out this work is clear and double. On the one hand, to raise awareness of this problem in my environment, both educational and social (and, why not, researcher), and try to improve existing systems by focusing on the case of buoys from a single point of support, designing and creating a new proposal.

Objectives

The objective is to analyze some existing wave energy systems for, subsequently, and from the buoy format, to design and build a system that improves the performance for obtaining energy from the movement of the waves (wave energy) from of an increase of fixation points that have a vertical path, following the sinusoidal movement (McCormick, 2007).

On the other hand, the energy obtained from the prototype will be monitored with the help of environments closer to reality, such as a wave pool (controlled system) or in the sea itself, close to the coast. For this purpose, it is intended to contact the Nautical Faculty or the facilities of the Maritime Research and Experimentation Channel (CIEM), both belonging to the UPC.

Materials and methods

Several buoy designs have been made to find a potentially viable system based on the existing one at the Porto do Pacem wave power station (Brazil). This one presents a triple subjection with an angle of 120º that glides by a structure type Delta, equal to the one that is used in the systems of 3D printer (Figure 3). To fulfill the final objective, two specific ones are proposed:

- Make construction as didactic as possible because it is a not very well known technology.
- Check the viability of the proposed system, initially in a controlled and simulated situation and, subsequently, in a situation as real as possible.

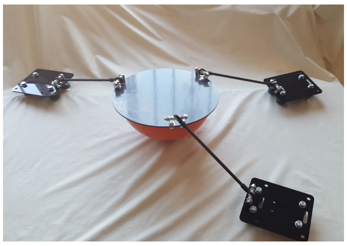


Figure 3. Buoy fastening system.

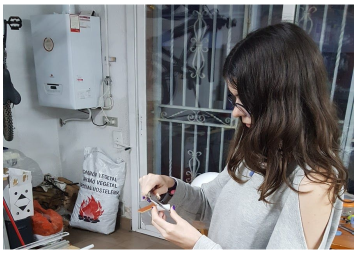


Figure 4. Modifying parts to improve the system.

Of all the raised system, the main element is the buoy, which must generate enough force to move and support the weight of the whole unit that generates energy. Throughout the process several buoys were designed to find the optimum. The main problems were:

- **First design**: It was too small to produce enough energy; likewise, its high weight was a big problem, invalidating this option (**Figure 5**).

Figure 5. First buoy model.

- **Second design**: It consists of a smaller and lighter polyurethane buoy, however, when tested it was not kept still or steady reason why it was discarded (**Figures 6** to **8**).

Figure 6. Second buoy model.

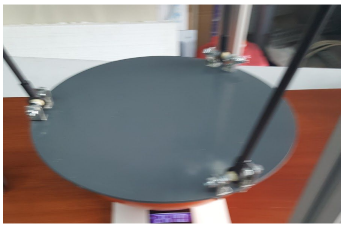


Figure 7. Second model with the fixation system.

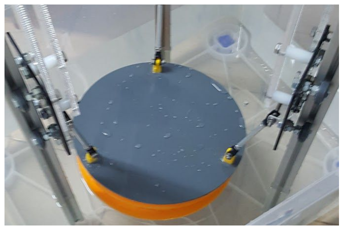


Figure 8. The mechanism can get out of the body of the structure and get stuck.

- **Third design**: Is the one presented in the project and described below.

The system consists of three layers of polyurethane with a cylindrical base 50 cm in diameter with three notches where the support system is fixed. To validate its stability and buoyancy capacity, a weight of 5 kg was placed on the set and the following was observed (**Figures 9** and **10**):

- It was very stable
- It sank very little, so that the movement of the wave is used to a greater extent for the production of energy.

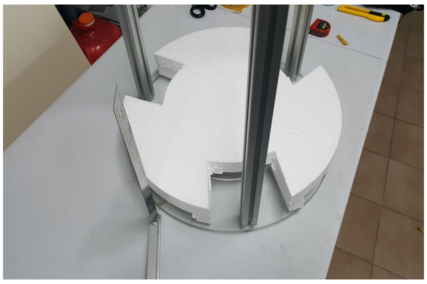


Figure 9. Third buoy model.

Figure 10. Test of the stability of the third model.

Once the buoy was defined, the construction of the mechanical system was based on three equidistant axes in sectors of 120º, fixed between two circular pieces that would form the skeleton of the prototype. The buoy is fastened on the inside (notches) to the structure . The outside is larger, fitting in the diameter of the circular bases of 50 cm in diameter (same as the buoy). This system has three characteristics that would favor its functionality (**Figure 11**): compact system more resistant to extreme sea conditions, facilitate buoyancy and maintain the buoy within the structure.

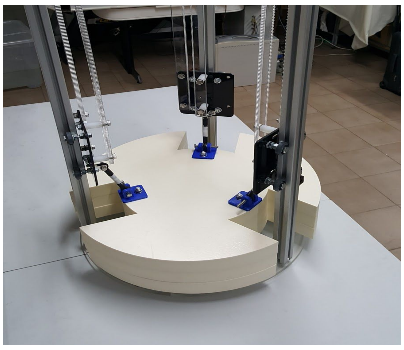


Figure 11. Compact buoy model incorporated in the body of the prototype.

In order to fulfill the purpose, a rack-and-pinion system has been chosen for its ease of execution (**Figure 12**). The connecting rods that form part of the structure support the full force of the buoy movement (**Figure 13**). To increase its efficiency, a ball-and-socket system has been added so that it has a bit of mobility (**Figure 14**) instead of fixed rods as had been thought for the first two systems. The assembly is accompanied by three step motors (**Figure 15**) located on each of the axes and which allow the vertical movement of the rack-and-pinion system.

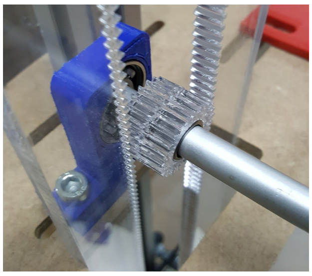


Figure 12. Pinion-rack system used for the vertical movement of the simulator.

Figure 13. System of connecting rods that hold the buoy.

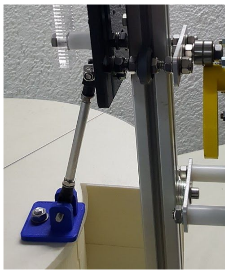


Figure 14. Detail of the ball joints.

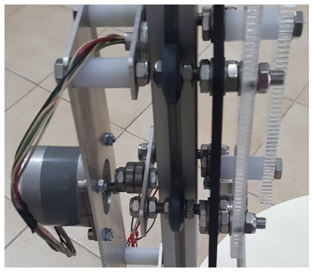


Figure 15. Stepping motors on each axis.

A summary of images of the construction of the mechanical part can be seen in the photographic annex **(Figures 16** to **19**).

Figures 16 to 19. Sequence of images of the process of design and manufacture of the second buoy prototype.

Once this was designed, it started with the electronic part, connected to the mechanical system. It consists of three elements:

- **Upper base of the system** (**Figure 21**): A base of alucobond (mixture of aluminum and methacrylate) that takes advantage of the superior subjection of the vertical axes. In it are located, among others, the motors that generate energy and the transmission system formed by the pinions that move the racks.
- **Wave simulation system** (**Figure 22**): Contains, among others, the Arduino Mega board and the power drivers of the step motors.
- **Energy generation system** (**Figure 23**): Contains all the electronic components that allow the generation of energy, among which we can highlight the prototype plate where the components and the dc-dc converter are welded.

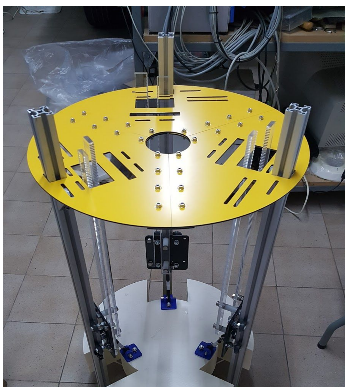


Figure 21. Upper base where part of the electric mechanism would be placed.

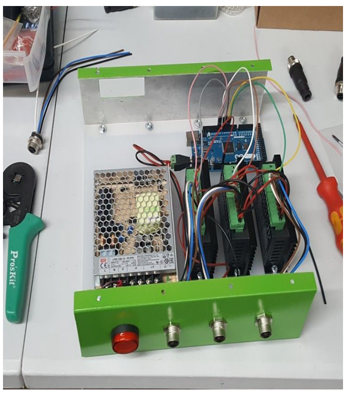


Figure 22. Electronic circuit to simulate the mechanical functioning of the waves.

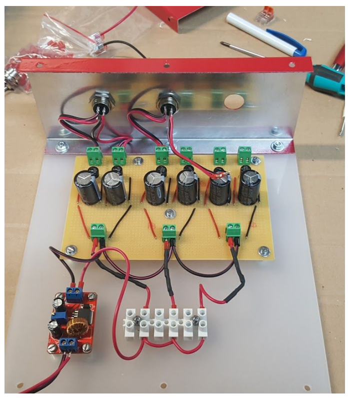


Figure 23. Electronic board for the use of energy.

A summary of images of the construction of the electronic part can be seen in the photographic annex (**Figures 24** to **27**).

Figures 24 to 27. Sequence of images of the development process of the electronic part.

Results

Buoy and delta structure

First, the prototype designed (**Figure 28**) is formed by a buoy of 50 cm, centered on the assembly and held by three points (delta-like structure) by means of rods at the ends of which there are articulated heads (**Figure 29**) . These are joined to the skids that slide through the aluminum structure (**Figure 30**). In these, in turn, fasteners are attached that attack the pinions in whose axis is the pulley that moves each step motor (**Figure 31**) used to generate energy, whose ratio is 1:10.

This buoy, according to estimates and data analysis of existing systems, should have a real situation, at least, between 5 and 10 m in diameter to get the necessary force to move the entire power generation system.

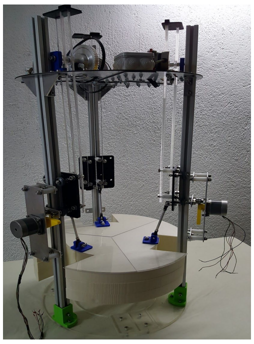


Figure 28. Overview of the prototype.

Figure 29. Detail of the mobile system for the buoy.

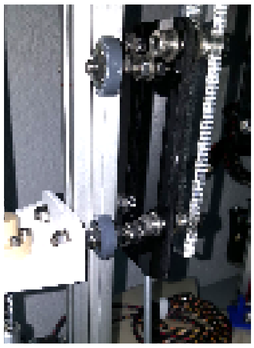


Figure 30. Detail of the mobile skate system.

Figure 31. Detail of one of the step motors.

Wave simulator system

In order to make the prototype more functional and not have to depend on a water channel to explain its operation, a wave simulator is designed ("green box", **Figure 32**). Its objective is to approach the real movement by moving the buoy in the different axes, up and down. This will also make the entire power generation system operational. Its main elements are the power supply, TB6600 driver, stepper motors and Mega Arduino, all installed in a custom made box.

To generate this movement, step motors are used attached to each of the legs of the structure by means of a connecting piece (**Figure 33**). Step motors are electromechanical devices that convert a series of electrical impulses into discrete angular displacements, which means that it is capable of rotating a number of degrees depending on its control inputs. Those used to simulate the waves have a consumption that oscillates between two and three amps; for this reason it is used a Power Drivers (TB6600), since the outputs of the Arduino Mega can only handle loads of up to 40 milliamps, this arduino model is capable of generating enough impulses to be able to move the three motors at the same time. Consequently, they must have sufficient torque to push the whole assembly since the resistance that the generating motors exert when being moved by the rack-and-pinion system must be taken into account.

Figure 32. Structure of the wave simulator ("green box").

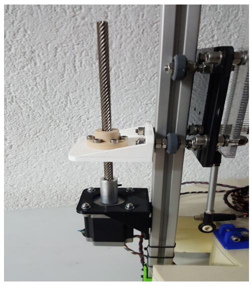


Figure 33. Wave simulator mechanism.

To transmit this movement we use a special spindle and nut (of step 50), with a complete rotation of the motor we move the skate 50 mm. The nut is attached to the shoe by means of a piece that transmits the movement of the spindle (**Figure 34**).

The connections between the different components are made according to manufacturer specifications, the TB6600 are connected directly to each stepper motor and power supply, to control them the Arduino only needs three outputs, the positive of Arduino connected to DIR +, PUL +, EN +, sense of turn (right or left) DIR- to outputs 9, 7, 5, pulse frequency (higher frequency, more speed but less torque and vice versa), PUL- to outputs 8, 6, 4, according to the diagram (**Figure 35**).

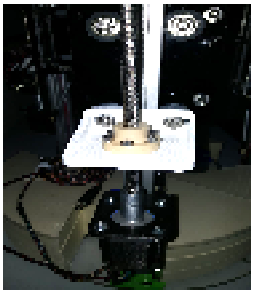


Figure 34. Detail of the nut attached to the piece that moves the skate.

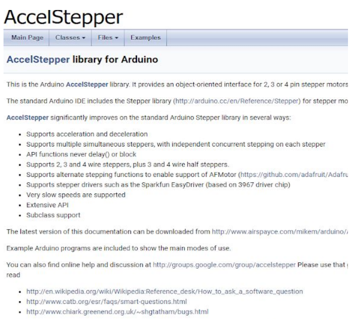
Varios_motores_a_la_vezTB6600.ino: Bloc de notas

Archivo Edición Formato Ver Ayuda

```
include <AccelStepper.h>

nsigned long interval = 700;       //Temporiza motor2
nsigned long interval2 = 1400;      //Temporiza motor3
nsigned long previousMillis;

nt velocidad = 185;
nt acceleracion = 1000;
nt desplazamiento = 250;

/ Direccion Digital 9 (CW), pulso Digital 8 (CLK)
ccelStepper motor1(1, 8, 9);

/ Direccion Digital 7 (CW), pulso Digital 6 (CLK)
ccelStepper motor2(1, 6, 7);

/ Direccion Digital 5 (CW), pulso Digital 4 (CLK)
ccelStepper motor3(1, 4, 5);

oid setup()

 delay(1500);
 previousMillis = millis();
 motor1.setMaxSpeed(velocidad);      //Velocidad.
 motor1.setAcceleration(acceleracion);  //Aceleracion.
 motor1.moveTo(desplazamiento);          //Mover 135 pasos.

 motor2.setMaxSpeed(velocidad);
 motor2.setAcceleration(acceleracion);
 motor2.moveTo(desplazamiento);

 motor3.setMaxSpeed(velocidad);
 motor3.setAcceleration(acceleracion);
 motor3.moveTo(desplazamiento);

oid loop()
```

Figure 35. Arduino program to control motor movement.

Its operation is very simple: we only control the direction of rotation (right or left) and how much we want to move each axis. Through a timer we start each one with a lag of a second, getting a back and forth effect. The program uses the AccelStepper library (**Figure 36**), very easy to use, we just have to enter speed, acceleration and displacement, the library generates all the necessary calculations, the repetitive part of the program is in charge of inverting the direction of rotation of the motors once they reach the entered displacement as well as the sequence of start-up of the motors with a lag of one second by means of a timer to simulate the effect of the wave.



AccelStepper

Main Page | Classes | Files | Examples

AccelStepper library for Arduino

This is the Arduino AccelStepper library. It provides an object-oriented interface for 2, 3 or 4 pin stepper motors

The standard Arduino IDE includes the Stepper library (http://arduino.cc/en/Reference/Stepper) for stepper mo

AccelStepper significantly improves on the standard Arduino Stepper library in several ways:

- Supports acceleration and deceleration
- Supports multiple simultaneous steppers, with independent concurrent stepping on each stepper
- API functions never delay() or block
- Supports 2, 3 and 4 wire steppers, plus 3 and 4 wire half steppers.
- Supports alternate stepping functions to enable support of AFMotor (https://github.com/adafruit/Adafru
- Supports stepper drivers such as the Sparkfun EasyDriver (based on 3967 driver chip)
- Very slow speeds are supported
- Extensive API
- Subclass support

The latest version of this documentation can be downloaded from http://www.airspayce.com/mikem/arduino/

Example Arduino programs are included to show the main modes of use.

You can also find online help and discussion at http://groups.google.com/group/accelstepper Please use that read

- http://en.wikipedia.org/wiki/Wikipedia:Reference_desk/How_to_ask_a_software_question
- http://www.catb.org/esr/faqs/smart-questions.html
- http://www.chiark.greenend.org.uk/~shgtatham/bugs.html

Figure 36. Screenshot of the library.
Source: https://www.airspayce.com/mikem/arduino/AccelStepper/index.html

The electronic box of the simulator is completed with a power supply (12V; 8A), which feeds the entire circuit.

Power generation system

The system is divided into three zones of the prototype: in the axes (step motors), in the upper base (power generating motors) and in the power converter system ("red box"). Since the revolutions achieved were not very high, it was necessary to look for a generator that at low r.p.m. will generate a usable voltage. This step gave some problems. Finally, generators were located (step motor used as a generator) whose specifications (**Figure 37**, 200 r.p.m., 84 V) were adapted to the marked objectives.

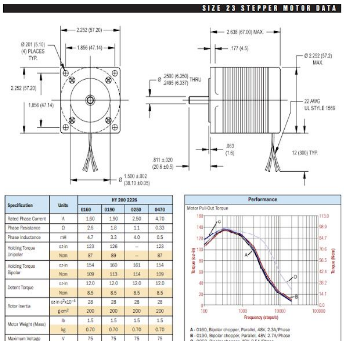


Figure 37. Characteristics of the generator engines.
Fuente: [https://www.elmeq.es/ftp/ productsFiles/1402/MOTOR-PAP-HY2226-ES.pdf](https://www.elmeq.es/ftp/productsFiles/1402/MOTOR-PAP-HY2226-ES.pdf)

The power generating motors (**Figure 38**) produce an alternating type voltage. Each one has four coils, they are connected in series two to two (**Figure 39**) according to the manufacturer's specifications to achieve the highest possible voltage. The pair of coils is connected to a rectifier circuit formed by two diode bridges model DC W02M. Its output is filtered by electrolytic capacitors 35 V and 2200 microfarads, converting this voltage to continuous, this circuit is repeated for each generator, all electronic components are soldered to a prototype plate (**Figure 40**).

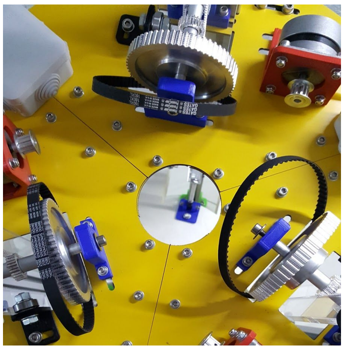


Figure 38. Power generating motors.

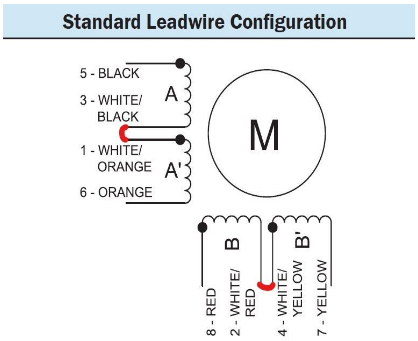


Figure 39. Diagram of the connection.

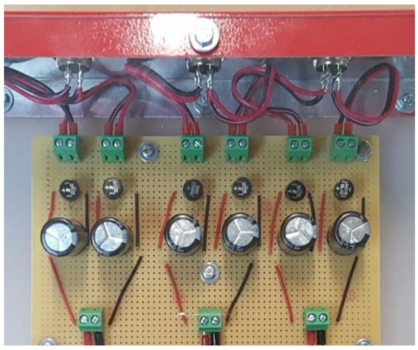


Figure 40. Diode bridges.

These, at their output, are connected in series, getting about 15 V - 18 V continuous that we convert to 5 V by dc-dc converter (**Figure 41**), allowing to feed a LED display (**Figure 42**).

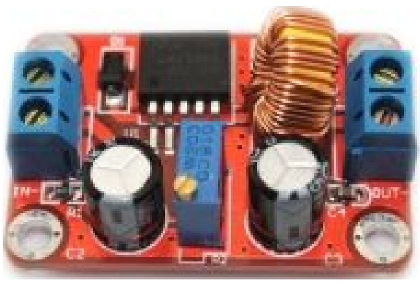


Figure 41. Dc-dc converter.

Figure 42. LED display.

Conclusions

First, it was possible to make a first viable prototype following the delta-type structure and buoy system model (**Figure 43**), with a final cost of approximately 1,600 €, basically due to the different trial-error tests carried out to determine which buoy was the most appropriate. Its useful cost would be about 1,000 €. If compared with a similar one, the presented one is more compact and, possibly, it would support the harsh conditions of the sea, since the delta system itself (in three axes) would facilitate this resistance, more than the system of a single point of support. Given that these systems are relatively new, the technology aims to achieve a degree of functionality rather than solving some aspects such as the discontinuity of energy and irregularities in amplitude, phase and direction of the waves.

Figure 43. Overview of the finished prototype, with the buoy and the delta structure (left), the wave simulator and the power generator (center), and the display working (right).

From the environmental point of view, the absorption and modification of the waves can vary the morphology of the coast and the associated marine life, as it happens in the buoy system of Porto do Pacem (Brazil). Other impacts, of a visual and sound nature, must be taken into account, especially in populated areas (in the example of the Motriku wave power plant, this effect has been minimized by placing the power plant on a breakwater in the port). The use at sea, far from the coast, does not imply any aesthetic problem, however it would be necessary to determine how it affects the waves in marine life. Also the anchorage systems of generators in the high seas can affect the habitats of animal and plant species of the seabed, as it happens in the set of buoys of Sotenäs (Sweden). In this sense, the proposed system would have an impact that would vary depending on the number of buoys that would be placed in the exploitation zone, since this should also be anchored in the bottom, and would not affect the littoral zone. In any case, it is evident that the devices for the use of wave energy in the coast or close to it can have considerable impacts on the environment that it is necessary to study and evaluate in order to commercialize this type of technology.

Currently, the system presented has tried to analyze some existing models and minimize some impacts that these could cause, but has focused on the idea that could be more effective energetically by the system of three monitoring points presented by the buoy, in relation to a unique one of those studied in the bibliography, since it would follow better the sinusoidal movement that a wave presents. This aspect is clearly conditioned to at least two aspects to be taken into account. On the one hand, the possibility of being compared with a model of the same relationship as that presented here. On the other, test the system in a situation closer to reality.

Since this is a first step, and therefore the project is not closed, the objective that would follow would be to contact a research center that works with this energy to evaluate the product obtained so far, and how it could be continued, in case considered to be minimally viable. Currently, he has already contacted the Nautical School of the Polytechnic University of Barcelona. Other possible contacts that are being worked on are, on the one hand, the Institute of Marine Sciences (ICM), center of the CSIC and, on the other, the Technical School of Civil Engineering, of the Polytechnic University of Catalonia, two of spaces where there are channels that produce waves and that could be a test point for the system.

In short, for the system to be viable, it should be possible to move the whole with the minimum possible swell, solving the problematic potential of the irregular swell that occurs in many coastal and marine areas. For this, the simulation in a wave channel could answer, in an important way, this doubt. I consider, in this sense, that maintaining the proposed system and using a buoy of generous dimensions could be achieved.

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