Optimization of an invention based on a force multiplier mechanism for wave power generation

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Abstract. The development and exploitation of new sources of clean energy that do not depend on traditional sources based on the use of fossil fuels, is the focus of this research, which starts with the optimization of an invention capable of transforming a reciprocating rectilinear motion into continuous circular motion in a very efficient way, to be used in the development of a Wave Energy Converter (WEC), capable of operating with low wave height and taking advantage of the oscillating movement of the waves both when rising, and when lowering, unlike other similar devices that harness it only in one way.

Introduction

Meeting climate objectives requires having a significantly increased share of low-C generation technologies in the future energy mix [1] and in that concert of possibilities, not relying on traditional sources for power generation, goes through the intensive development of alternative energies and clean energies, among which stand out in addition to the most explored and exploited (solar and wind), other possibilities such as the wave power. The oceans provide a huge potential resource of energy [2] and the waves are a barely tapped resource, yet, concentrated and predictable, close to large amounts of consumers and highly available virtually all year round. Even its energy density is the largest of all renewable resources.

The first wave power patent was filed in 1799 by the Frenchman Pierre-Simon Girard [3] and since then the technologies have been optimized, extensively tested and pilot wave energy projects have been realized. The knowledge and experiences gained lead to a development status that is ready for the market [4], while it is true that these devices are in early stages compared to other renewable technologies (solar, wind) and compared with conventional fossil plants, and most importantly, there is still no design outweighing over the rest [5].

However, its potential is huge, it is estimated that wave energy could cover four times the EU gross energy consumption in 2009. It also has the property of being an energy accumulator, as it is able to receive it, transport it from one place to another and store it. This feature can provide many benefits to society, as the energy generated anywhere in the ocean ends up reaching the continental edge concentrating on the coast, where there are the main settlements of population, which would be supplied from the proximity of the resource. For this reason, a major advantage of this energy resource is that is close to consumers.

The 37\% of the world population live ninety km away or less from the coast. This finding suggests that a priori the application of the proposed technology might be adaptable to a large number of markets. In Spain, according to the municipal census of 2005, population rises to 44,708,964 people of which 60\% of the population live fifty km or less away of the coast. The coastal areas and nearby valleys are the most densely populated and where there are the main population centers and metropolitan areas (excluding from Madrid), for example, Barcelona extends
its area of influence throughout the Catalan coast, Valencia and Murcia, through Alicante-Elche-Murcia-Cartagena, and other axes like Seville-Cadiz-Malaga-Granada, Guipuzcoa-Bilbao-Santander-Asturias-La Coruna-Vigo, etc. That is, the potential market which could be provided with electricity from the waves, taking advantage of the existing infrastructure of power lines is around 26 million people, only in Spain. Such energy contribution coming from wave energy could not only involve reducing electricity costs once the investment has been recovered, but also that energy could reach remote locations and that even other types of local infrastructures could be dismantled, with the thereby saving costs.

This paper outlines the advances of a project of relevance in the field of energy generation with zero emissions to the environment. The research addresses the development of a Wave Energy Converter (WEC), based on the results of an exploration about the possibilities of power generation from the use of the ocean wave’s force, by applying an invention based on a new mechanism which enables the transmission of that force, to produce electricity. The process starts with the conception of a new system able to use marine energy, allowing higher performance than other existing systems of wave energy generation. This device facilitates the uptake of the wave energy both when rising and when lowering, through a system of buoys and levers, with the possibility of being operated asynchronously, generating the rotation of a shaft in a continuous manner, which at the same time actuates an alternator.

The invention has been patented as a utility model [6] and published by the ‘Spanish Office of Patents and Trademarks’ (OEPM) and the possibility of power transformation that the invention provides from its operation, constitutes a differential value little explored in the sphere of mechanical systems applied to the field of alternative energies, in such a way that the approach of the study if projected from the optimization of the invention in terms of its operation efficiency and performance, for further use as a starting point in the development of the WEC, as well as the accomplishment of specific requirements such as, allowing operation even with low wave height and on the other hand, harnessing to its maximum extent the oscillatory motion of waves in both directions, namely both when going up and when going down, unlike other systems that use the motion in one only direction.

From the point of view of a firm with clean technology interests, according to Jaffe et al., [7] management operations are carried out in two major stages: invention and development of a new and clean product or process technology, and the adoption and use (deployment) of the clean technology over time, and from this perspective, the research is on the first stage, but with the necessary inputs to advance towards the second. Moreover, some authors identify among the key drivers for any change towards clean technologies, both operational (supply side) and marketing (demand side) as well as regulatory [8] and the proposed development, although it may be associated with the supply side in a primary approximation, can also serve as a liaison among the three aspects to enable its agreed deployment in time and within a large scale frame.

Description of the mechanism.

In general terms, the essential purpose of the invention consists in transforming a reciprocating rectilinear movement into a continuous circular motion. The mechanism consists of some driving levers which are attached to a series of gears meshing with each other. Inside these, is located a mechanism that allows the levers, when moving them vertically, actuate the mechanical system that provides continuous circular motion to an output shaft. (Fig. 1).
It is noteworthy that due to the strategic position of the internal mechanisms is achieved the leverage of the force exerted upon the levers both when climbing and when going down. Besides, as the levers increase their movement, is possible to increase progressively the speed of rotation, so that for the purpose of its use as a starting point for the development of a WEC device, it is about a buoy-Arm-gear-joint, in such a way that a buoy attached to an arm moves vertically due to the change in the height of the water generated by the waves, which ends up creating movement in various gears, which can be connected in turn via a shaft to an alternator.

The operation of the invention is characterized by operating the levers that are attached to the series of toothed wheels meshing with each other, situated on the axes. Continuous transmission of movement between the gear mechanism and the output shaft is carried by a set of pinions and chain. These pinions placed on the same axes as the toothed wheel and the output shaft are not in contact to thus permit rotation of the transmission chain in a single direction.

The force applied on the levers must be done out of phase so that the continuous circular motion of the output shaft is uniformly accelerated. On the other hand, due to the strategic position of the internal mechanisms is possible to leverage the force exerted upon the levers both when climbing and when going down. Moreover, as their movement increase, twirl speed also increases progressively.

**Optimization process and results.**

For the realization of the studies inherent to the overall performance of the invention, in addition to the contents explained in the utility model, an initial physical prototype was used. Once described and analyzed in mathematical and physical terms the functioning of the invention, the assessment of the mechanical system through preliminary measurements was addressed, in order to improve the mechanism and compare the results obtained with the starting physical prototype.

It was carried out a preliminary diagnosis, focusing on components which had lower efficacy in the mechanical system, and it was found that the set of pinions and chain used for transmission of continuous movement between the gear mechanisms and the output shaft, had a number of disadvantages that arise be mentioned, firstly, due to the length of the transmission chain, the system occupies a considerable size. Second, this set produces a lower overall mechanical and energetic efficiency compared to other mechanisms. Third, the degree of effort supported by the chain is less than the endured by toothed wheels and finally, to absorb the vibrations of the chain, one must resort to the installation of an additional tensor that was not incorporated in the initial prototype.

Therefore, to find and evaluate possible alternatives that replace the 'pinion-chain' mechanism by another system more efficient and optimized, apart from the initial physical prototype, it was also used a test bench developed ad hoc, composed of modular components. First,
the physical prototype was reproduced at a scale to perform relevant experiments and once made
the corresponding tests, it was estimated that the set of the three pinions and the transmission chain
could be replaced by another system, formed by toothed wheels and a new pinion that engages to
wheels.

Once the theoretical and practical studies were performed, then another physical prototype
was built to validate the proposed solutions, and also with the purpose of conducting the relevant
testing of the system and functionally validate the findings oriented to the field of wave energy
applications, since the available previous prototypes tested before, generated interesting electrical
potencies through manual operation, and it was proved that the changes introduced into the device
meet the requirements of efficiency and optimization accordingly to what was expected, thus
confirming the degree of optimization achieved (Table 1).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Initial physical prototype</th>
<th>Rectified physical prototype</th>
<th>Degree of Optimization</th>
<th>Optimization percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle speed ($\omega_2$) on 2nd stage (output axis)</td>
<td>0.688 rad/s</td>
<td>1.054 rad/s</td>
<td>(+ 0.366 rad/s)</td>
<td>53%</td>
</tr>
<tr>
<td>Transmission ratio between 2nd and 1st stage ($i = \omega_2 / \omega_1$)</td>
<td>6.573 min$^{-1}$</td>
<td>10.065 min$^{-1}$</td>
<td>(+ 3.492 min$^{-1}$)</td>
<td>53%</td>
</tr>
</tbody>
</table>

From the construction of this rectified prototype, the system has been parameterized in order
to obtain its energy efficiency data, while enabling its constructive scalability according to
electricity demand.

**Characteristics of the optimized system and context of use.**

In general terms, for the classification of the proposed system once the mechanism has been
optimized, it will be used the approach tackled by López et al., [5] to categorize WECs, according
to three characteristics: location, size and working principle. The location is given with respect to
the distance from the coast, and in this sense there are three types of converters: onshore, nearshore
and offshore devices. Based on the best use of available power from the ascendant and descendent
motion of the waves, the device proposed in this study could be used in the three sites, at a distance
that ranges between zero meters and above forty meters (0 - 40 m) and depths starting from one
meter. In our first choice for the prototype testing, an onshore location was selected due to its lower
complexity, less cost, and less impact on the environment, taking advantage of even the movement
of the waves with little height.

Regarding the size, it may enter the group of Point absorbers, which includes devices that
generate electricity from the floating or pitching action, converting the up and down movement of
the waves in circular or oscillatory movements (depending on the particular device).

Finally, with respect to the operating principle is akin to floating structures which base its
actuation on a floating body that is moved by waves (blades or levers). Usable oscillatory motion
can be vertical, horizontal, inclined or a combination thereof.

At present it has been developed a kinematic simulation using a CAD program, with its
corresponding 3D parametric model, it has been conducted a work on a prototype power generator
driven by human actuation, making tests regarding the number of revolutions generated and its
connection to an alternator in order to measure and determine the electrical potency. And finally, It
has built a prototype that simulates the movement of the waves to determine the energy efficiency
reaching values of 50% that are higher than the yields of Eolic and photovoltaic renewable energies,
placed in the best of cases around 30%.
The built prototype currently has a generation capacity of 1500W, but given the aforementioned scalability the desired power might be obtained depending on demand, through the dimensioning of the system, which means that the number of appropriate modules will provide the desired energy.

Advantages and differential values.

By its possibility of placement onshore to harness the wave motion with little height, cabling costs and grid connections are considerably reduced, in the same manner that facilitates access to the machinery and other devices. A simple approach is assumed in relation with low maintenance operations since it is in short a gear system, oil or grease placed on firm soil, so that the only contact with the water would be through the set of buoys and its actuating arms.

Moreover, usually in analogous solutions, reciprocating devices produce a high torque and low speed output [2], but with the system developed in this research such problems are minimized. Another advantage is the modularity, since it is a technology of restrained size that can easily be articulated in a modular way in order to adapted it to different possible locations, or specific energy demands, with which potency limitations are not considered, due to the fact that they will depend the number of modules installed according with demand.

Likewise, with regard to the possibilities of local application, the energy can be easily transported to nearby areas, which means a lowering in the costs of wiring and in the case of islands or isolated locations can be very useful. The influence on port traffic or in nautical areas, is practically nil and does not alter the navigation. The space required for its operation depends on the power supply demand but is considered small compared to other technologies.

Flexibility is equally remarkable for its location, which could eventually be applied to other water contexts such as waterfalls or rivers, as the waves can be natural or created through dams or other elements that can channel the water, producing level differences that allow the movement of buoys or levers.

Finally, in environmental terms, apart from contributing with the development of clean energies with low carbon emissions, in concrete terms, the device location in onshore areas would avoid the alteration in water column patterns, interference with benthic habitats, artificial reef effects, and noise disturbance, among others issues [4].

Conclusions.

It can be stated that the aim of the invention of transforming an alternating rectilinear movement in a circular motion is equivalent to continuous movement offered by other similar mechanisms (for example, rod-crank mechanism), but using a completely different actuation and functioning principle, very versatile furthermore. Due to the use of other kind of components and to harness the use of force exerted on the levers both when climbing and when going down, it is concluded that this is a completely innovative mechanical system.

Regarding the actions done around the invention and referred in the research to work as starting point in the developing a new WEC system, it has finally been achieved the optimization in aspects such as reduction of number of components, size reduction in whole, less static and dynamic friction between elements, mechanical and energy efficiency (better performance), increased degree of supported global effort, increased number of revolutions in the output shaft and especially the feasibility of scaling and adapting the mechanical system to applications in the fields of alternative and clean energies through the harnessing of the ocean waves, becoming optimally functional in wave conditions of low rise and in the dual role of taking advantage of the wave motion both when rising, and when going down, in the frame of a very low environmental impact in relation with the traditional sources of power generation and even regarding other clean production alternatives with low carbon emissions.

Finally, is worth pointing out that along with mitigation pathways such as behaviour change [in consumption], the success of climate change policies depends more heavily on the development
and commercial scale implementation of new energy technologies [9] and in this sense, the findings of this research are intended to contribute in a practical way with this line of thought.

References


