Sea Wave Energy Overview of Current Technologies and views

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ABSTRACT

The proposal of new technologies capable of generating electrical energy from renewable energies has directed research resources on seas and oceans. Research in this field finds the future of renewable energy very promising, especially in areas where there are specific climatic and morphological conditions that have the characteristics to exploit large amounts of energy from the sea. In general, this type of energy includes six energy sources: waves, tidal range, tidal current, ocean current, ocean thermal energy conversion and salinity gradient. The purpose of this review is to list several wave energy, converter power plants and analyze their years of operation. In this research, we try to know how many wave energy converter power plants work on average and whether it is really necessary to use such technologies.

Keywords: *Sea wave, electric energy, renewable energy, root, mod*

1. *INTRODUCTION*

This review is focused on the exploitation of sea wave energy. However, this is only one of several types of energy related to the oceanic environment, so a brief description of the main sources of marine energy is necessary [1, 2].

Oceans represent a huge energy reserve that is distributed in various phenomena. Meanwhile, the main types of energy related to oceans are sea currents. Osmotic salinity, OTEC (ocean thermal energy conversion), tides and waves. Every ocean energy source has good potential for human applications. However, as shown in Table 1, sea waves and ocean currents have the highest energy potential [3].

Table 1. Potential installed capacity and energy production from marine energy sources [3].

Ocean Energy	Capacity (GW)	Potential Generation (TWh/y)
Tide	90	800
Marine currents	5000	50000
Osmotic salinity	20	2000
OTEC	1000	10000
Sea wave	1000-9000	8000-80000

All these oceanic energy sources are classified as renewable energy [4]. In fact, tides are caused by the moon's orbit around the earth, the earth's orbit around the sun, and the earth's rotation. As a result, a huge amount of sea water flows around the world and the sea level changes locally. Local effects vary due to the uneven distribution of land around the world. In any case, tides are a regular phenomenon whose effects can be accurately predicted. Thus, tides represent an interesting renewable energy source that allows the exploitation of tidal currents or tidal ranges. The second one is of little use around the world, because this phenomenon allows the installation of the power plant near the coastline, creating a barrier equipped with low hydraulic turbines. The first power plant was installed in Lawrence (France) in 1966 and is still active. Other power plants have been installed in Russia (Kislaya Guba, 1.7 MW), Canada (Annapolis, Royal Generating Station 20 MW), China (Jiang Xia, 3.9 MW) and Korea (Sihua Lake, 254 MW) [5].

The term oceanic current is used to emphasize the different origin of marine currents compared to the tidal currents described earlier. Ocean currents are seawater powered by solar energy. Since the sun's radiation changes with latitude and due to the irregular distribution of land on the surface of the earth and the topography of the seabed, the density of water also changes and water currents are created that extend for thousands of kilometers. Surface currents are also created by the interaction of wind (which is the effect of solar radiation) with the surface of the sea. Summing up all these contributions, the thermohaline circulation is created. The Gulf Stream is a well-known ocean current (about 100 km wide and 800 m to 1200 m deep) that originates in the Gulf of Mexico and flows towards the North Pole at a speed of about 2.5 m/s [6]. Other famous currents include the Kuroshio Current (in the western Pacific Ocean) [7] and the Agulhas Current (in the southeastern part of the Indian Ocean, along the coastline of South Africa) [8].

In the case of ocean thermal energy conversion (OTEC), the idea of installing a heat engine using surface sea water as a heat source and deep water as a heat sink has been proposed [9]. The main problem of this system is its low energy efficiency. In the best case, considering the installation of an ideal Carnot heat engine to exploit the available heat sources, the energy efficiency is not more than 7%. As a result, introducing the irreversibility of a real system, the power plant requires huge dimensions (especially heat exchangers) to produce significant power. Hence, high investments are required. Two designs have been proposed for a possible OTEC power plant:

Open cycle and closed cycle [9,10]. In the first case, warm water is flashed from the sea surface to produce steam and then condensed using cold deep water. The main disadvantages are related to operational conditions. In fact, steam production requires vacuum conditions that accompany the entire plant, so air penetration is possible. At the same time, the specific mass of steam is very high (30-100 m3/kg), so the system requires large pipes for small power outputs. In the second solution, surface-heated water is used to vaporize a working fluid commonly used in the cooling section, such as ammonia, propane, or chlorofluorocarbon. This steam is used to run a turbine and is then condensed using deep water as a coolant. The advantage of this system is that it works under pressure, so air infiltration is avoided. As a disadvantage, large heat exchangers are required [11].

As for the salinity gradient energy source (called osmotic power), the idea is to harness the chemical energy released when freshwater from rivers mixes with saltwater from the sea. Two solutions with different ion concentrations show different values of osmotic pressure. A solution proposed in 1937 is osmotic pressure reduction, in which salt water is pressurized before a semipermeable membrane. If the external pressure gradient is less than the osmotic pressure, water will flow from the dilute solution to the concentrated solution. As a result, salt water is produced, which has the same pressure as salt water but with a higher flow. It is possible to use a water turbine that collects more energy than the pumping cost and produces electrical output [12, 13]. Finally, a sea wave is a form of marine energy that occurs due to various forces acting on the surface of the water, such as friction caused by wind, the Coriolis force (related to the rotation of the Earth), gravity (tides), or other Unpredictable phenomena such as earthquakes and volcanic eruptions (tsunami) [14].

2. *Current technologies in the field of sea wave energy*

2.1 Oscillating water column

Several oscillating water column (OWC) devices have been proposed in the past. According to the location of the system from the shoreline, OWC devices can be classified as fixed or floating. In the first case, the OWC power plant is installed through a fixed structure on or near the coastline, or in natural or artificial structures, such as breakwaters and rock reefs [15]. Installing WEC directly on the shoreline has several advantages. Maintenance and operation are simplified and relative costs are reduced. At the same time, the costs of the docking system have been minimized. In addition, the entire electrical equipment for energy conversion is installed outside the water [16]. OWC devices are designed to create a vertical oscillation of water inside a chamber to alternately compress and expand the air inside the same chamber. Because the airflow constantly changes direction, traditional horizontal axis air turbines cannot be used. A solution is provided by the Wells turbine, developed in the mid-1970s by Alan Arthur Wells. The Wells turbine is a low-pressure air turbine that is characterized by the ability to rotate in a direction independent of the direction of the air flow. The blades have symmetric airfoils whose plane of symmetry is the same as the plane of rotation [16].

A Wells turbine is affected by low (or negative) torque in small air flows; It also has significant aerodynamic and noise losses compared to other wind turbines. Therefore, this turbine needs a larger section to achieve the same output power as other turbines. Nevertheless, the Wells turbine has been used in several OWC plants.

As an example of a full-scale OWC system, the Körner Bragg OWC power plant in Norway was realized in 1985 [17], with a rated electrical power of 500 kW [18]. The lower part was made of concrete with a height of 3.5 meters above the sea level. As shown in Figure 1, this part of the system forms a chamber that communicates with the sea below. The upper part (steel tower) reaching a height of 21 meters, was equipped with a self-correcting air turbine with a nominal power of 500 kW. Unfortunately, the plant was destroyed by a severe storm at the end of 1988 and the system was decommissioned, leaving only the concrete part at the test site. In its short lifetime, the Koerner Bragg OWC power plant delivered 29 MWh of electricity to the grid [19].

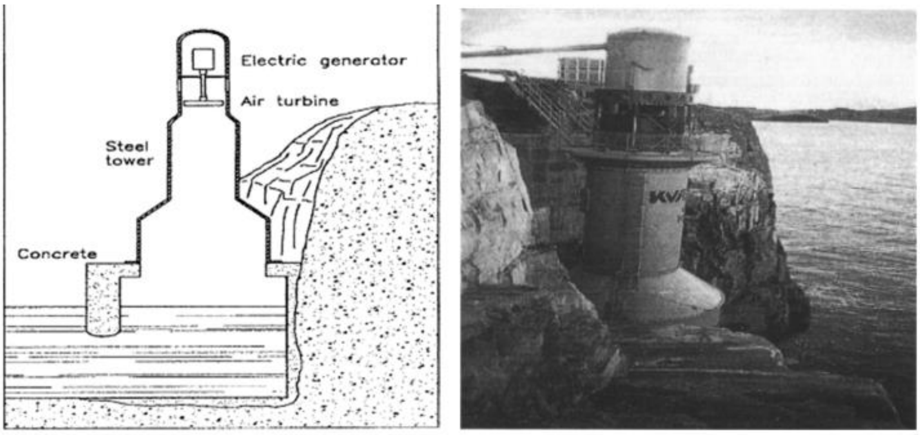

Fig. 1. (Left) cross-sectional design and (right) view of Corner Bragg OWC factory [17]

In 1990, an OWC system was installed in Vizh Najam, Kerala, India. This system consists of a concrete caisson and is installed near the main structure. The project considered the installation of a Wells turbine together with an induction generator (150 kW) in order to connect directly to the power grid [20]. In reality, the results were less than expected: the power output was highly variable, varying from 0 to 60 kW in seconds, and the induction motor often acted as an electrical load rather than a generator, producing more energy than it produced. was used [21]. In 2004, the plant was investigated to provide osmosis desalination water, and the OWC was finally decommissioned in 2011 [22]. This OWC system is shown in Figure 2.

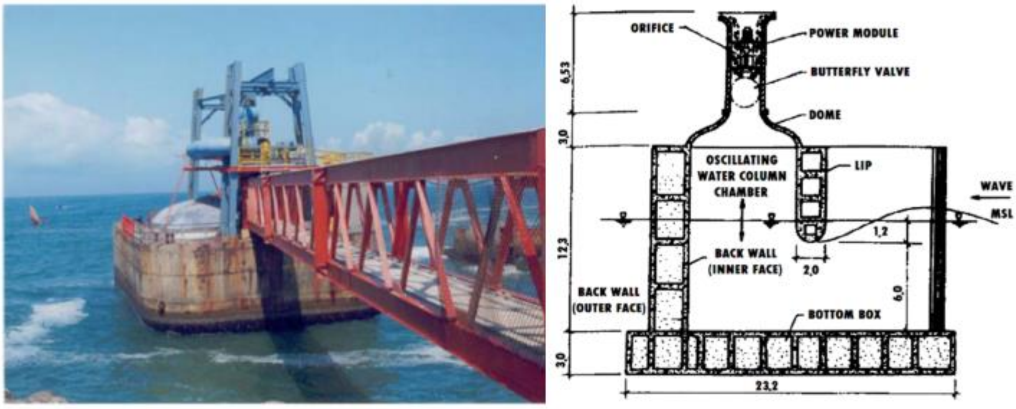

Fig. 2. (left) view and (right) cross-section of the OWC Visionjam system [23]

Based on the same principle, in 2000 the Islay LIMPET was installed by the Navy on the Scottish island of Islay in the field of energy transfer. The Islay LIMPET was a complete version of a prototype (75 kW) built in 1991. The OWC system is shown in Figure 3.

Fig. 3. LIMPET OWC plant installed on the island of Islay, Scotland [24]

The LIMPET cover was completely concreted on the shoreline. This system was equipped with two Wells turbines, each with a rated power of 250 kW [3]. However, the power generated in the first two years of operation reached a maximum of 180 kW. For this reason, the power plant was classified as a rated power of 250 kW [25]. The power plant was decommissioned in 2012 and today is the only concrete building left on the shoreline.

An OWC system called REWEC3 (Resonant Energy Wave Converter) has been developed in Italy by the University of Reggio Calabria [15]. The system is designed to be installed in a traditional vertical breakwater in the port. Compared to other OWC devices, the main difference is the U-shaped connection between the inner chamber and the sea (Figure 4), which is chosen to match the resonant frequency of the system with the sea wave. Therefore, energy extraction can be maximized [55]. In Civitavecchia port, a full-scale plant has been installed, which consists of 136 chambers and has a rated power of 2.5 MW [3]. This system produced 500 MWh per year in 2016 with a length of 100 meters. After optimization, the designers want to reach an annual production of 800 MWh per year.

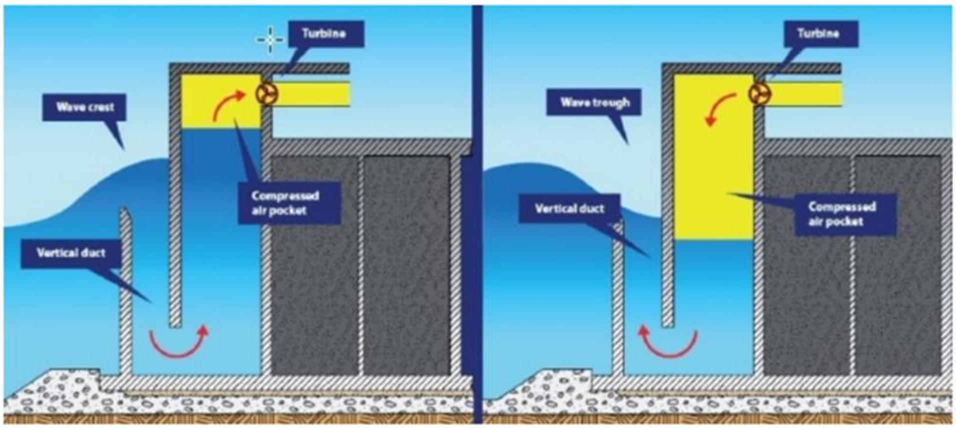

Fig. 4. How REWEC3 works [26]

The Yongsoo plant (Figure 5) is another fixed OWC system completed in July 2016 near Jeju (South Korea) [3]. This system is installed on the seabed, 1.5 km from the coastline [27]. The plant is equipped with two horizontal axis impulse turbines connected to different types of generators (a synchronous generator and an induction generator), both with a nominal power of 250 kW [3]. The length and width of this factory are 37 meters and 31 meters, respectively.

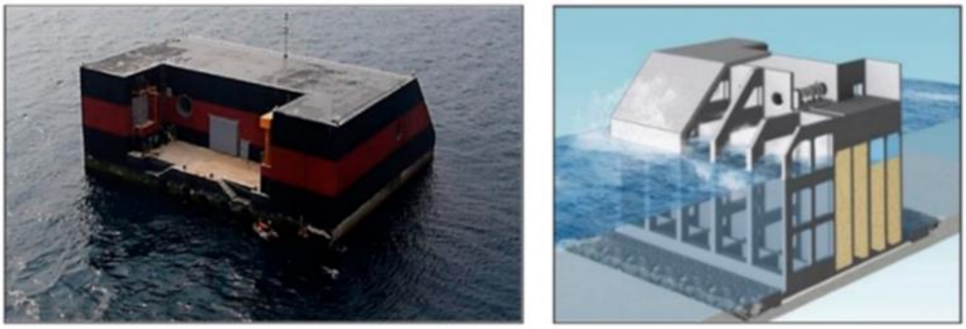

Fig. 5. Back view (left) and perspective view (right) of the OWC factory in Yongsoo [3]

A similar concept was adopted in King Island, Tasmania. The project was developed by Wave Swell Energy after a lengthy permitting process, including an initial assessment of energy potential and seabed characteristics. In 2019, an OWC device with a nominal power of 200 kW was installed at 100 m of the shoreline and at a depth of 6 m (Figure 6) [28]. In January 2021, the device was connected to the Tasmanian electricity grid. According to this project, the device was removed after one year of testing [29].

Fig. 6. Swell the Wave (King Island, Australia) [28]

Another group of OWC devices consists of floating systems. The working principle is the same, but the main difference is related to the structure on which the OWC device is installed. In fact, the most popular solution is indicated by floating acceptance; Floats that are equipped with chambers that are used to generate water oscillation.

One of the first floating OWCs was developed in Japan between the 1960s and 1970s by Yoshio Masuda's team. This system, called a "backward-bent floating channel" (BBDB), consists of a floating vessel attached to the seabed and equipped with an L-profile chamber [30]. This chamber is open to the sea at the back and below the water surface, as shown in Figure 7.

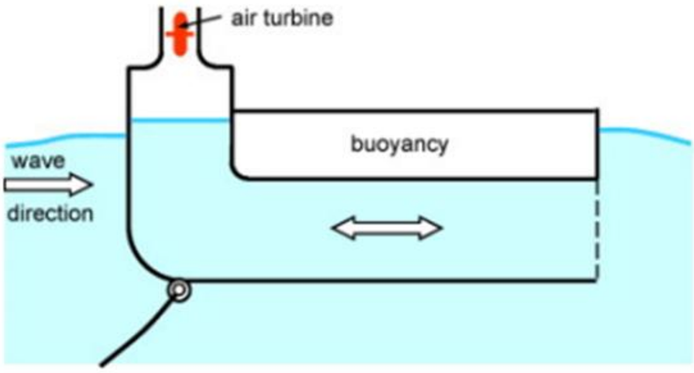

Fig. 7. The floating part of the back curved duct [16]

A few years later, other similar systems were developed. Among them, the most well-known inclined floats, spar floats, and mighty whales are reported in Figure 8 [31]. In detail, the inclined float consists of three parallel tubes mounted on a floating float with an inclination angle of 45° [32]. The lower part is open to the sea while the upper part is towards the air.

A spar float is a vertical tube installed in a cylindrical float. This design improves energy extraction from sea waves because the system works independently of wave direction. For this reason, it is classified as a point absorber. This device absorbs the energy of the waves through the oscillation of the air. As a result, the air inside is intermittently pressurized and depressurized due to movement [33].

Fig. 8. Buoy (left) [31], floating spar (middle) [31] and whale power (right) [34]

As shown in Figure 7, the case report of the Mighty Whale, which consists of a whale-shaped float (50 m long and 30 m wide), is interesting. This OWC device consisted of two chambers and four Wells turbines, two of which had a nominal power of 30 kW, one of which was 10 kW, and the other of 50 kW (total installed power equal to 120 kW) [35]. The turbines were activated intermittently according to the sea states [36]. The prototype was installed 1.5 km off the coastline of Gokashu Bay (Japan), in July 1998. At the end of 2000, the field test was completed [35]. This device was removed in 2002. In Table 2, the main specifications of current technologies for harvesting sea waves based on the OWC principle are given.

Table 2. A summary of the main OWC devices

Project	Country	Position	Inst.	Power	Status	Note
Backward Bent-Duct Buoy	Japan	Floating	1960–70	Concept		
Sloped IPS Buoy	Edinburgh (UK)	Floating	1970–80	Concept		
Kværner Brug's OWC	Toftesfallen (Norway)	Fixed Onshore	1985	500 kW	Decommissioned	Damaged by a severe storm in 1988. 29 MWh produced.
Vizhinjam OWC	Trivandrum (Kerala, India)	Fixed Nearshore	1990	150 kW	Decommissioned in 2011	Production under the expectation, with high variability. Inactive for a long period.

Mighty Whale	Gokasho Bay (Japan)	Floating Offshore (1.5 km to the coastline)	1998	120 kW	Decommissioned in 2002	
Pico OWC	Pico Island (Azores, Portugal)	Fixed Onshore	1999	400 kW	The project concluded in 2018	Malfunction due to the Wells turbine and its supports.
Limpet	Islay (Scotland, UK)	Fixed Onshore	2000	500 kW	Decommissioned in 2012	High level of noise. The attenuation causes malfunctions.
Spar Buoy	Portugal	Floating	2000–15	Concept		
Mutriku plant	Mutriku (Spain)	Fixed Onshore (harbor integrated)	2011	296 kW	Operating	Total electrical production 2.1 GWh (end of September 2020)
REWEC3	Civitavecchia (Italy)	Fixed Onshore (harbor integrated)	2016	2.5 MW	Operating	Annual production between 500 and 800 MWh/y
Yongsoo plant	Jeju Island (Republic of Korea)	Fixed Offshore (1 km to The coastline)	2016	500 kW	Operating	Adoption of two impulse turbines, connected to different generators
Wave Swell	King Island (Tasmania, Australia)	Fixed Nearshore (100 m to the coastline)	2019	200 kW	Operating	The device will test for a year

2.2 Wave activated objects

The Wave Actuated Objects (WAB) category includes several types of solutions for exploiting sea waves. These systems are usually composed of two or more parts to generate a relative motion and actuate the energy converter [37].

These systems are generally designed to be installed near or offshore to take advantage of open sea waves, which are more regular compared to systems installed on the shoreline. However, installation away from the coastline raises problems. In fact, long underwater cables or pipes are needed to collect the energy produced by the WEC to the main source of energy transmission. These devices also require a strong mooring system that is strong enough to withstand extreme weather conditions [38].

Since there are several WABs, a classification is introduced taking into account the working principle of the device as a criterion [16]: single-hull floating systems, double-hull floating systems, fully submerged floating systems, underwater devices, systems Bottom hinge and multibody systems.

This study's aim is to get metal flow and distributions of equivalent stress on some special sections such as longitudinal and transverse sections under processing tube tension-reducing.

2.2.1 Single-hull floats

An example is a system that basically consists of a float that can move along a metal base. This base is anchored to the seabed by a universal joint. The idea was to exploit this vertical movement to pressurize a reservoir of air and thereby start an air turbine. A prototype with a floating diameter of one meter, replacing the air turbine with an orifice, was tested in Trondheim fjord (Norway) in 1983 [16]. This technology (Figure 9) was developed at Uppsala University (Sweden) and is known as the Lysekil project [39]. In this figure, vertical motion is used to run a linear generator with a nominal power of 10 kW. This plant with two other WECs achieved a total installed power of 30 kW and is in operation today [40].

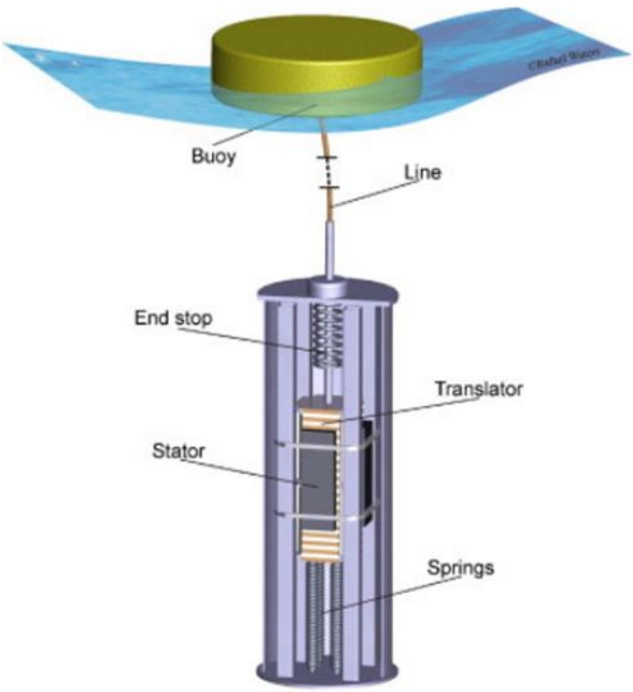

Fig. 9. The working principle of the Lysekil project [16]

2.2.2 Two-hull floats

The category of "two-hull lifting systems" was introduced to solve the problem of the distance between the float and the fixed structure on the seabed, where power generation occurs. In this case, the WEC consists of two floats that create a relative motion that can be used to extract energy. The shape of the two floats is usually different to maximize relative motion.

As shown in Figure 10, the bob wave is an example of a two-body lifting system. To improve the relative motion between the two WEC sections, the central buoy is equipped with a large mass that increases inertia and limits vertical motion. This lower float is designed to be submerged deep enough to minimize interference with sea waves. The vertical motion produced by the upper buoy (body 1) is used to operate an oil pumping system. A small-scale prototype (1:4) was tested in Galway Bay (Ireland) [41]. This prototype was installed in 1999 and retired in 2015.

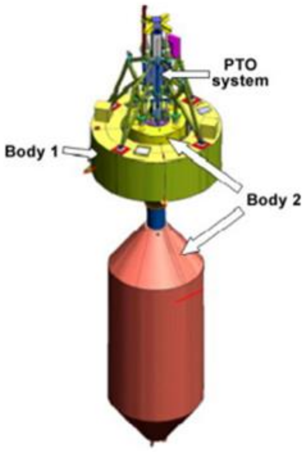

Fig. 10. Render view (left) and external view (right) of Wavebob [16]

Power Buoy (Power Buoy) is another example of a two-body heating system made by the American company Ocean Power Technologies. As shown in Figure 11 [42], this WEC is composed of a float that rises and falls according to the sea wave and a disc-shaped submerged body adopted to improve inertia and hydrodynamics. This design helps to maximize the relative movement between the two main parts of the machine. The idea is to create a wave energy farm by installing several devices, each of which produces electricity. To minimize the cost of electricity connection to the mainland, an offshore substation can be realized. In 2005, a pilot plant (40 kW) was tested at an offshore site near Atlantic City (NJ, USA) [43]. In 2008, another site of the same size was installed off the coast of Santona (Spain) [32].

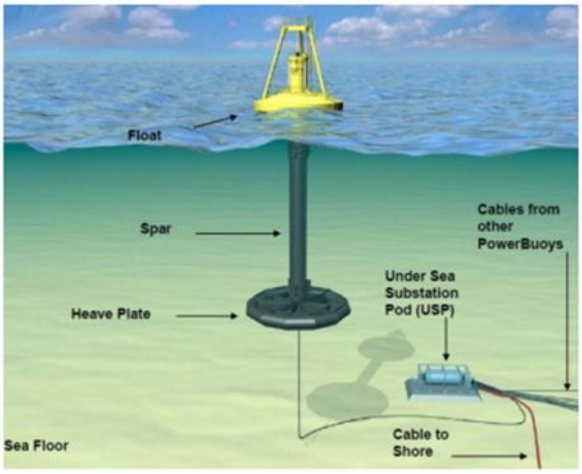

Fig. 11. The working principle [39] and the exterior of PowerBuoy [43]

2.2.3 Fully submersible floating systems

In the case of fully submerged floating systems, an example is the Archimedes wave developed in the Netherlands by Teamwork Technology in 1993. As shown in Figure 12, the system consists of two parts: a basement connected to the seabed and a float. The device works by changing the hydrostatic pressure applied to a float that pushes up and down a linear generator installed inside a pilot plant successfully in Portugal [16]. Following this trial, AWS Ocean Energy was launched in Scotland. Recent news reports the development of a 16 kW device [44].

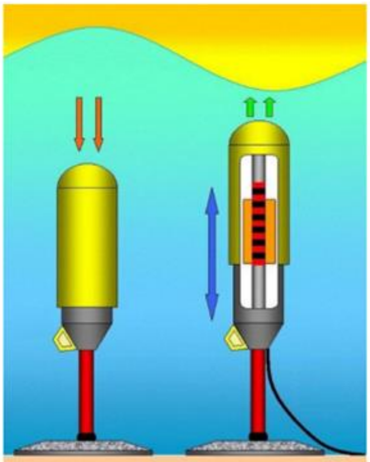

Fig. 12. The working principle of Archimedes wave oscillation [45]

CETO (a name inspired by the Greek goddess of the ocean) is another completely underwater device proposed by Carnegie Clean Energy. This system is designed to be installed near the shore, a few meters below sea level. An earlier version (CETO5) was used to pump water to an onshore station where electricity and fresh water were produced, using a reverse osmosis unit [45]. An upgraded version project (called CETO 6, with a nominal power of 1.5 MW) was commissioned in Western Australia in 2014 to generate electricity directly at the WEC. This technology is shown in Figure 13. However, the project was discontinued on October

31, 2019 [47]. Table 3 summarizes the main characteristics of current technologies for harvesting sea waves based on the WAB principle.

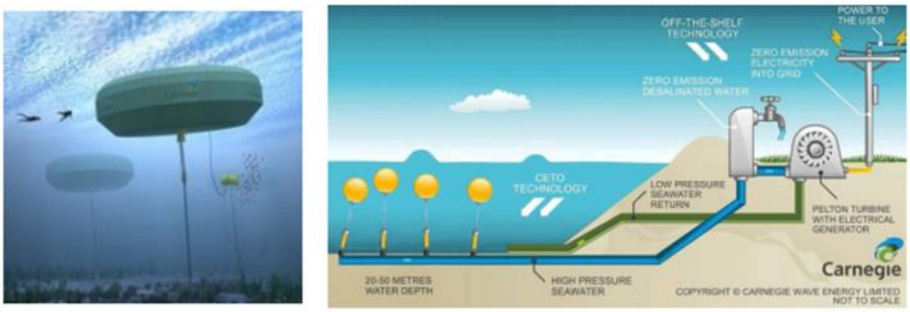

Fig. 13. External view of CETO [46] Working [45]

Table 3. A summary of the main WAB devices

Project	Country	Position	Inst.	Power	Status	Note
Salter's Nodding Duck	Edinburgh (UK)	Nearshore	1970–80	Concept		
Wavebob	Galway Bay (Ireland)	Offshore	1999	Prototype scale 1:4	Decommissioned in 2015	In 2013 end of the funding
Archimedes Wave Swing	Portugal	Offshore	2004	Pilot plant	Decommissioned	Available upgrade up to 16 kW.
Powerbuoy	Atlantic City (New Jersey, USA)	Offshore (22.5 km to the coastline)	2005	Up to 7.5 kW	Operating	Upgrade in 2020 with photovoltaic panels
Lysekil Project	Lysekil (Sweden)	Offshore (2 km to the coastline)	2006	30 kW (10 kW each)	Operating	Currently operating and enlarged with 2 WEC (June 2009)
Oyster 2	EMEC Orkney (UK)	Nearshore	2012	800 kW	Decommissioned	The plant worked until 2015 when the company ceased trading

CETO 6	Albany, Western Australia	Offshore	2014	1.5 MW	Discontinued	Project discontinued on 31 October 2019
Waveroller	Järvenpää (Finland)	Nearshore (0.3–2 km from the shore)	2015	350 kW	Project ended	The project ended in October 2013, leaving the device in situ for monitoring
Eco Wave	Gibraltar	Onshore	2016	100 kW	Operating	

3. *conclusion*

In this research, sea wave energy, an overview of current technologies and its perspectives, was examined. To this end, a number of different technologies described in the previous sections are shown. The exploitation of energy from the sea area has been the focus of academic studies around the world. Summary tables are provided to review the technologies in this research. As can be seen, some power plants have been successful and continuously produce electricity, and other power plants have unfortunately been out of order for various reasons. By reviewing the studies, the following conclusions can be reached:

- In WEC technologies, the costs of installing devices due to the proximity of the power plant to the power grid as well as the existing infrastructure can be easily converted for this application. The available OWC devices have a power rating of more than 200 kW, which enables the production of electrical energy for industrial applications.

- Regarding WAB, current devices can be classified into two categories. The first includes floating devices, installed in marine areas (Lysekil and PowerBuoy projects). In this group, the nominal power is about 10 kW, which is useful for indoor monitoring and communication. The second group includes devices installed on breakwaters, such as OWC devices, in this case, the nominal power is about 50-100 kW, which is useful for generating electrical energy.

- Consequently, wave energy harvesting is a very dynamic research area where different concepts and technologies are currently being proposed and developed. Pilot plants and full-scale devices are sometimes tested. However, the number of operating devices is very limited.

- Regardless of the chosen technologies, the main obstacle for the development of these systems is the costs, and in this field the participation of governments is very important. Many governments have participated in the construction of power plants because it is in their interest to enable the development of renewable technologies.

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